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(54) **THREE-DIMENSIONAL DATA ENCODING METHOD, THREE-DIMENSIONAL DATA DECODING METHOD, THREE-DIMENSIONAL DATA ENCODING DEVICE, AND THREE-DIMENSIONAL DATA DECODING DEVICE**

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#### Related U.S. Application Data

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(52) **U.S. Cl.**

CPC ..... **H04N 19/124** (2014.11); **G06T 9/40** (2013.01); **G06T 17/005** (2013.01); **G06T 2210/08** (2013.01)

#### ABSTRACT

A three-dimensional data encoding method includes: (i) in a first case where a layered structure is generated by classifying three-dimensional points into layers: encoding attribute information for the three-dimensional points based on the layered structure; and generating a bitstream including layer information utilized for the generation of the layered structure; and (ii) in a second case where the three-dimensional points are not classified: encoding attribute information for the three-dimensional points; and generating a bitstream not including the layer information.

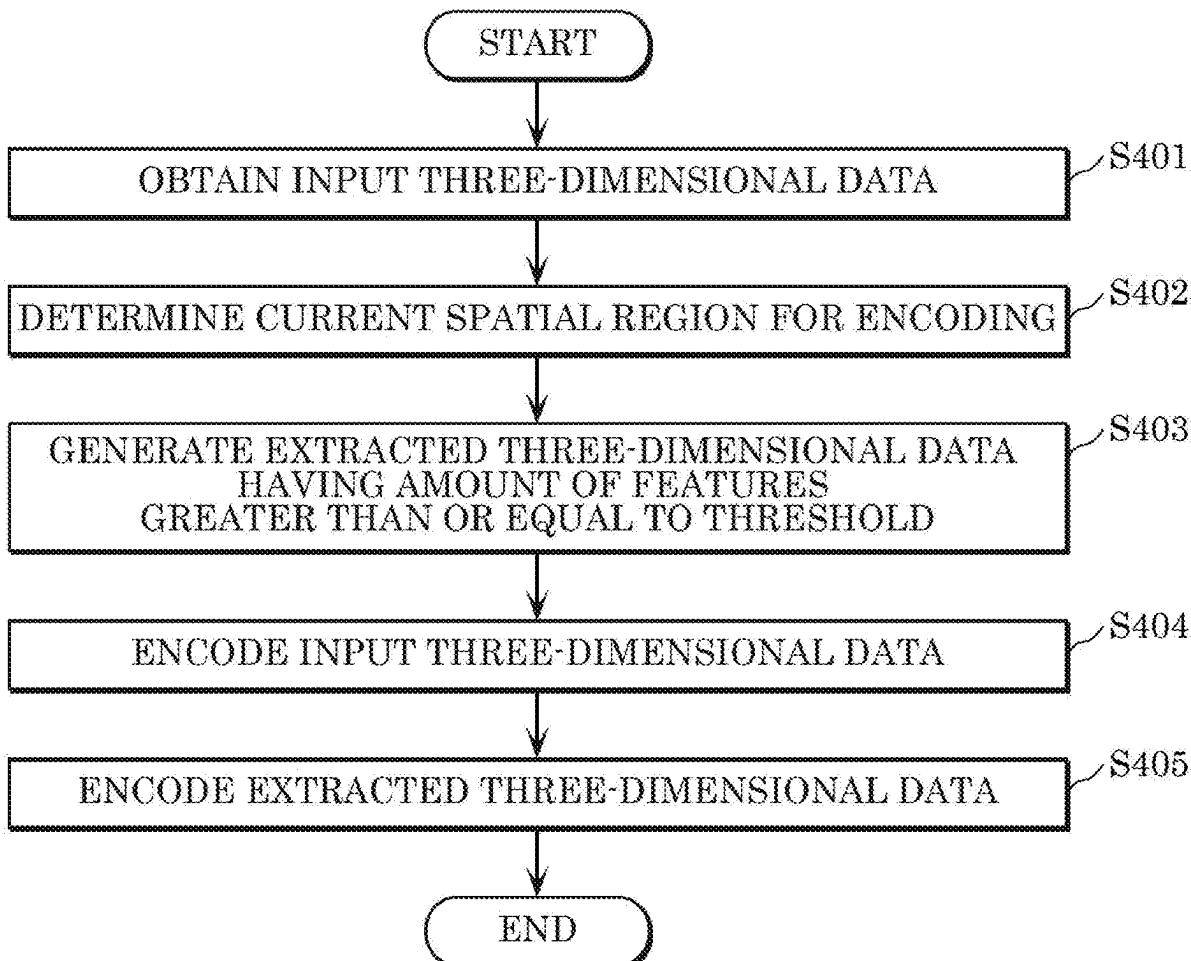


FIG. 1

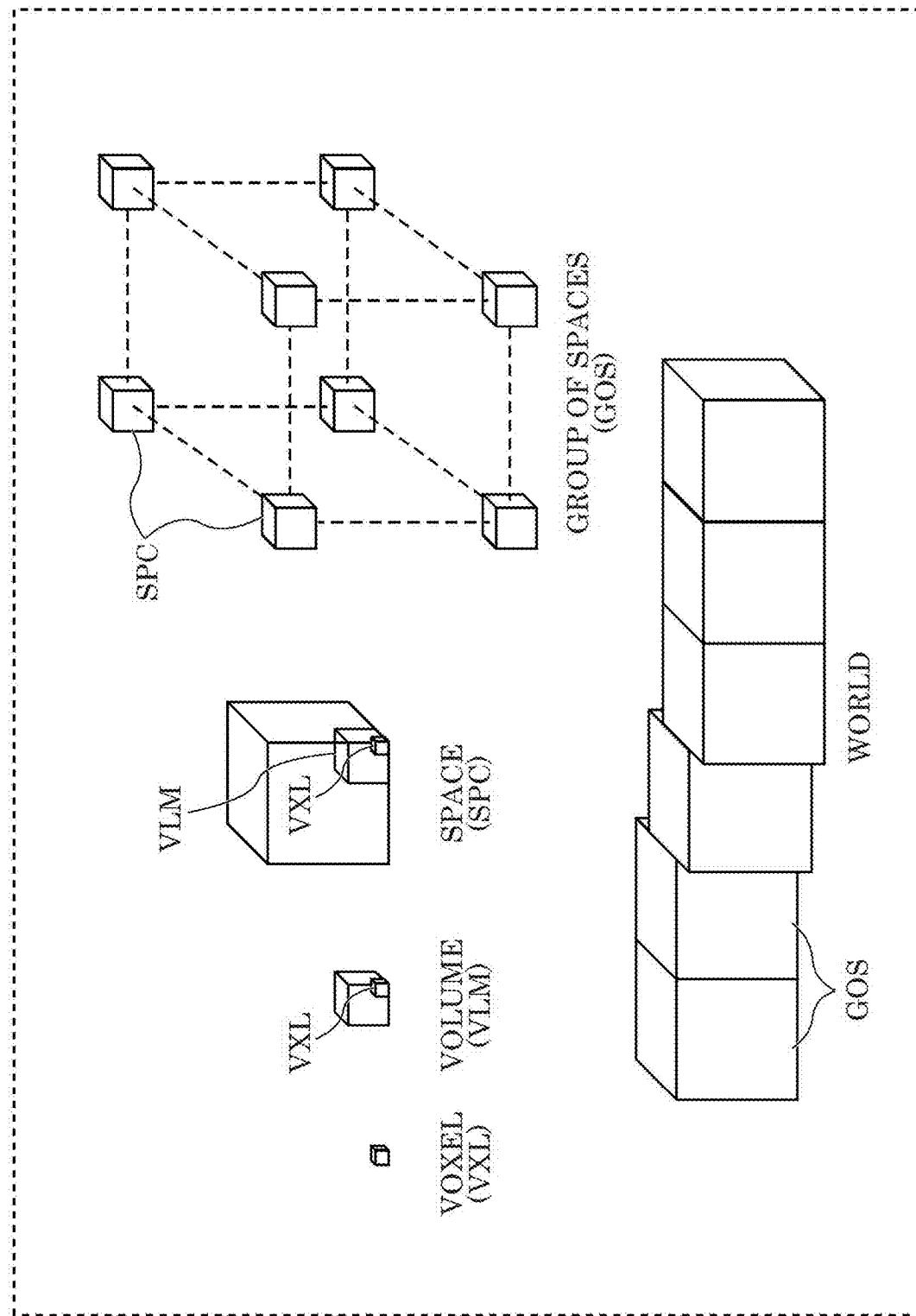


FIG. 2

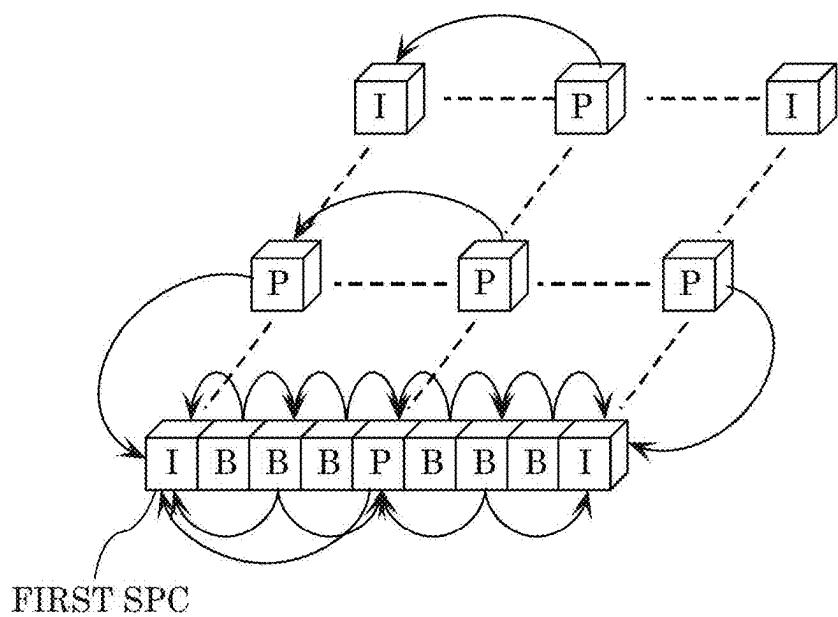


FIG. 3

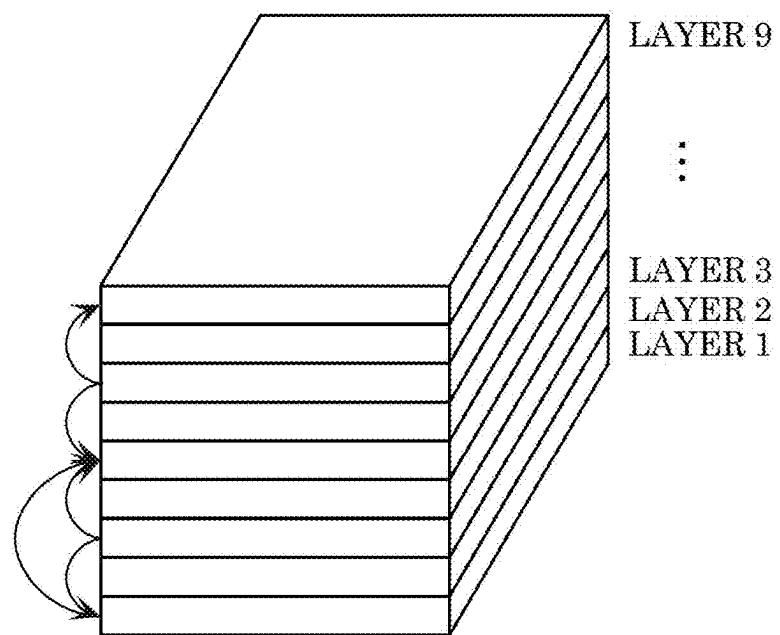


FIG. 4

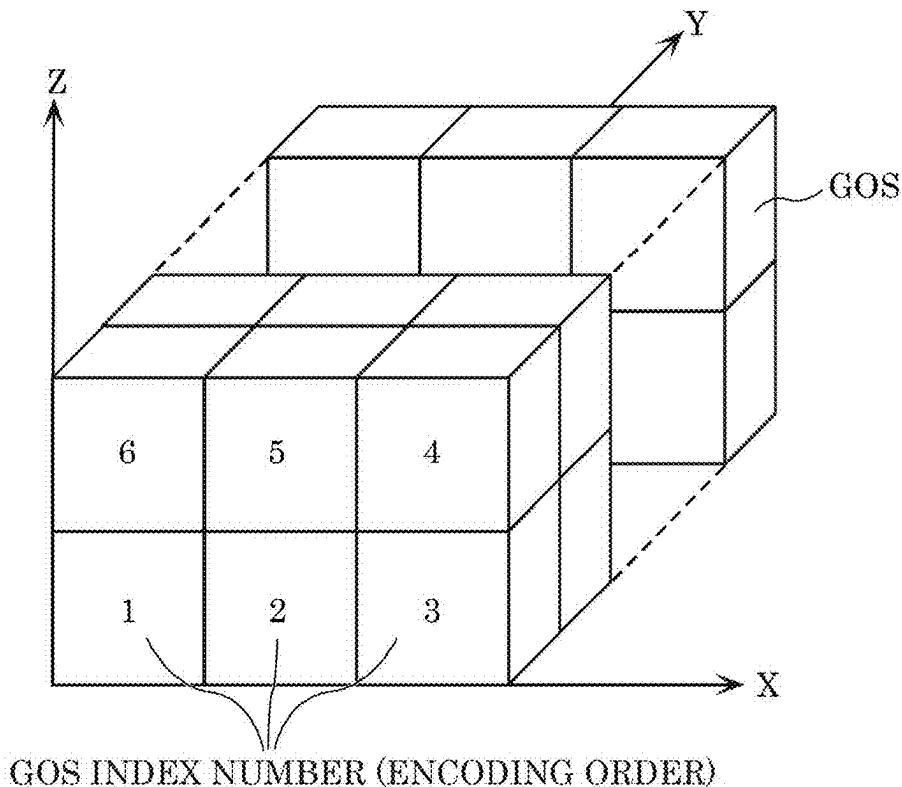


FIG. 5

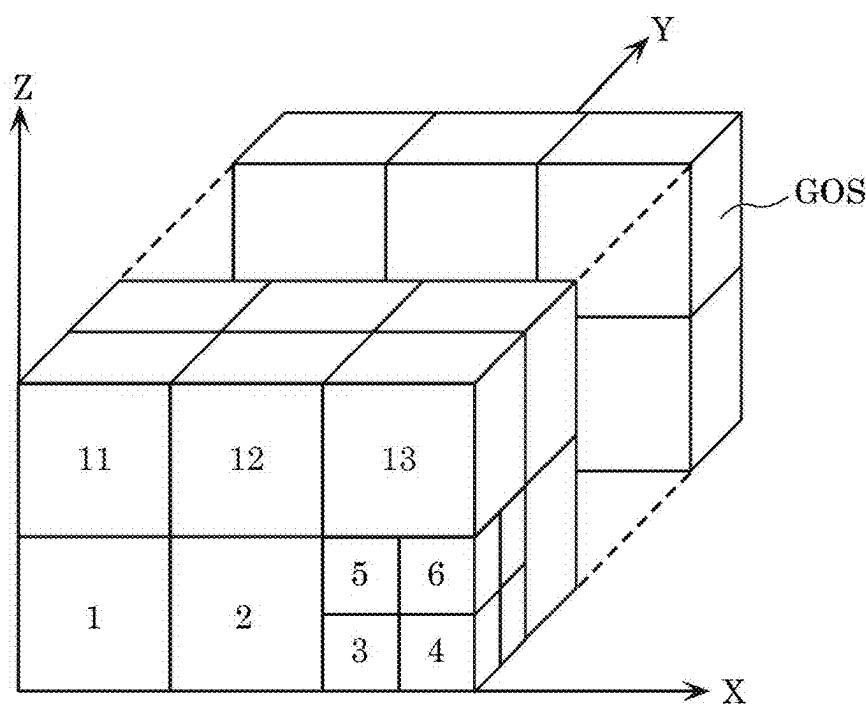


FIG. 6

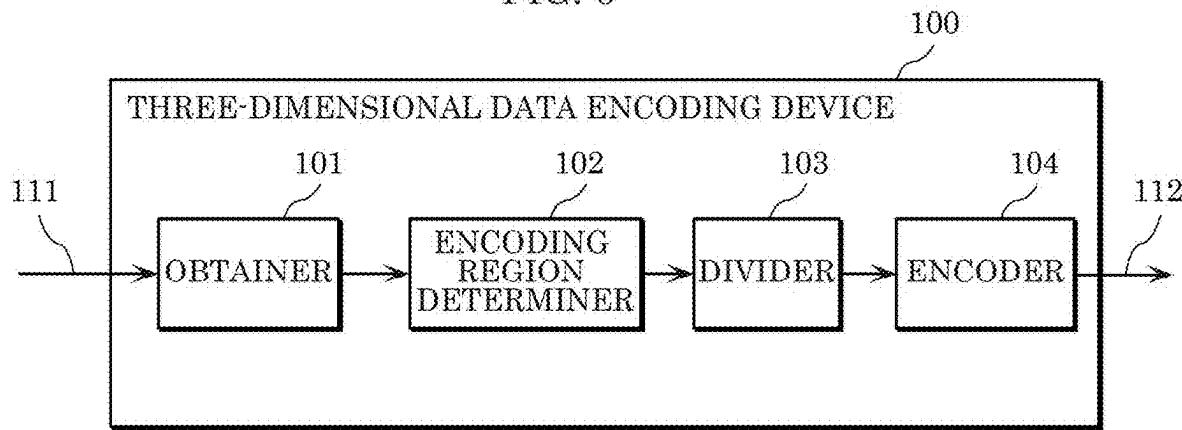


FIG. 7

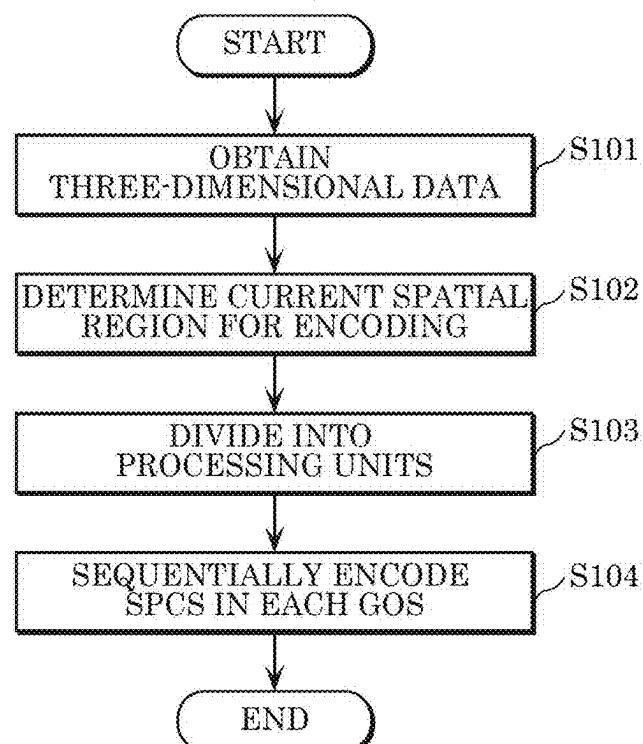


FIG. 8

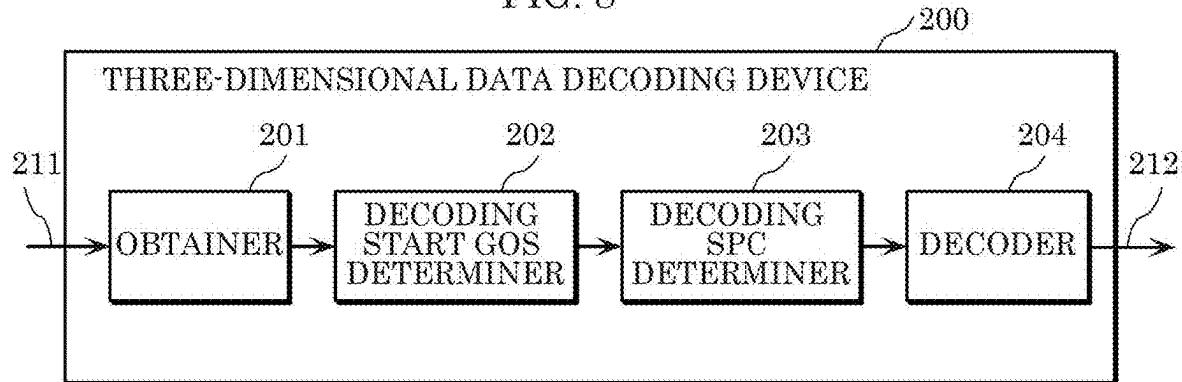


FIG. 9

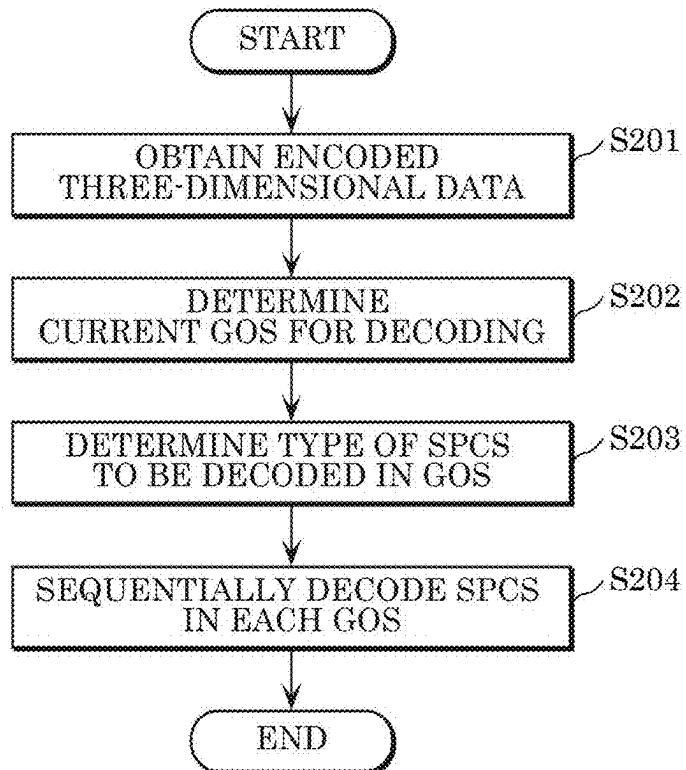


FIG. 10

OBJECT	GOS NUMBER
object(1)	1, 2
object(2)	5
object(3)	8, 9, 10
...	...
object(N)	101, 113, 125

OBJECT-GOS TABLE

COORDINATES	GOS NUMBER
(x1, y1, z1)	1
(x2, y2, z2)	2
(x3, y3, z3)	3
...	...
(xN, yN, zN)	N

COORDINATES-GOS TABLE

TIME	GOS NUMBER
pts(1)	1
pts(2)	30
pts(3)	50
...	...
pts(N)	200

TIME-GOS TABLE

GOS NUMBER	GOS ADDRESS
1	addr(1)
2	addr(2)
3	addr(3)
...	...
N	addr(N)

GOS-ADDRESS TABLE

FIG. 11

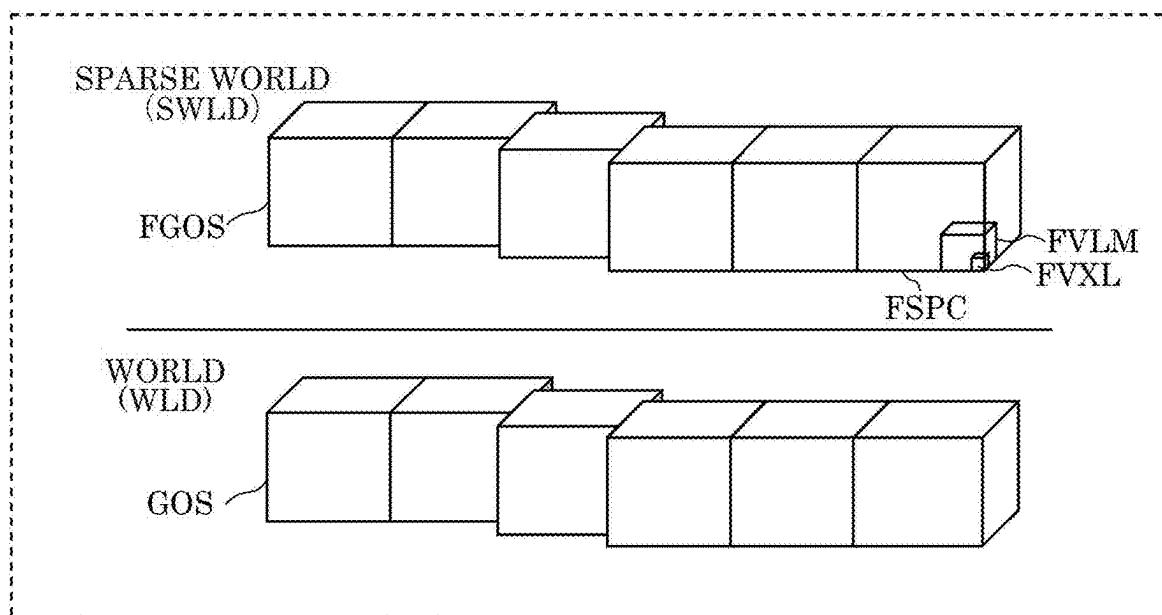


FIG. 12

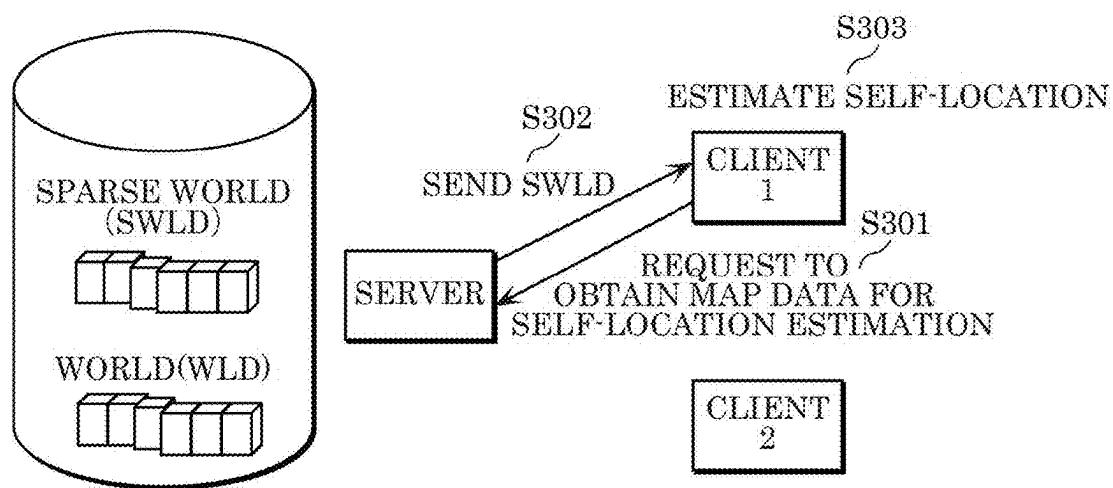


FIG. 13

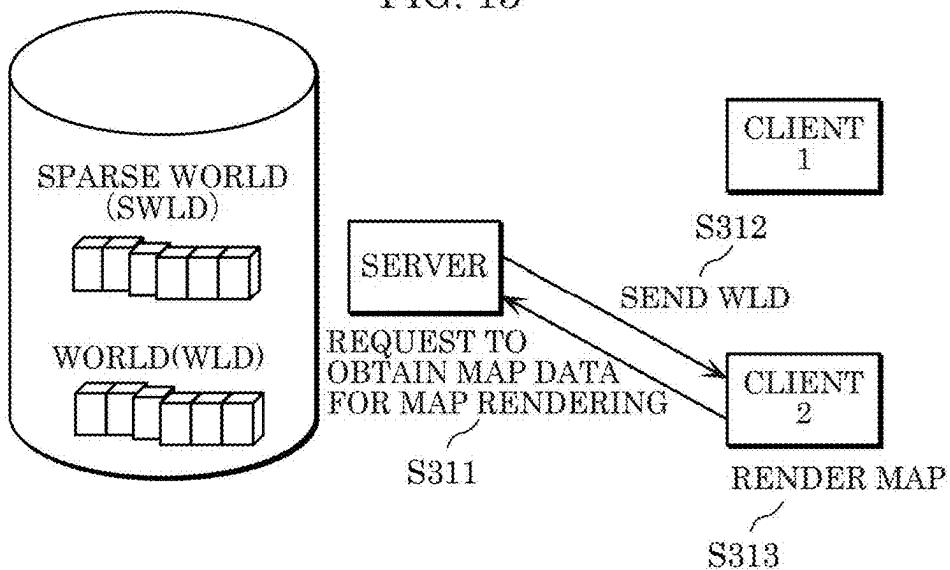


FIG. 14

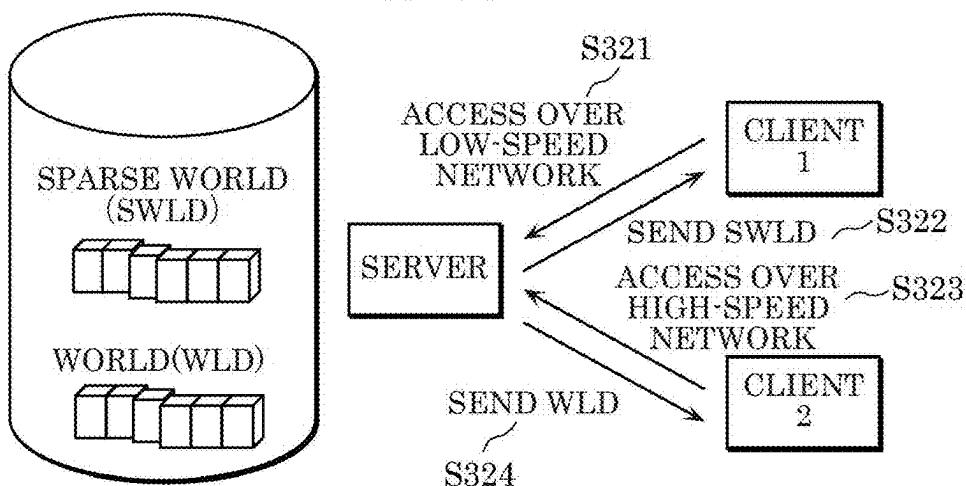


FIG. 15

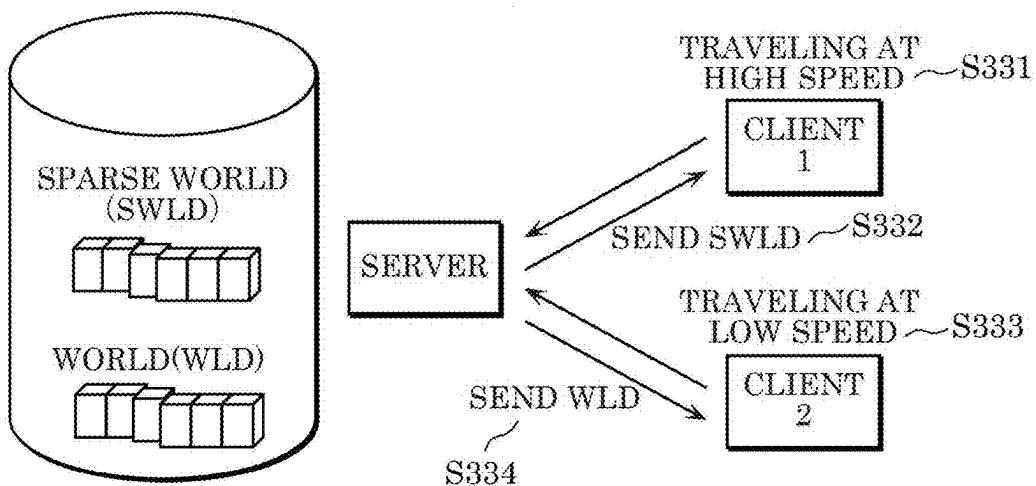


FIG. 16

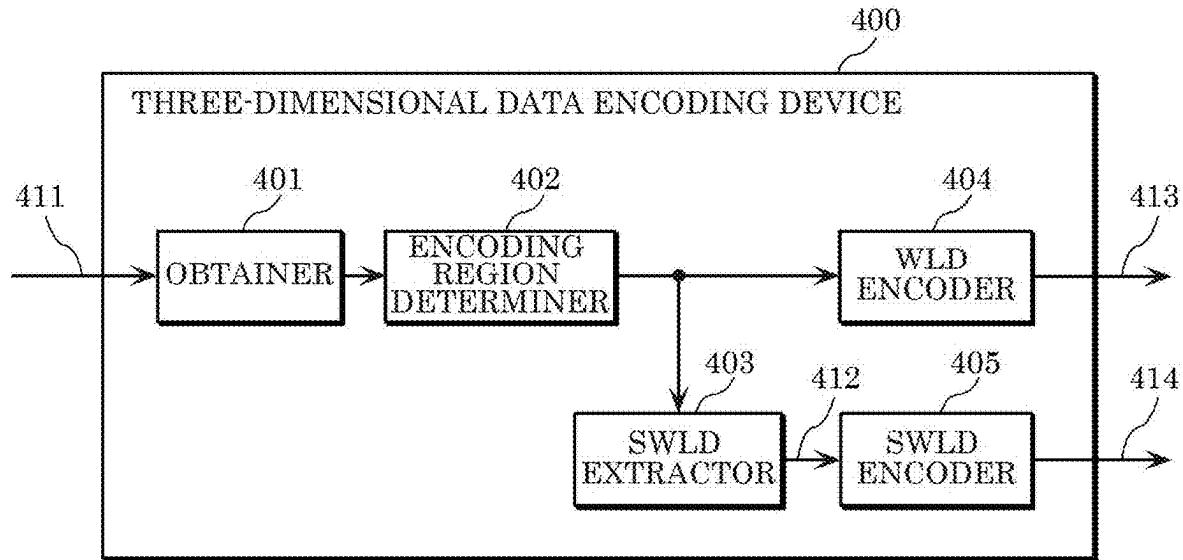


FIG. 17

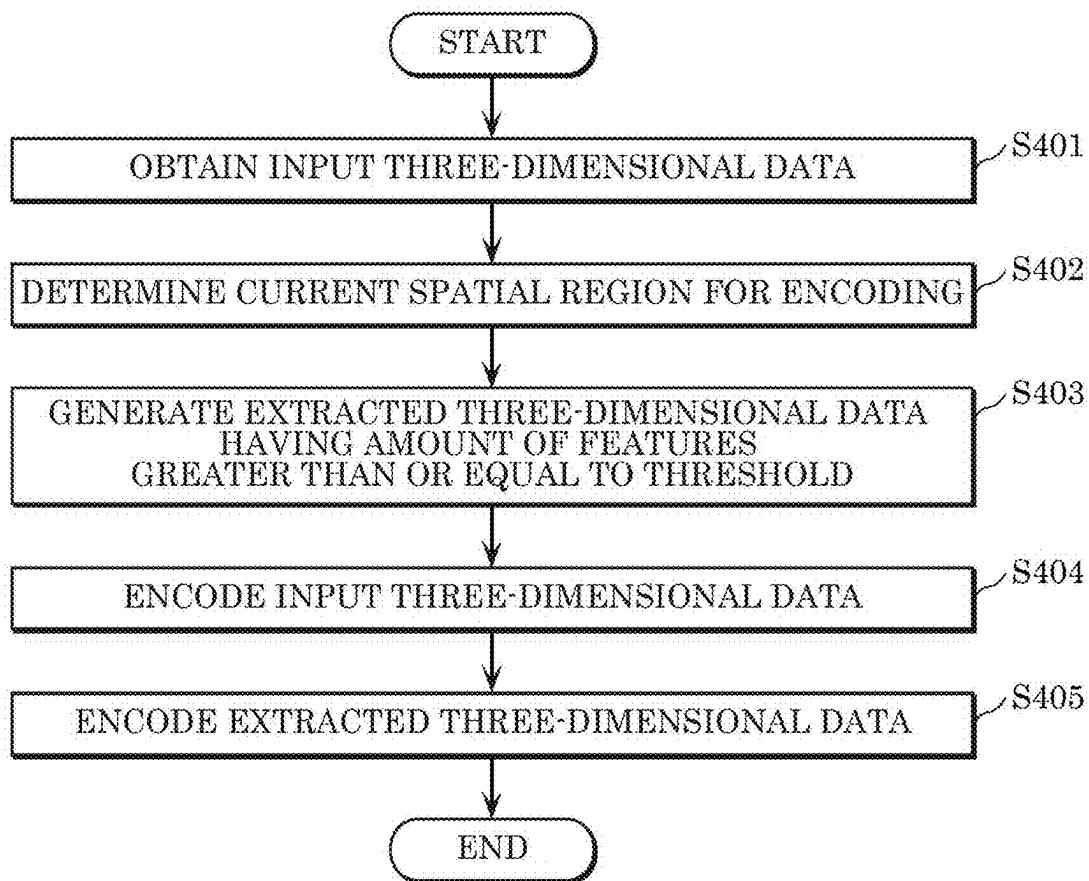


FIG. 18

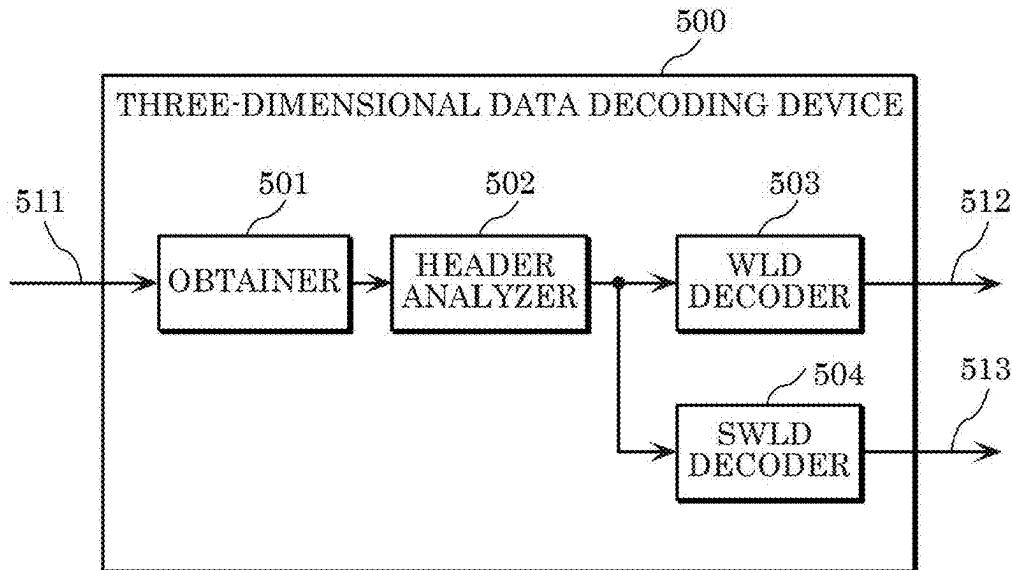


FIG. 19

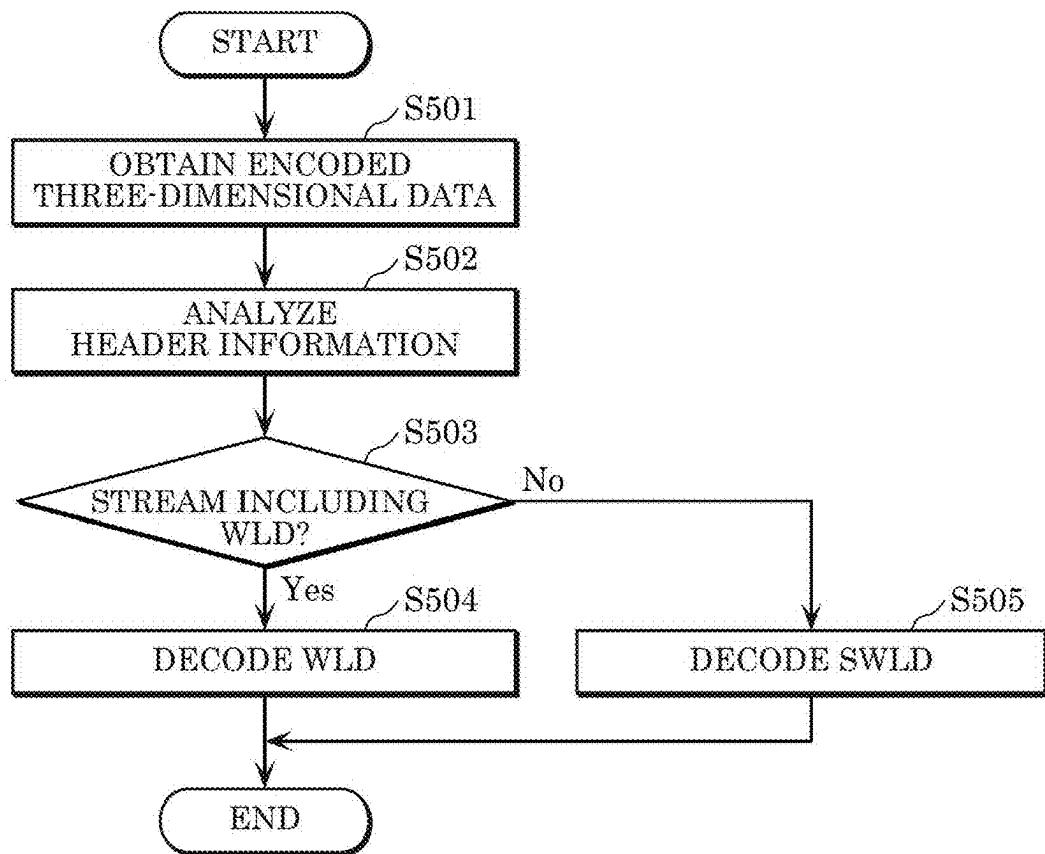


FIG. 20

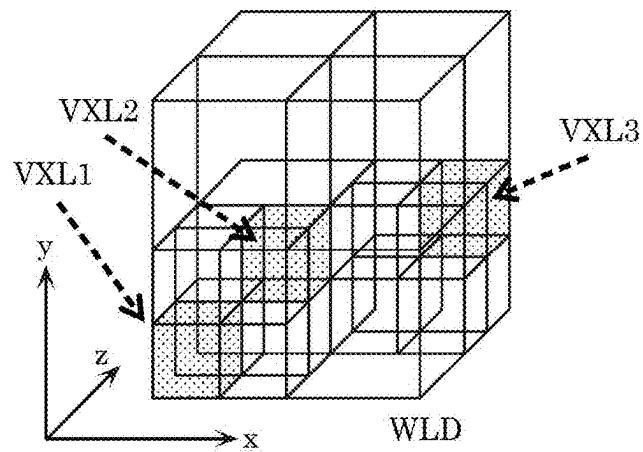


FIG. 21

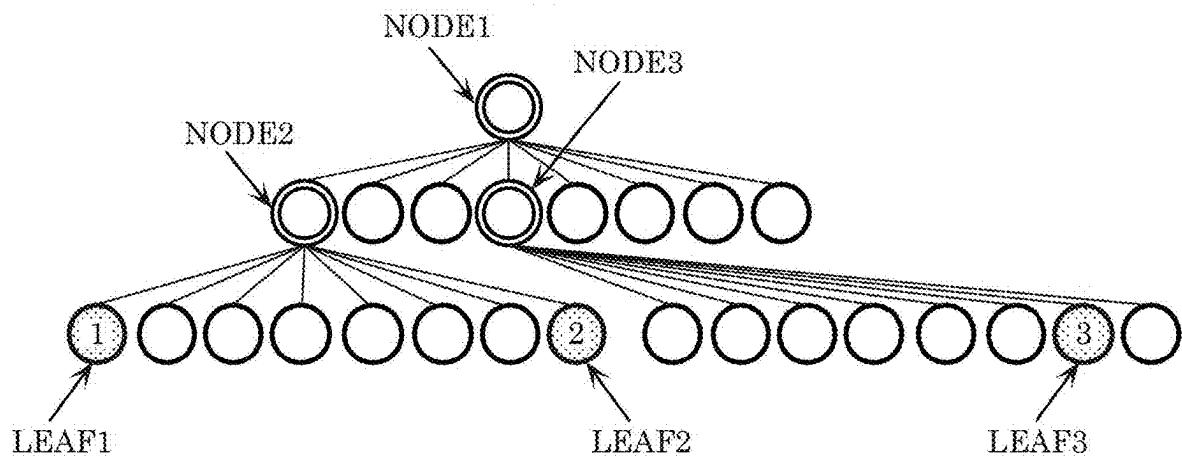


FIG. 22

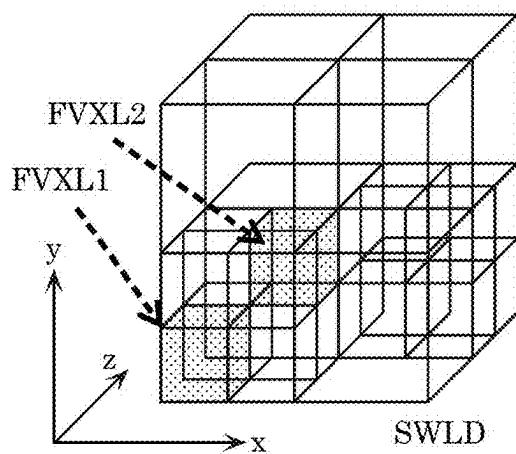


FIG. 23

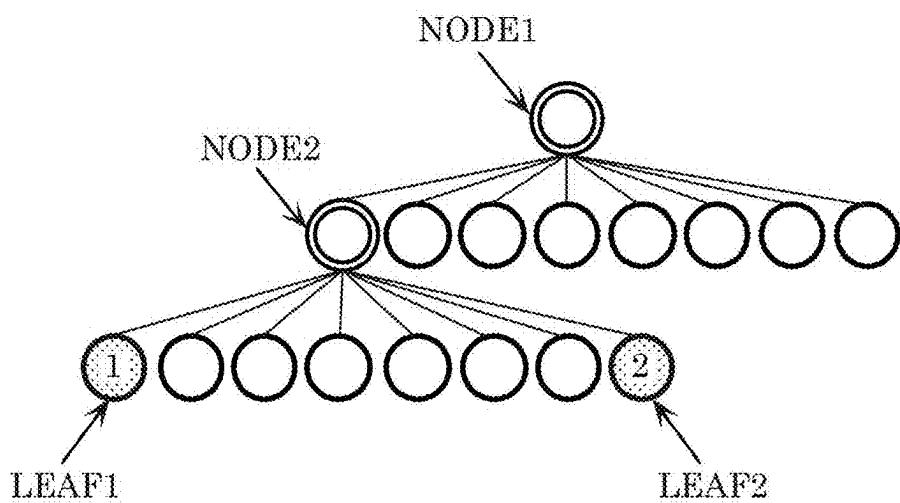


FIG. 24

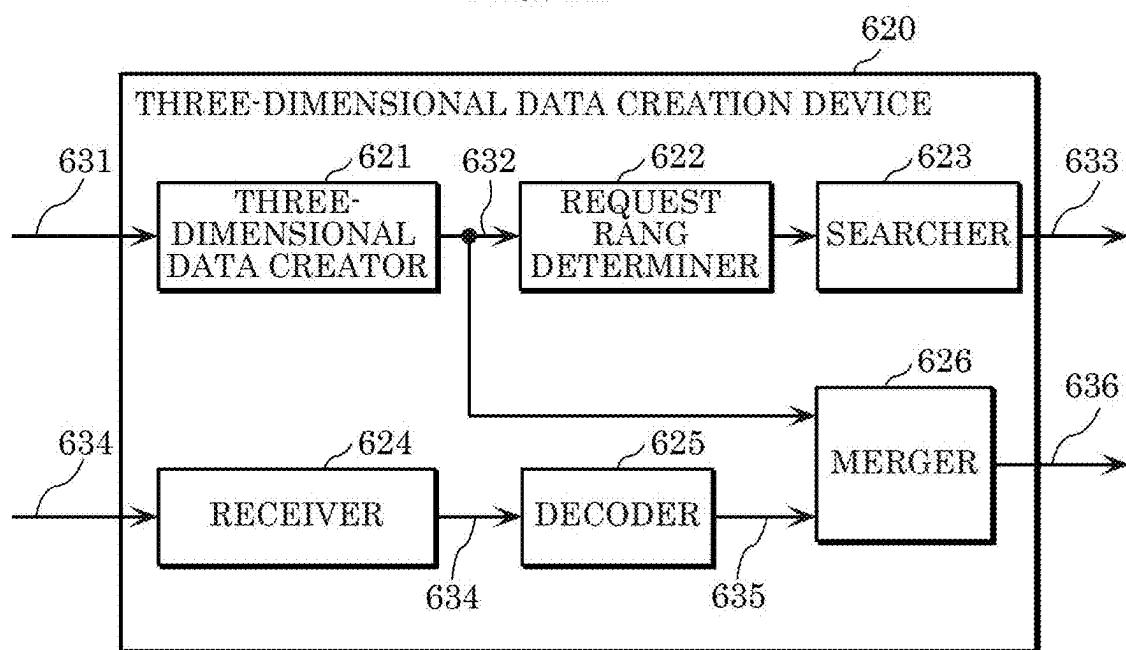


FIG. 25

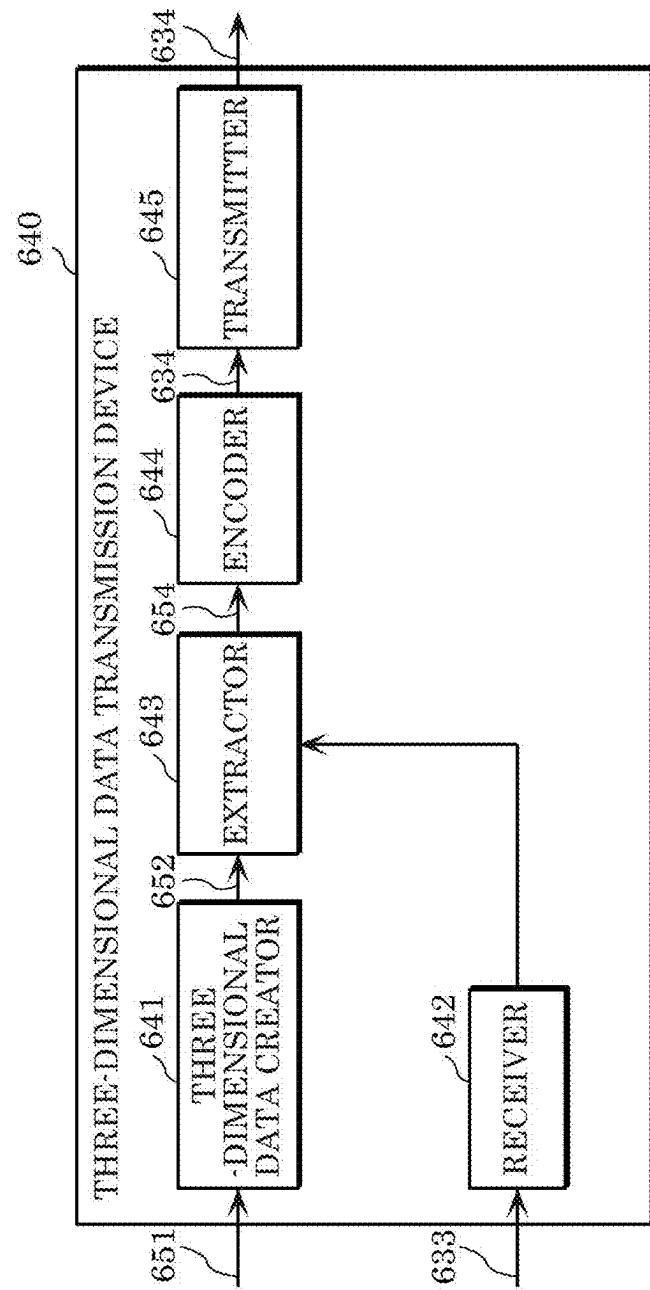


FIG. 26

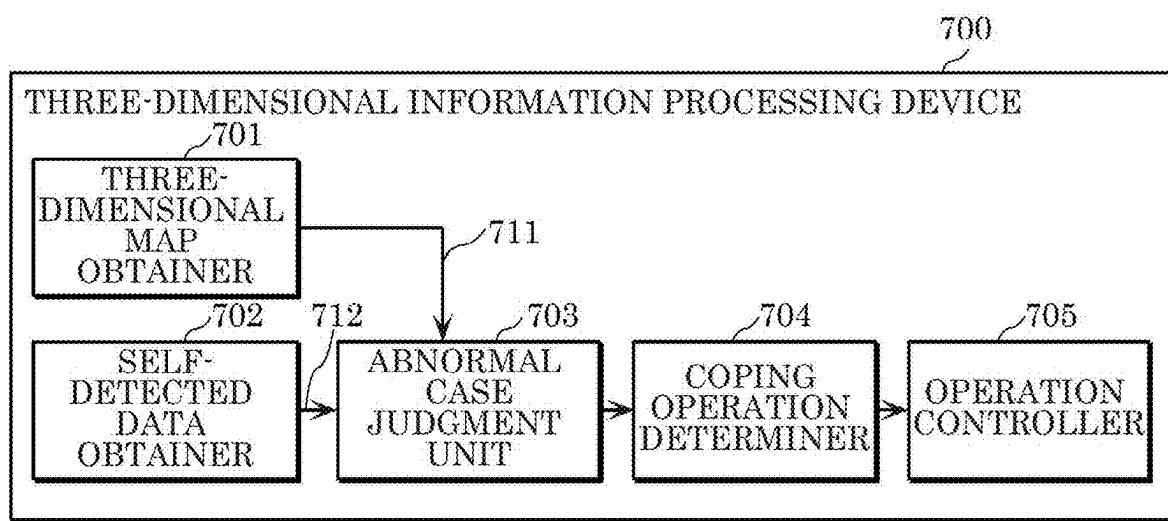


FIG. 27

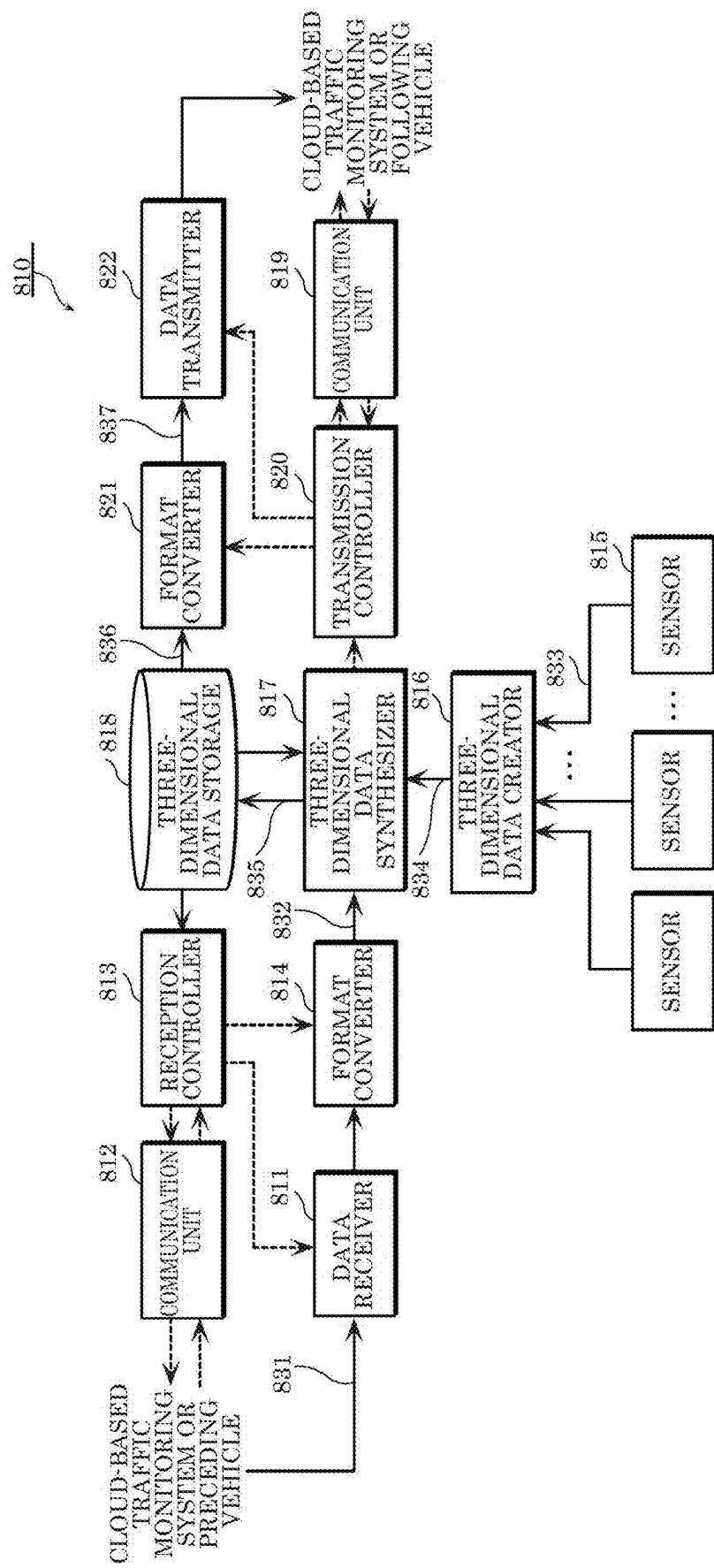


FIG. 28

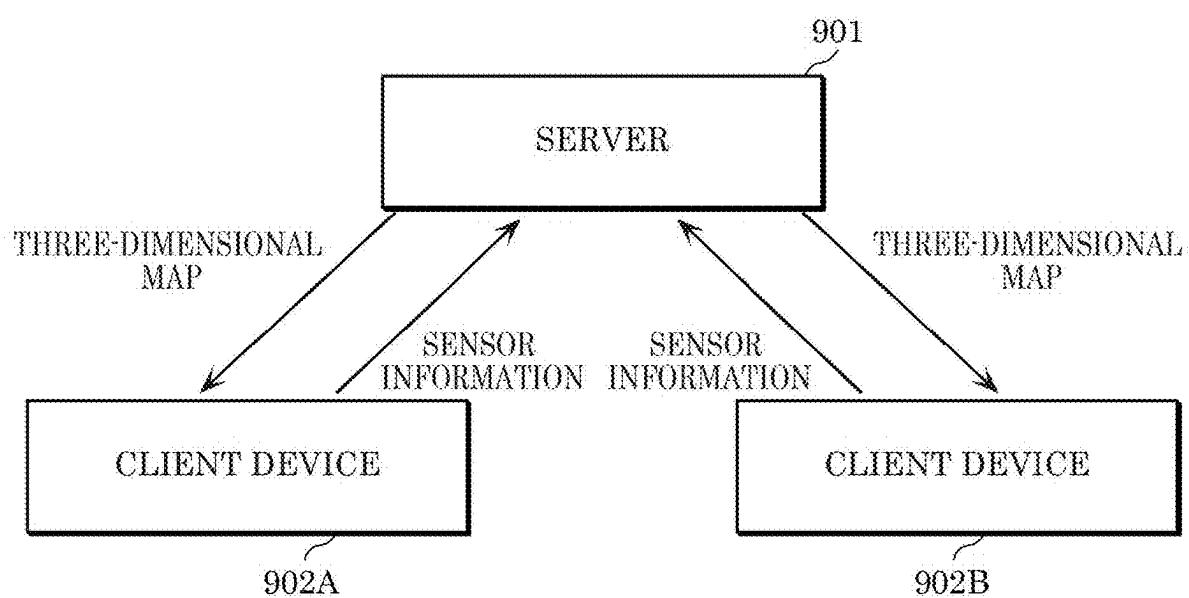


FIG. 29

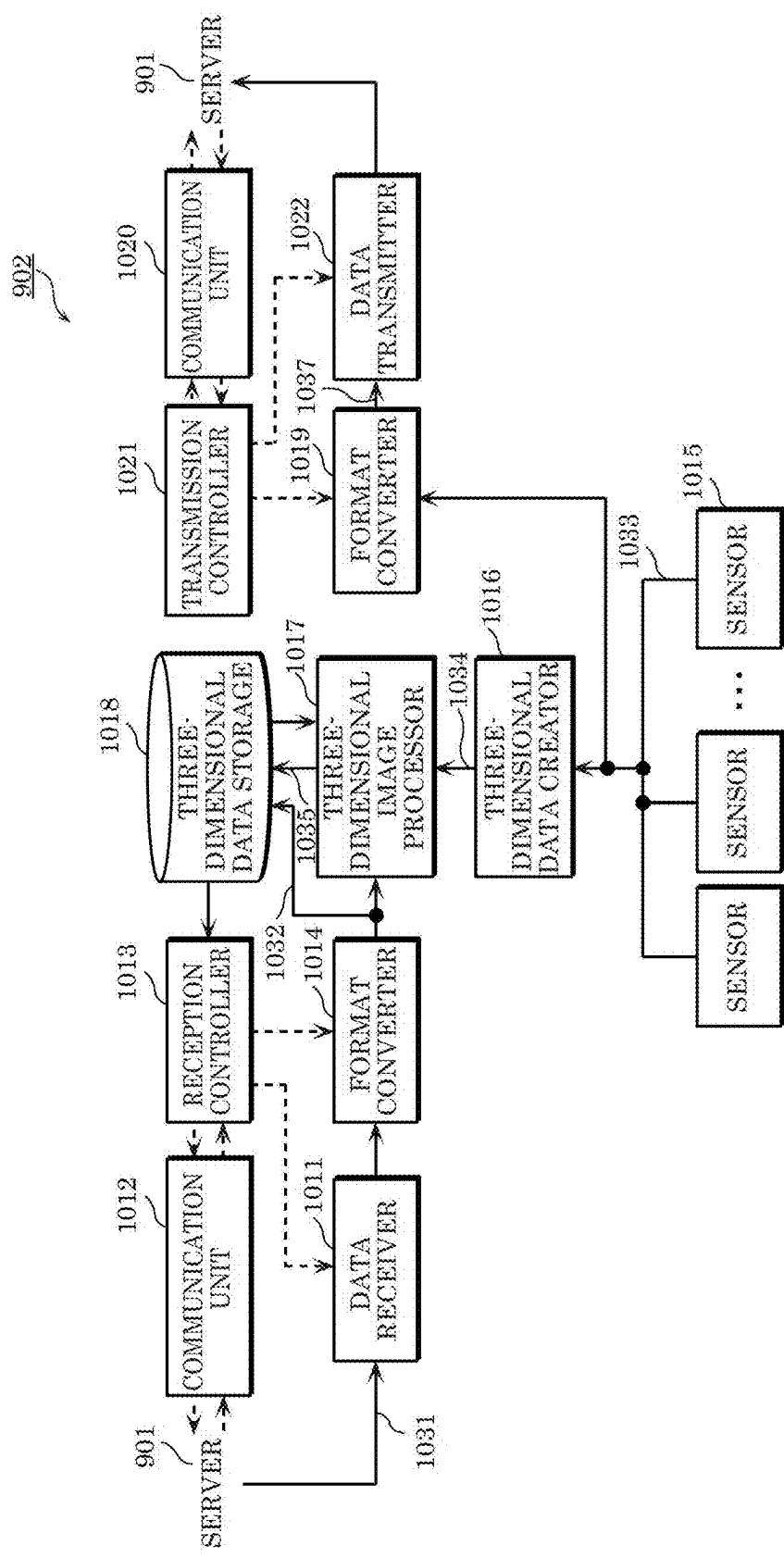


FIG. 30

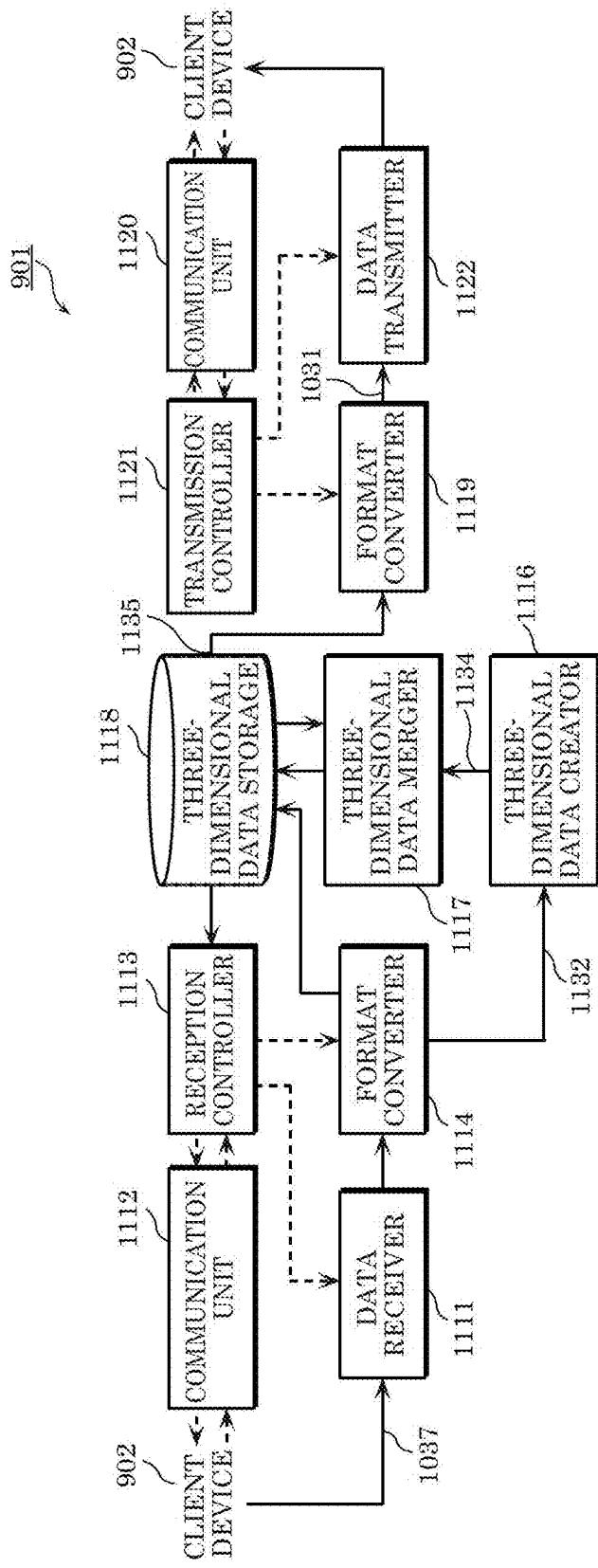


FIG. 31

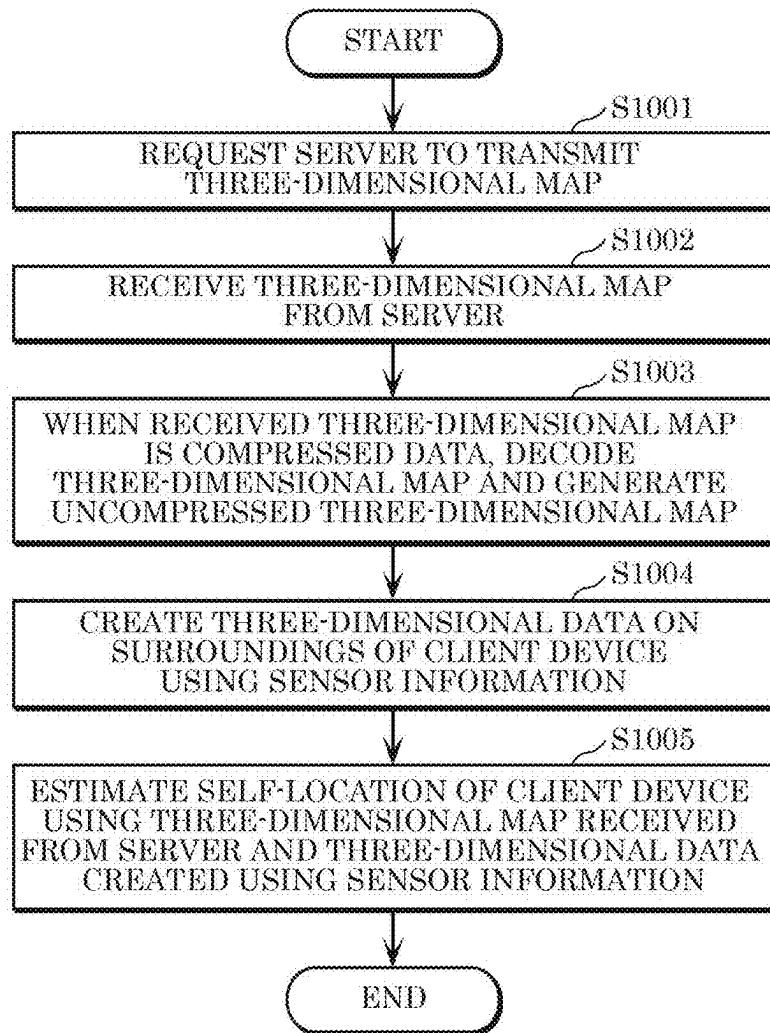


FIG. 32

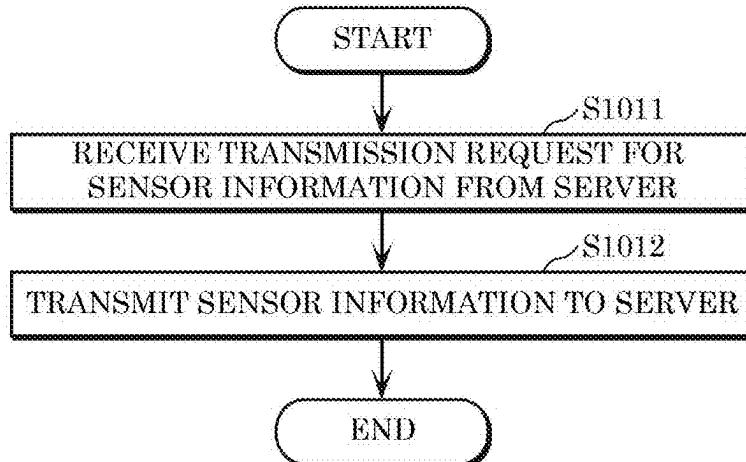


FIG. 33

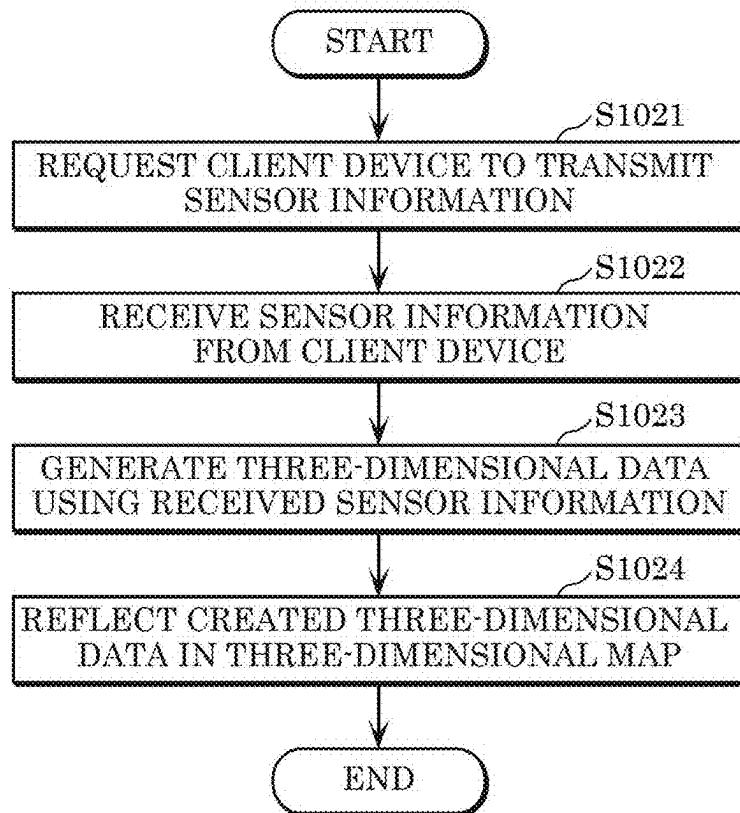


FIG. 34

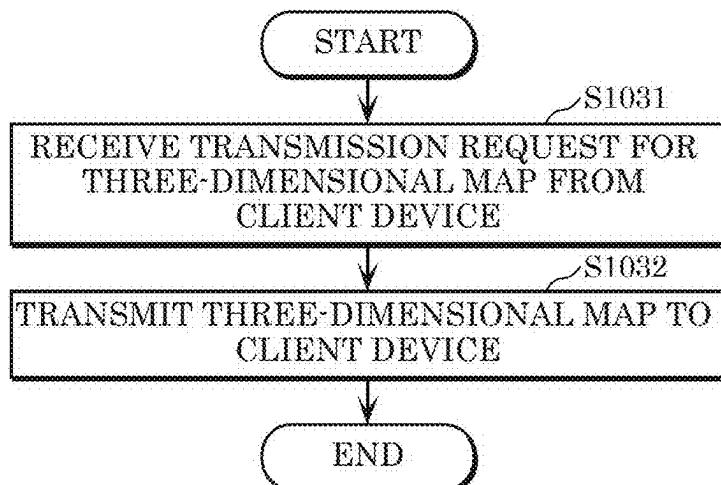


FIG. 35

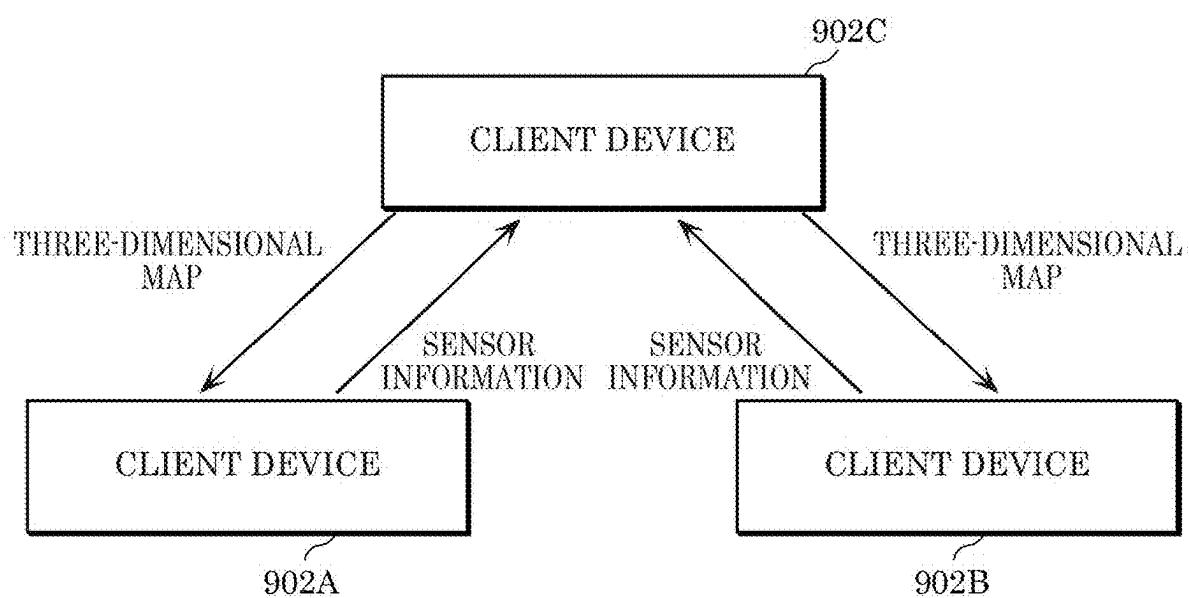


FIG. 36

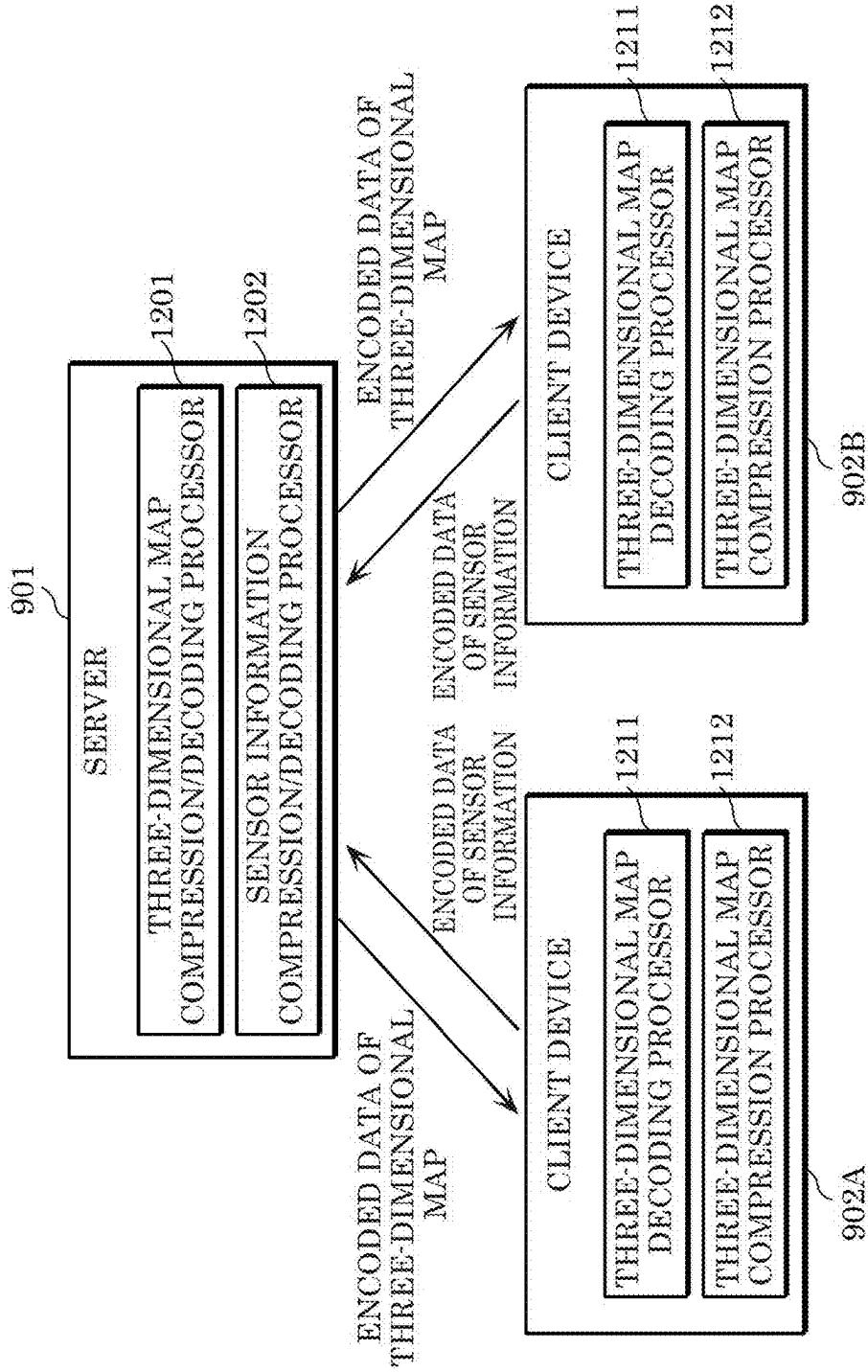


FIG. 37

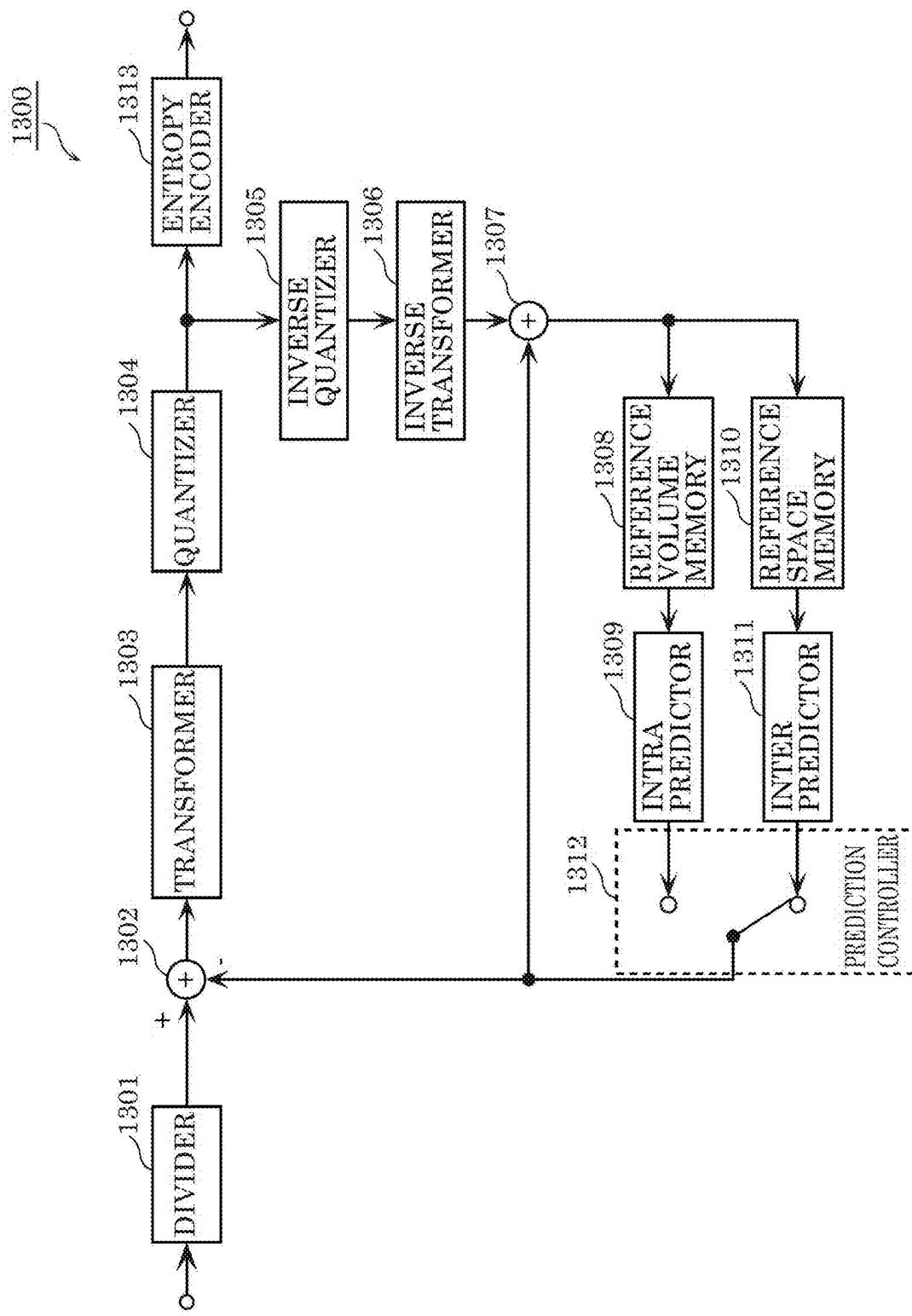


FIG. 38

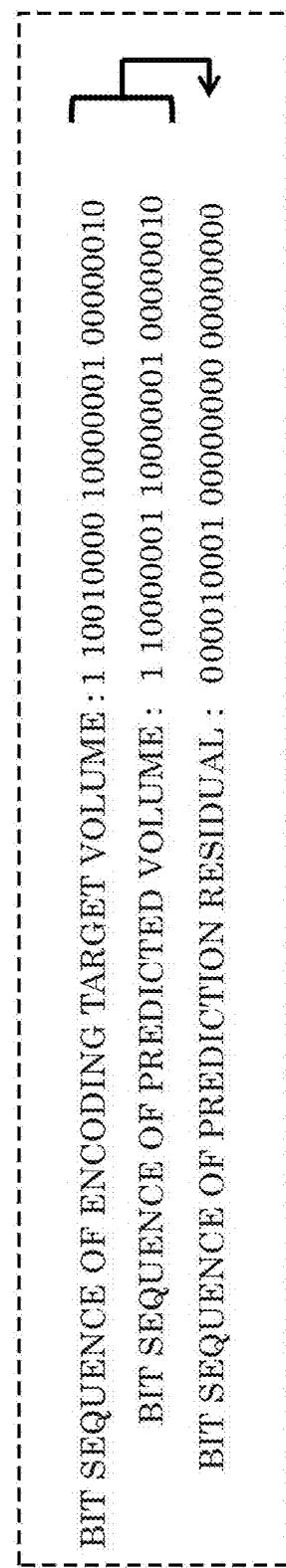


FIG. 39

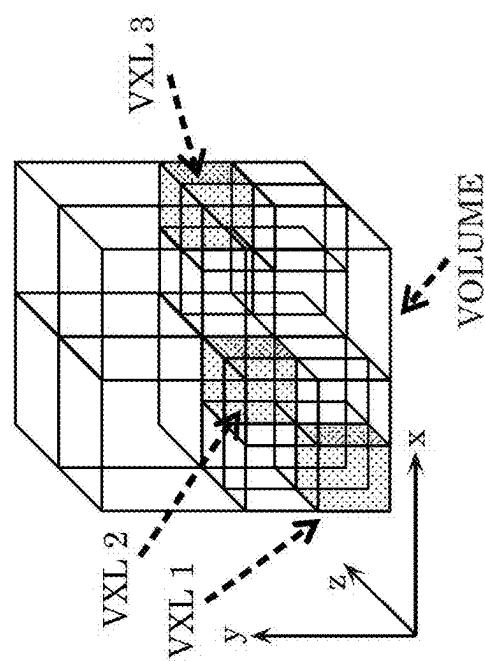


FIG. 40

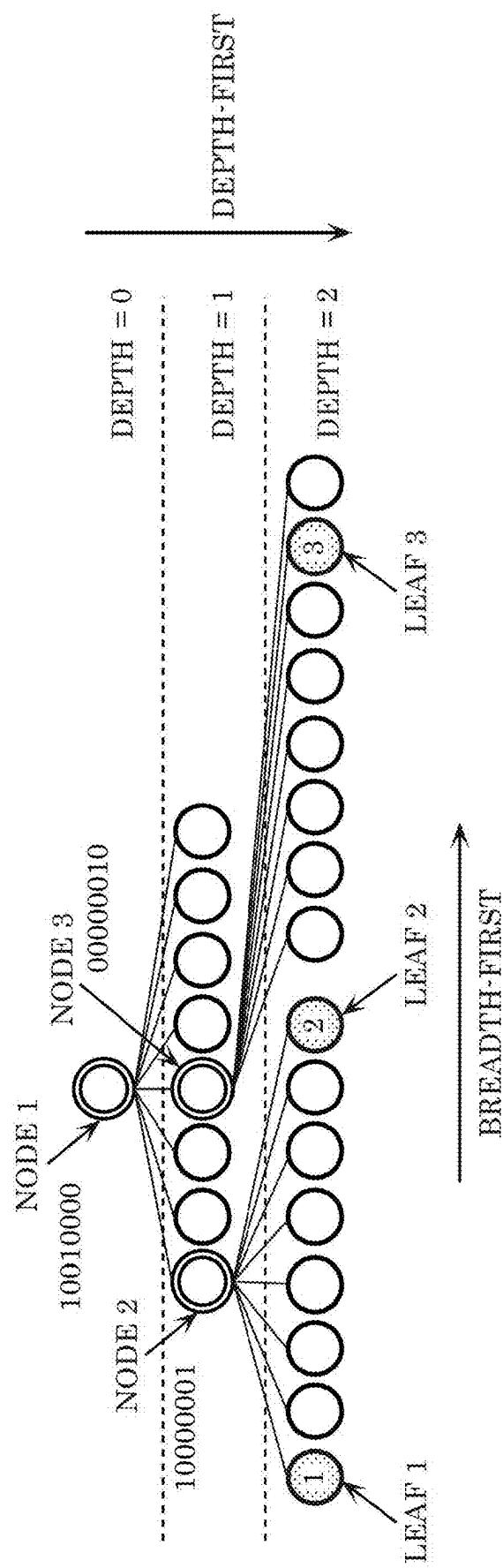


FIG. 41

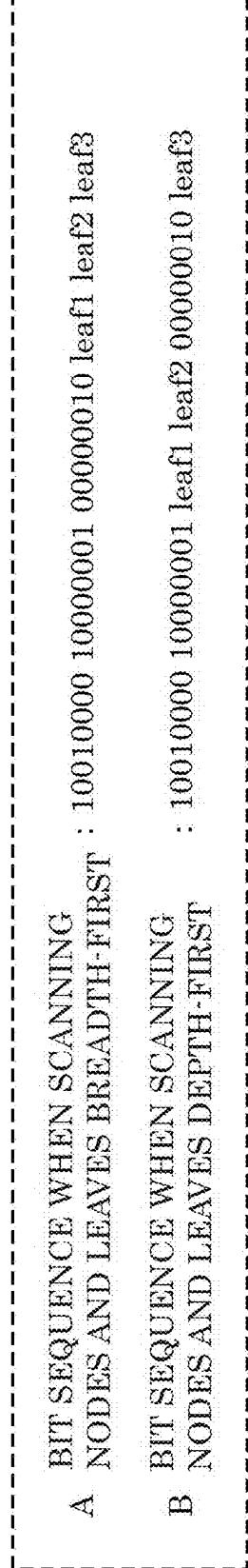
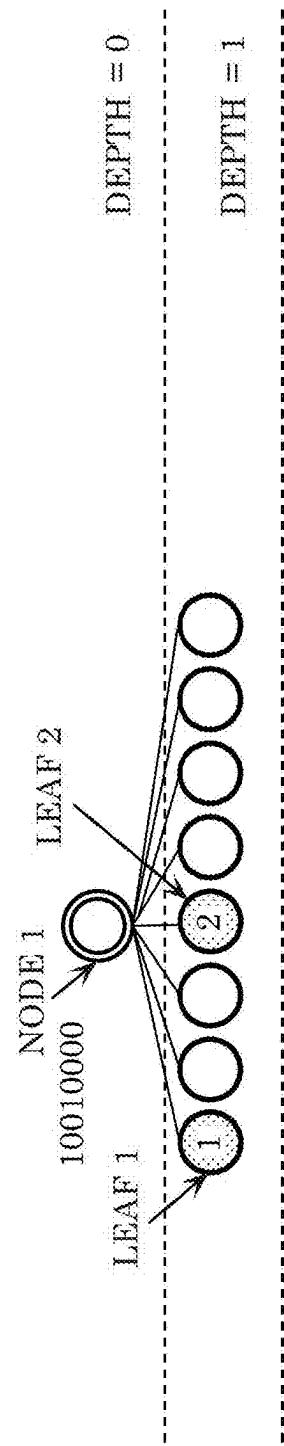
- 
- A BIT SEQUENCE WHEN SCANNING NODES AND LEAVES BREADTH-FIRST : 10010000 10000001 00000010 leaf1 leaf2 leaf3
  - B BIT SEQUENCE WHEN SCANNING NODES AND LEAVES DEPTH-FIRST : 10010000 10000001 leaf1 leaf2 00000010 leaf3

FIG. 42



BREATH-FIRST SCAN ORDER : 10010000

FIG. 43

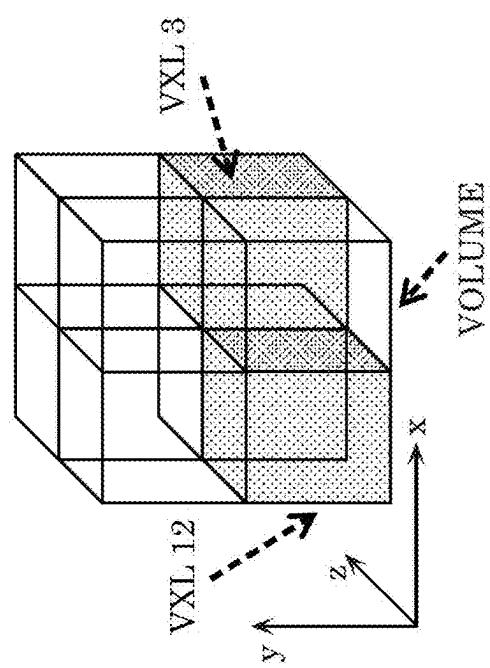


FIG. 44

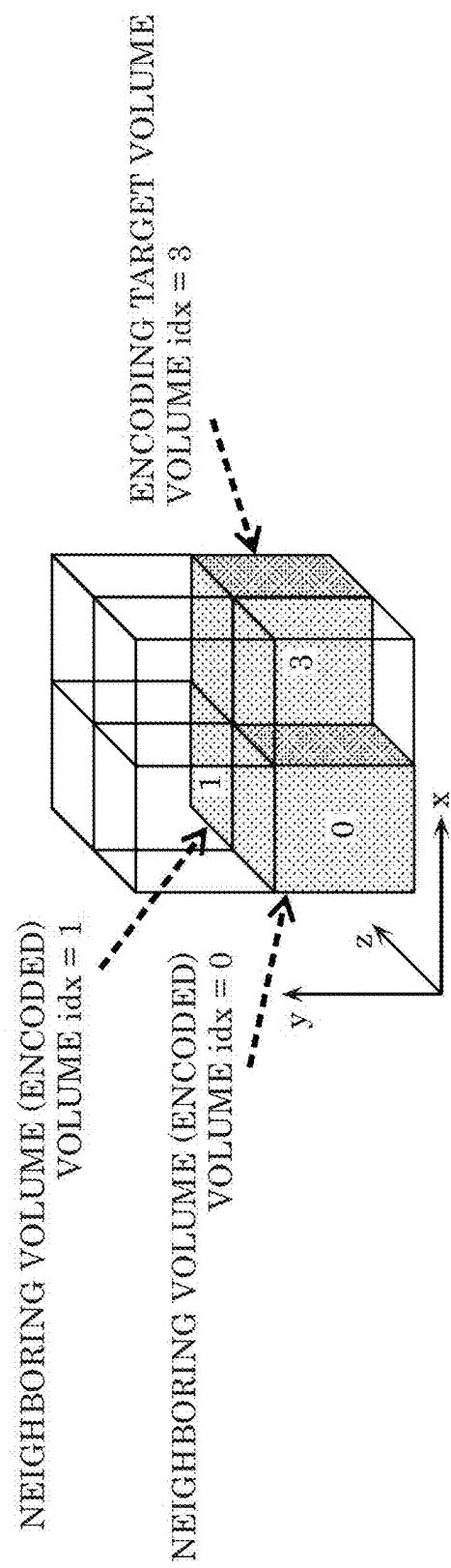


FIG. 45

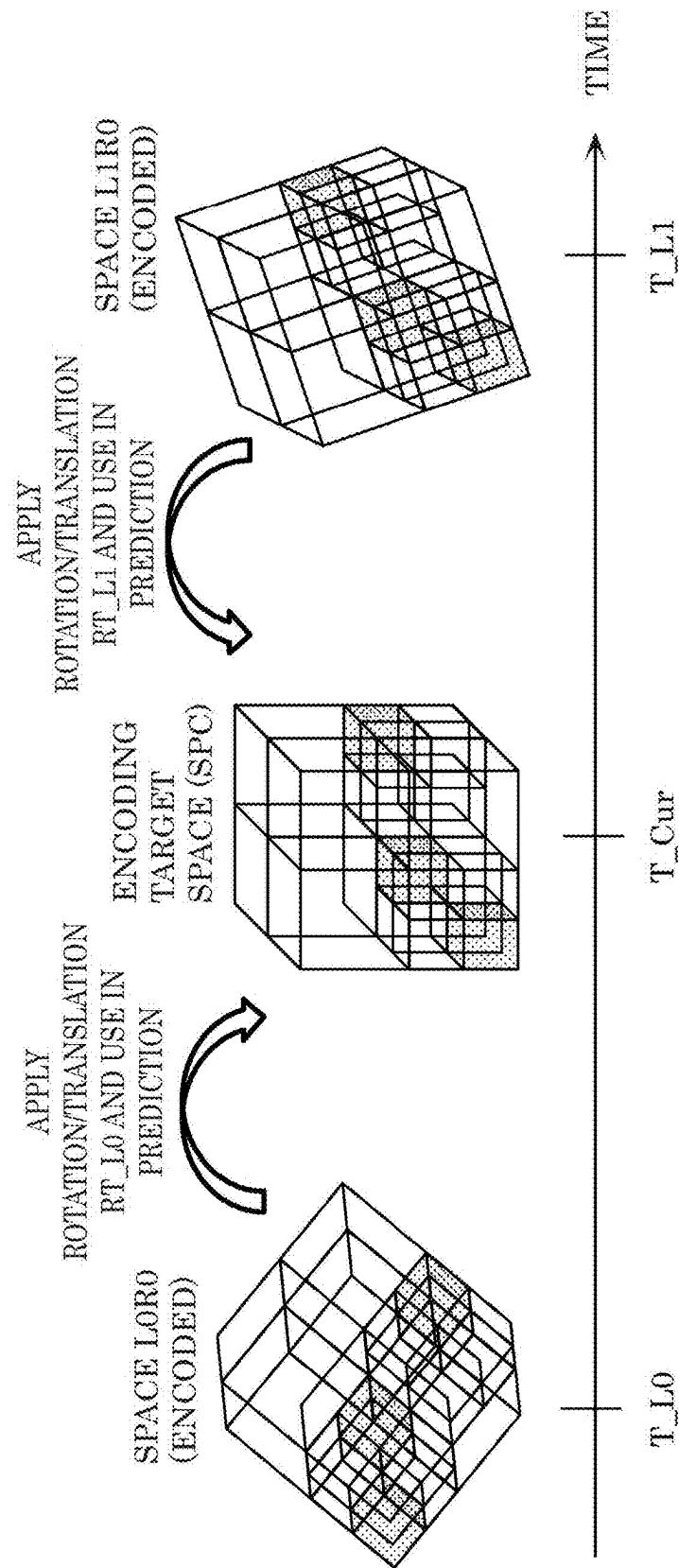


FIG. 46

```
space_header0 {  
    ...  
    for (i=0; i<MaxRefSpc_J0;i++) {  
        RT_flag_J0[i]  
        if(RT_flag_J0[i]) {  
            R_J0[i]  
            T_J0[i]  
        }  
    }  
    ...  
    for (i=0; i<MaxRefSpc_J1;i++) {  
        RT_flag_J1[i]  
        if(RT_flag_J1[i]) {  
            R_J1[i]  
            T_J1[i]  
        }  
    }  
    ...  
}
```

FIG. 47

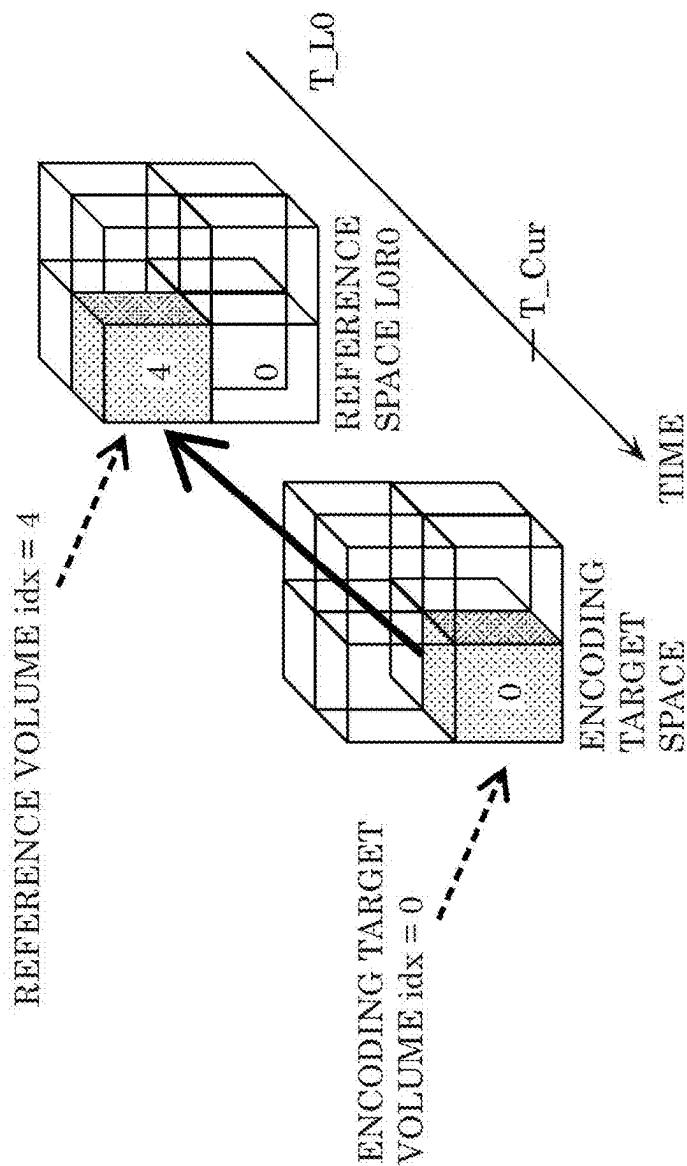


FIG. 48

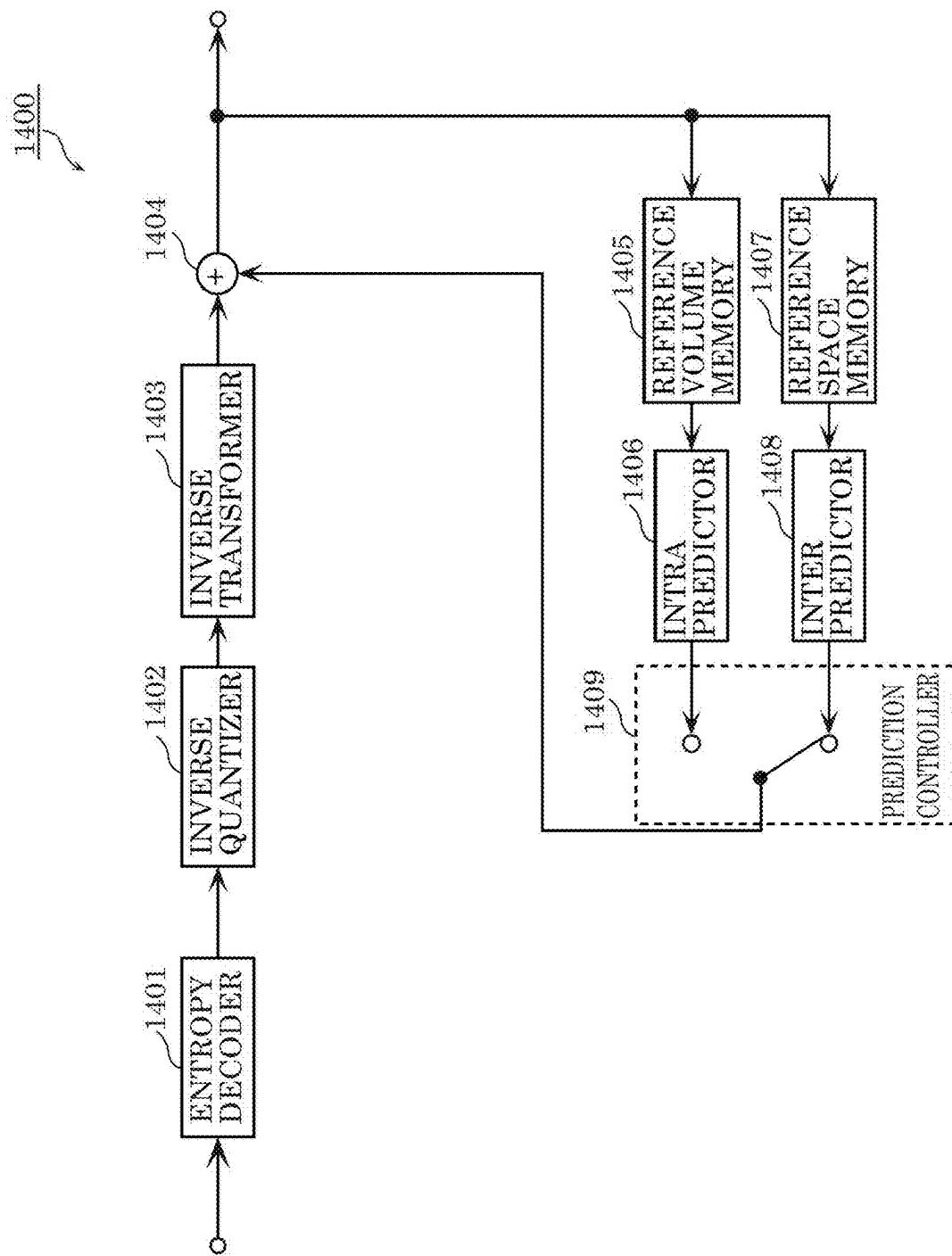


FIG. 49

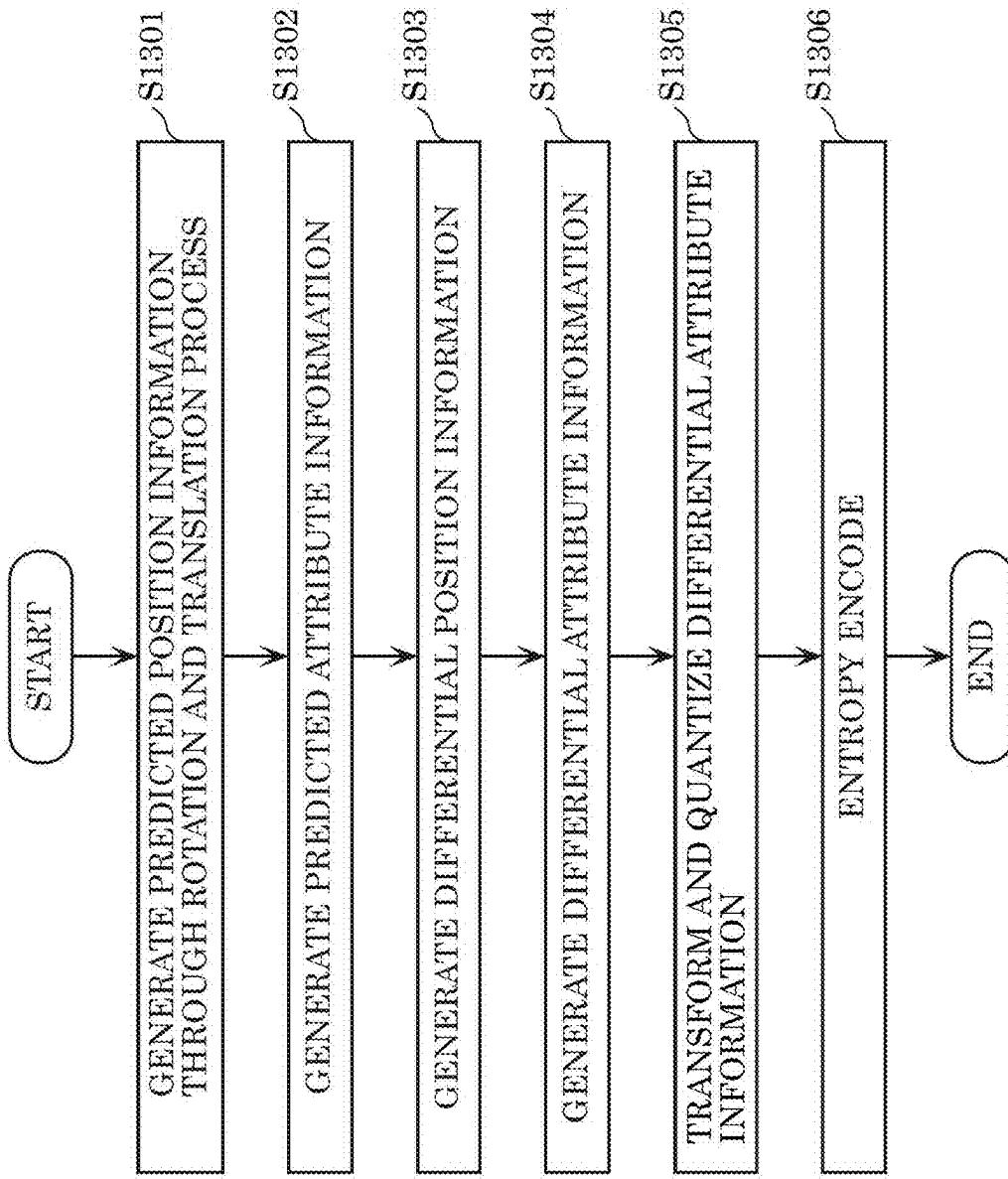


FIG. 50

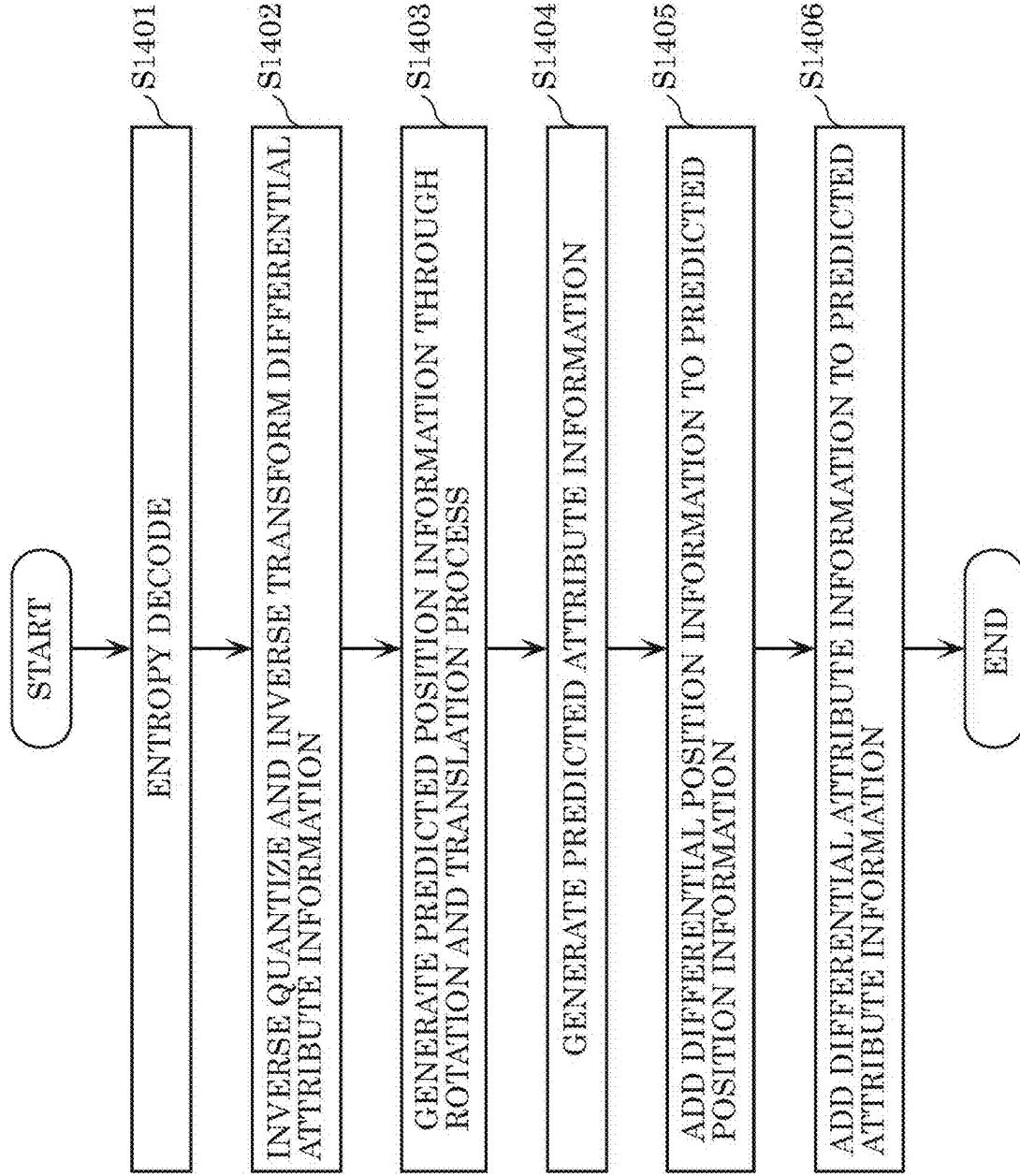


FIG. 51

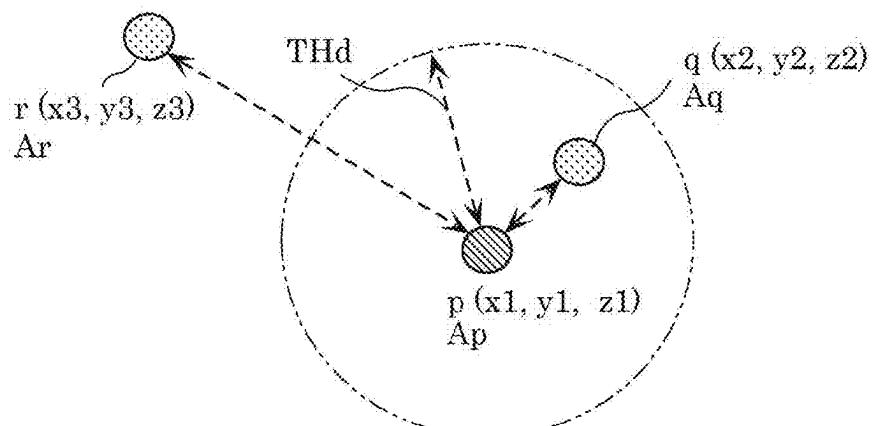


FIG. 52

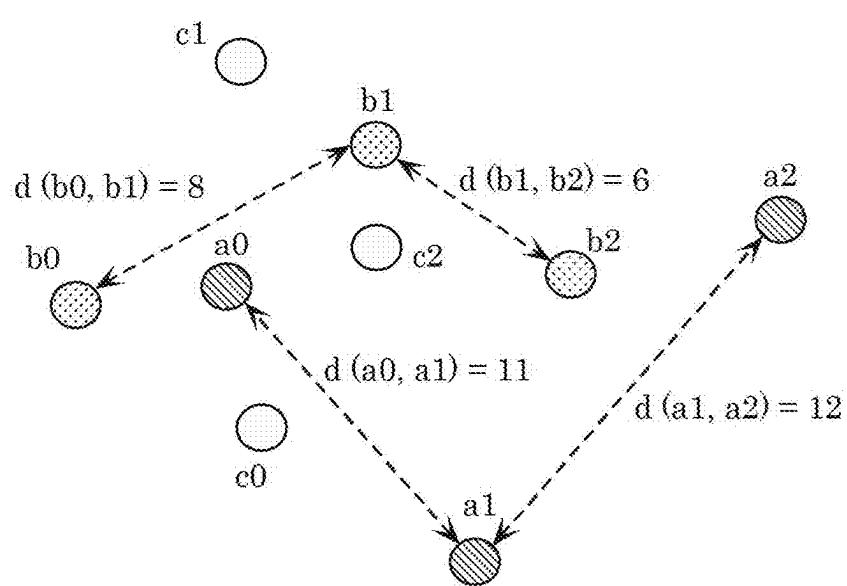


FIG. 53

a0	a1	a2	LoD0	Thres_LoD[0] = 10	SPARSE
b0	b1	b2	LoD1	Thres_LoD[1] = 5	
c0	c1	c2	LoD2	Thres_LoD[2] = 0	DENSE



FIG. 54

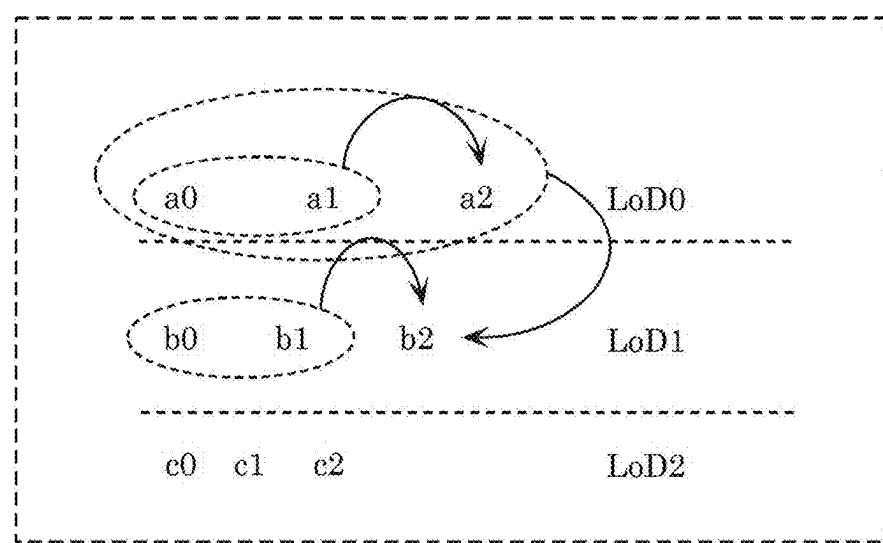


FIG. 55

VALUE	BIT
0	1
1	010
2	011
3	00100
4	00101
5	00110
6	00111
7	0001000
...	...

FIG. 56

VALUE	BIT	PREFIX	SUFFIX
3	00100	00	1 00
4	00101		
5	00110		
6	00111		

TERMINATE SYMBOL

FIG. 57

```
attribute_header{  
    ...  
    NumLoD  
    ...  
    for (i=0; i<NumLoD; i++) {  
        NumOfPoint[i]  
    }  
    ...  
    for (i=0; i<NumLoD-1; i++) {  
        Thres_LoD[i]  
    }  
    ...  
    for (i=0; i<NumLoD; i++) {  
        NumNeighborPoint[i]  
    }  
    ...  
    for (i=0; i<NumLoD; i++) {  
        THd[i]  
    }  
    ...  
    for (i=0; i<NumLoD; i++) {  
        QS[i]  
    }  
    ...  
    for (i=0; i<NumLoD; i++) {  
        R_TH[i]  
    }  
    ...  
}
```

FIG. 58

```
attribute_data{  
    ...  
    for (i=0; i<NumLoD; i++) {  
        for(j=0; j<NumOfPoint[i]; j++) {  
            n-bit code  
            if (n-bit code == R_TH[i])  
                remaining code  
        }  
    }  
    ...  
}
```

FIG. 59

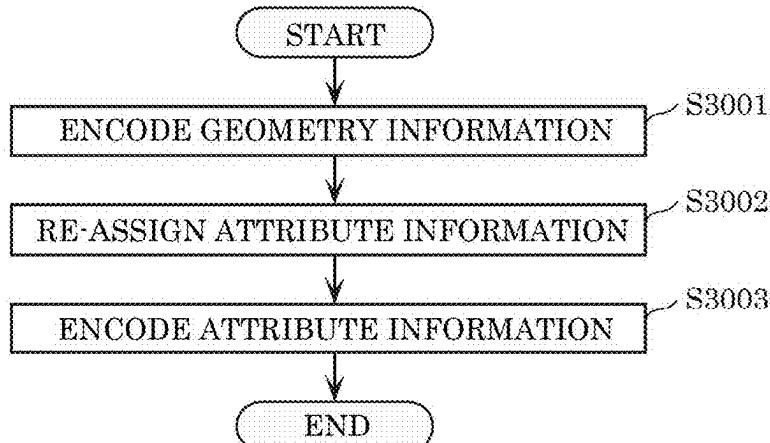


FIG. 60

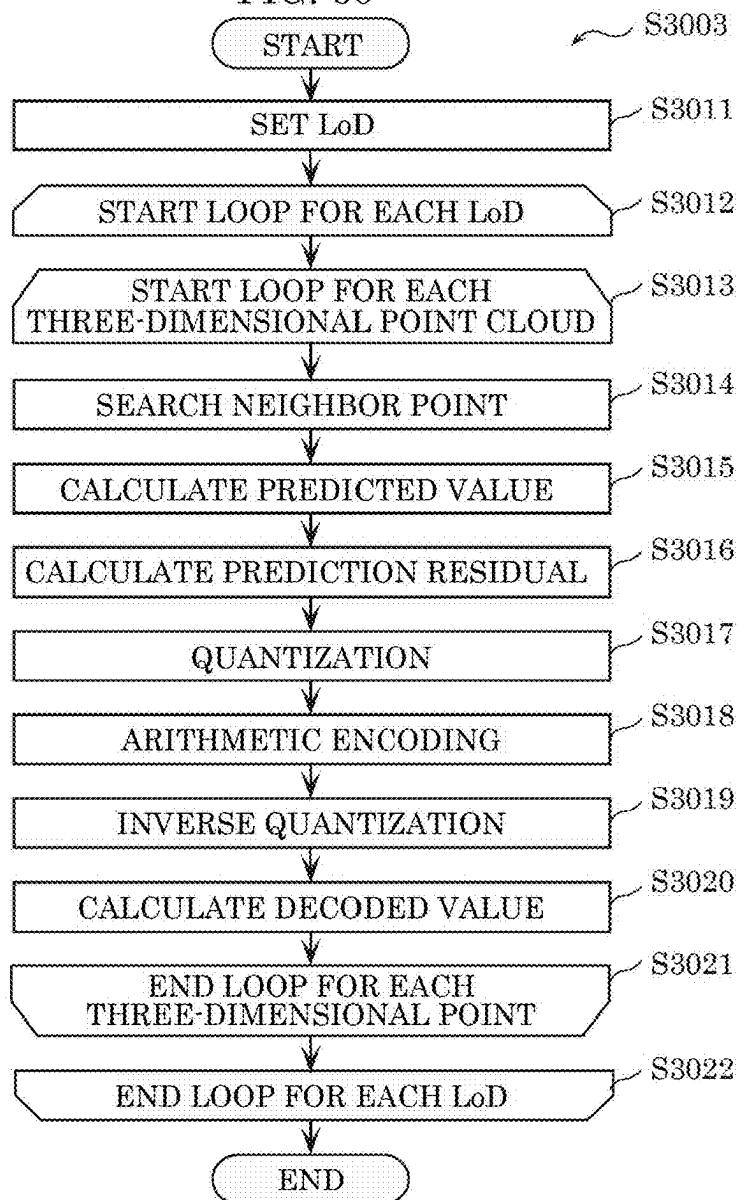


FIG. 61

VALUE	BIT	PREFIX	SUFFIX
3	00100	00	1
4	00101		00
5	00110		
6	00111		

TERMINATE SYMBOL

FIG. 62

VALUE	BIT
0	1
1	010
2	011
3	00100
4	00101
5	00110
6	00111
7	0001000
...	...

REVERSE LOOKUP

FIG. 63

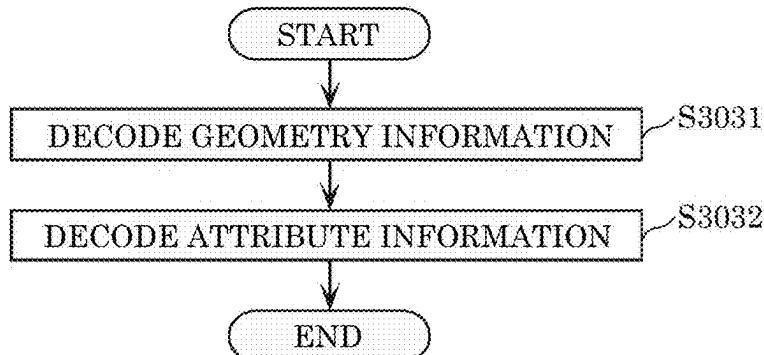


FIG. 64

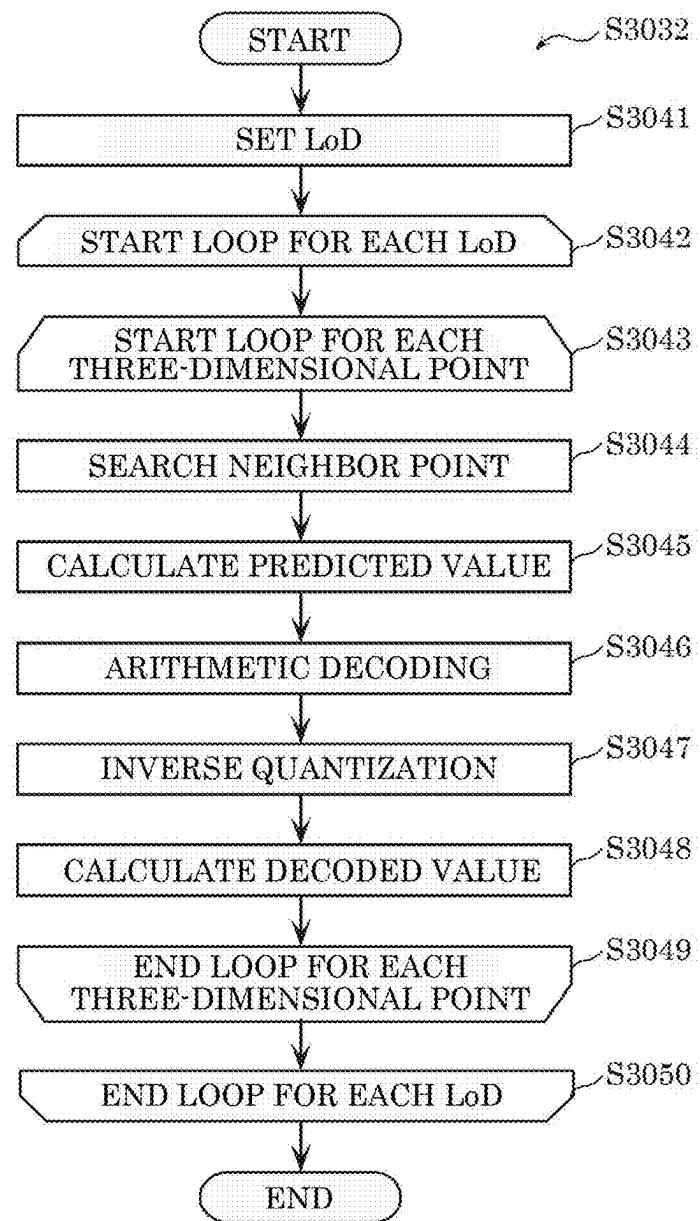


FIG. 65

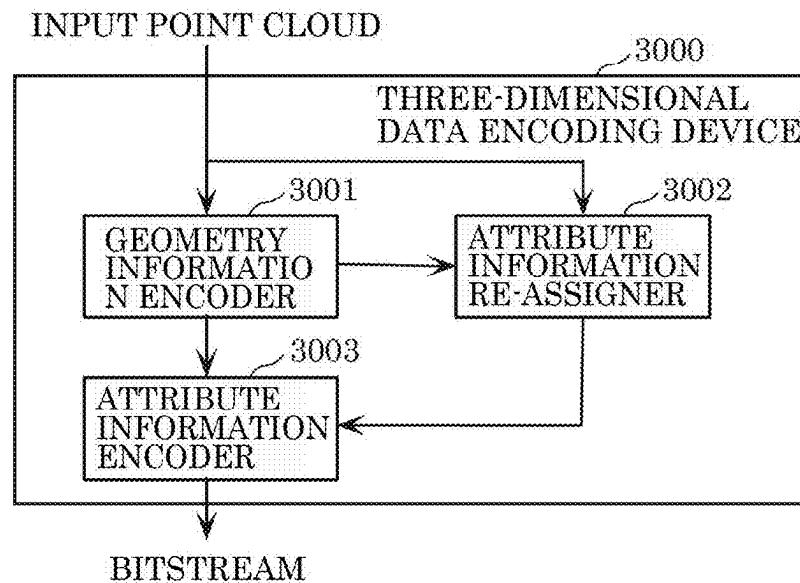


FIG. 66

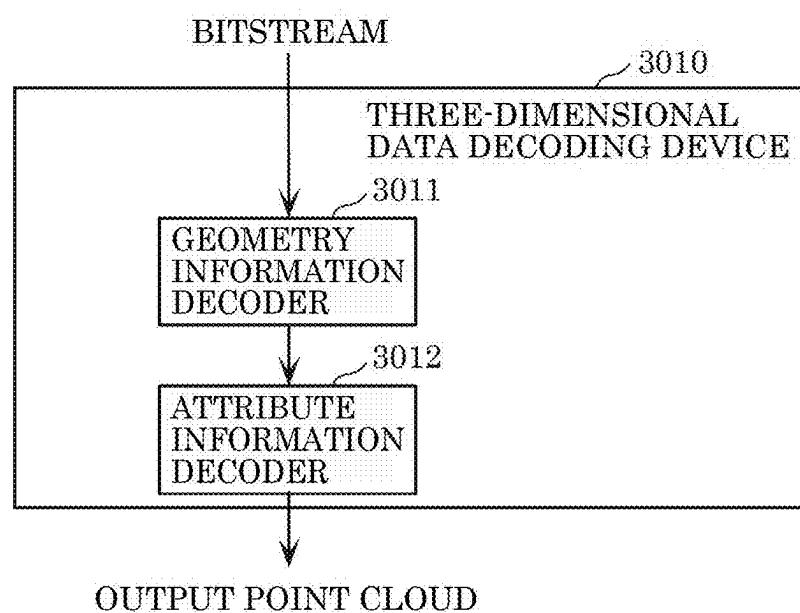


FIG. 67

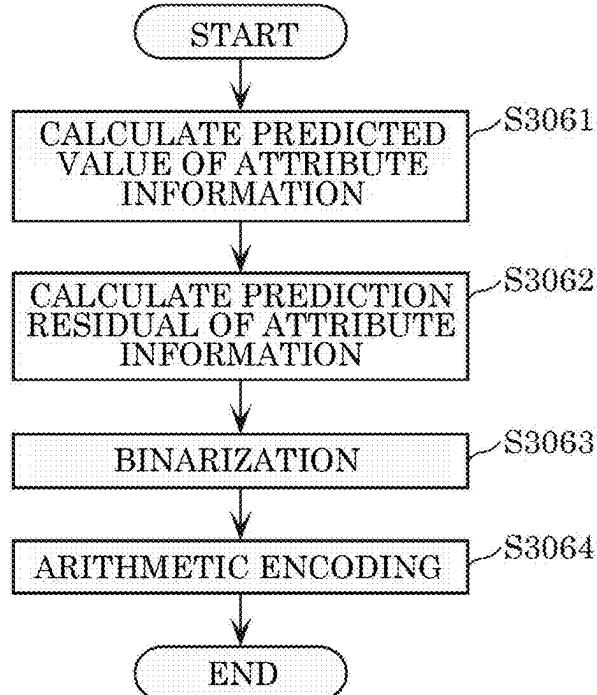


FIG. 68

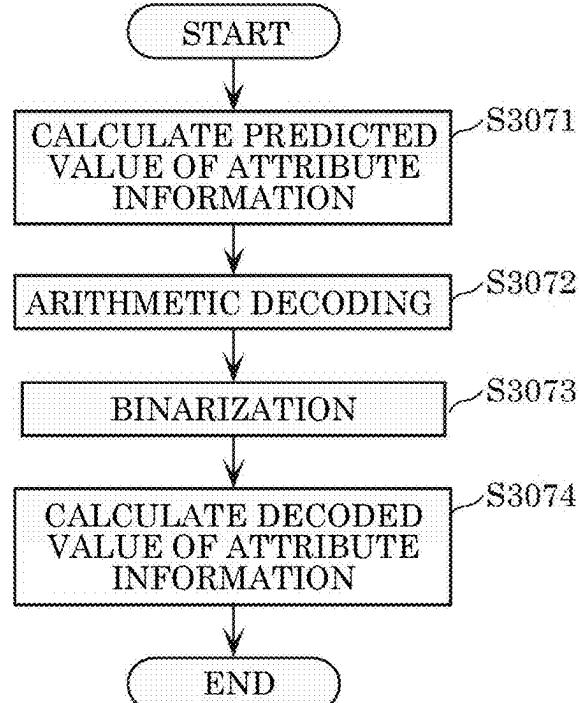


FIG. 69

PREDICTION MODE	PREDICTED VALUE
0	AVERAGE VALUE OF a0, a1, a2, b1
1	b1
2	a2
3	a1
4	a0

FIG. 70

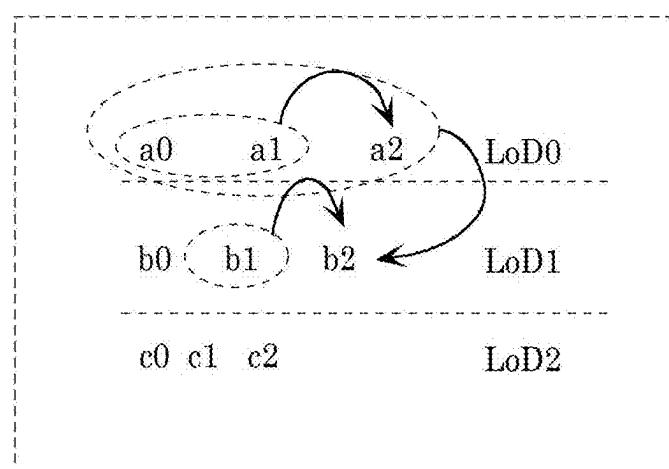


FIG. 71

PREDICTION MODE	PREDICTED VALUE
0	AVERAGE VALUE OF a <sub>0</sub> , a <sub>1</sub>
1	a <sub>1</sub>
2	a <sub>0</sub>
3	NOT AVAILABLE
4	NOT AVAILABLE

FIG. 72

PREDICTION MODE	PREDICTED VALUE
0	AVERAGE VALUE OF a <sub>0</sub> , a <sub>1</sub> , a <sub>2</sub> , b <sub>1</sub> (Y <sub>ave</sub> , U <sub>ave</sub> , V <sub>ave</sub> )
1	b <sub>1</sub> = (Y <sub>b1</sub> , U <sub>b1</sub> , V <sub>b1</sub> )
2	a <sub>2</sub> = (Y <sub>a2</sub> , U <sub>a2</sub> , V <sub>a2</sub> )
3	a <sub>1</sub> = (Y <sub>a1</sub> , U <sub>a1</sub> , V <sub>a1</sub> )
4	a <sub>0</sub> = (Y <sub>a0</sub> , U <sub>a0</sub> , V <sub>a0</sub> )

FIG. 73

PREDICTION MODE	PREDICTED VALUE
0	AVERAGE VALUE OF $a_0, a_1, a_2, b_1$ Rave
1	$b_1 = R_{b1}$
2	$a_2 = R_{a2}$
3	$a_1 = R_{a1}$
4	$a_0 = R_{a0}$

FIG. 74

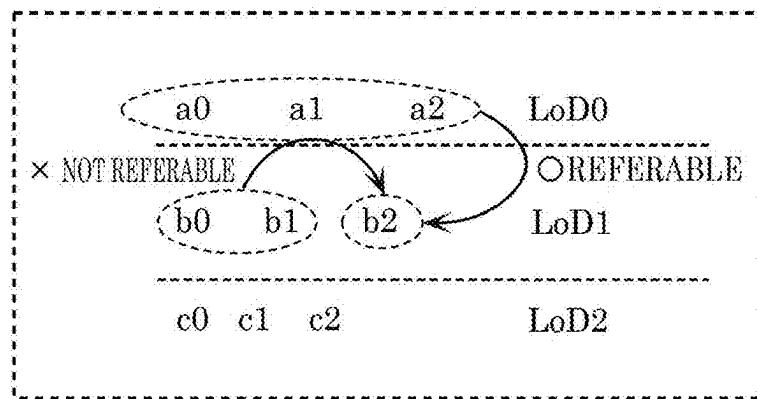


FIG. 75

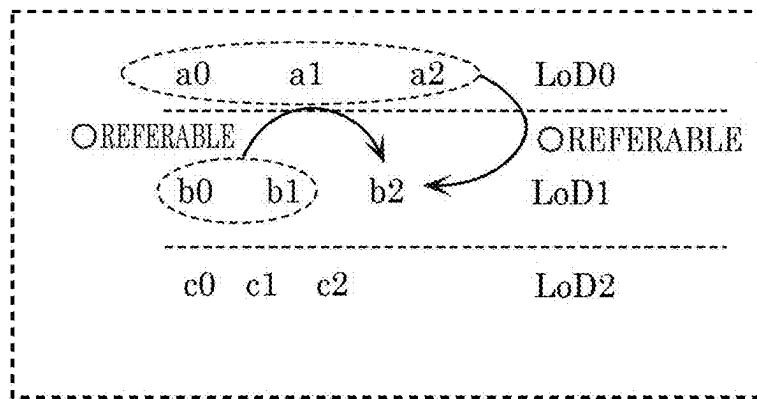


FIG. 76

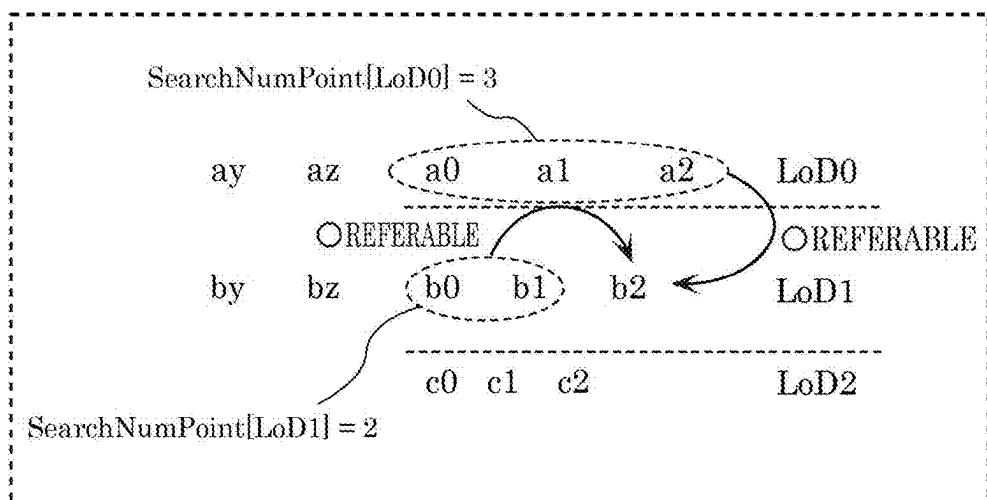


FIG. 77

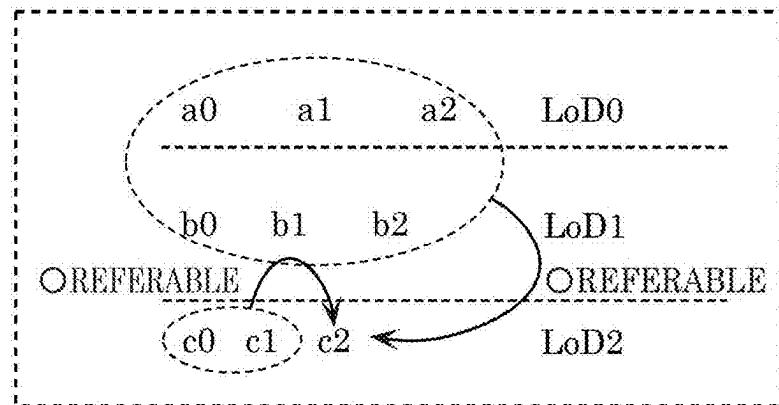


FIG. 78

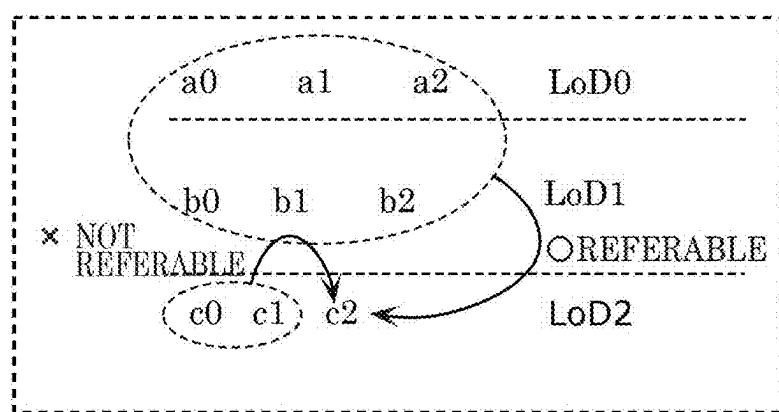


FIG. 79

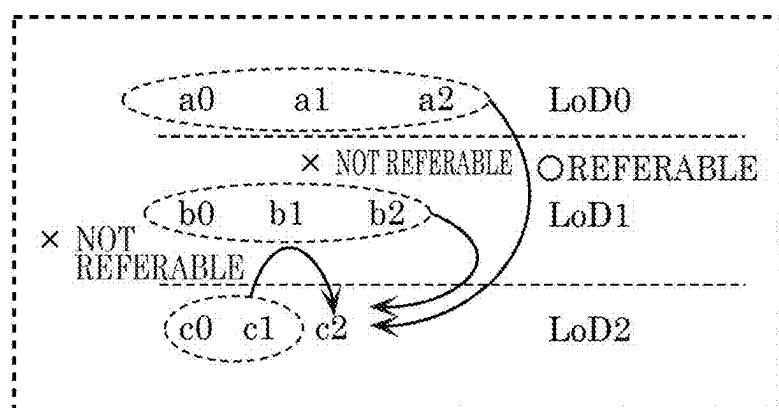


FIG. 80

```
attribute_header {  
    ...  
    EnableReferringSameLoD  
    ...  
    NumLoD  
    ...  
    for (i=0; i<NumLoD; i++) {  
        SearchNumPoint[i]  
    }  
  
    for (i=0; i<NumLoD; i++) {  
        NumNeighborPoint[i]  
    }  
}...  
}
```

FIG. 81

```
attribute_header {  
    ...  
    EnableReferenceLoD  
    ...  
    NumLoD  
    ...  
    for (i=0; i<NumLoD; i++) {  
        SearchNumPoint[i]  
    }  
  
    for (i=0; i<NumLoD; i++) {  
        NumNeighborPoint[i]  
    }  
}...  
}
```

FIG. 82

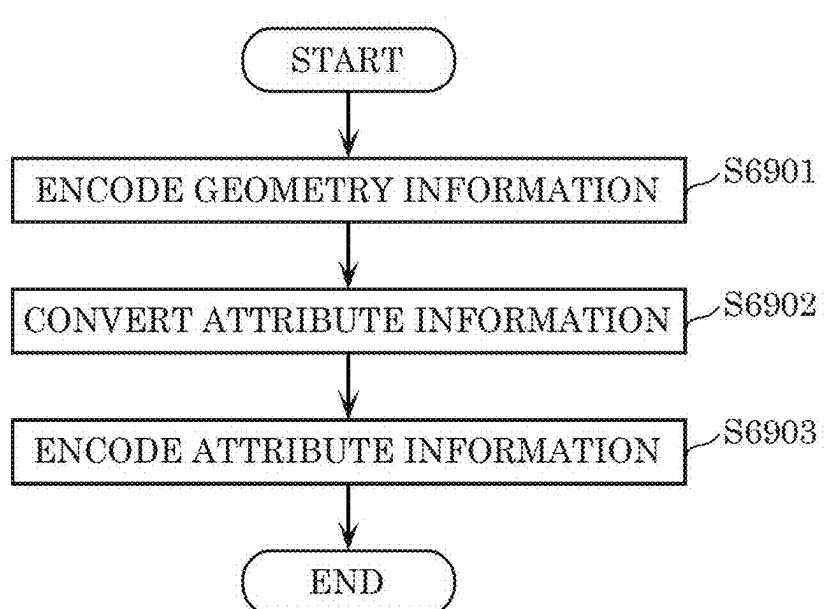


FIG. 83

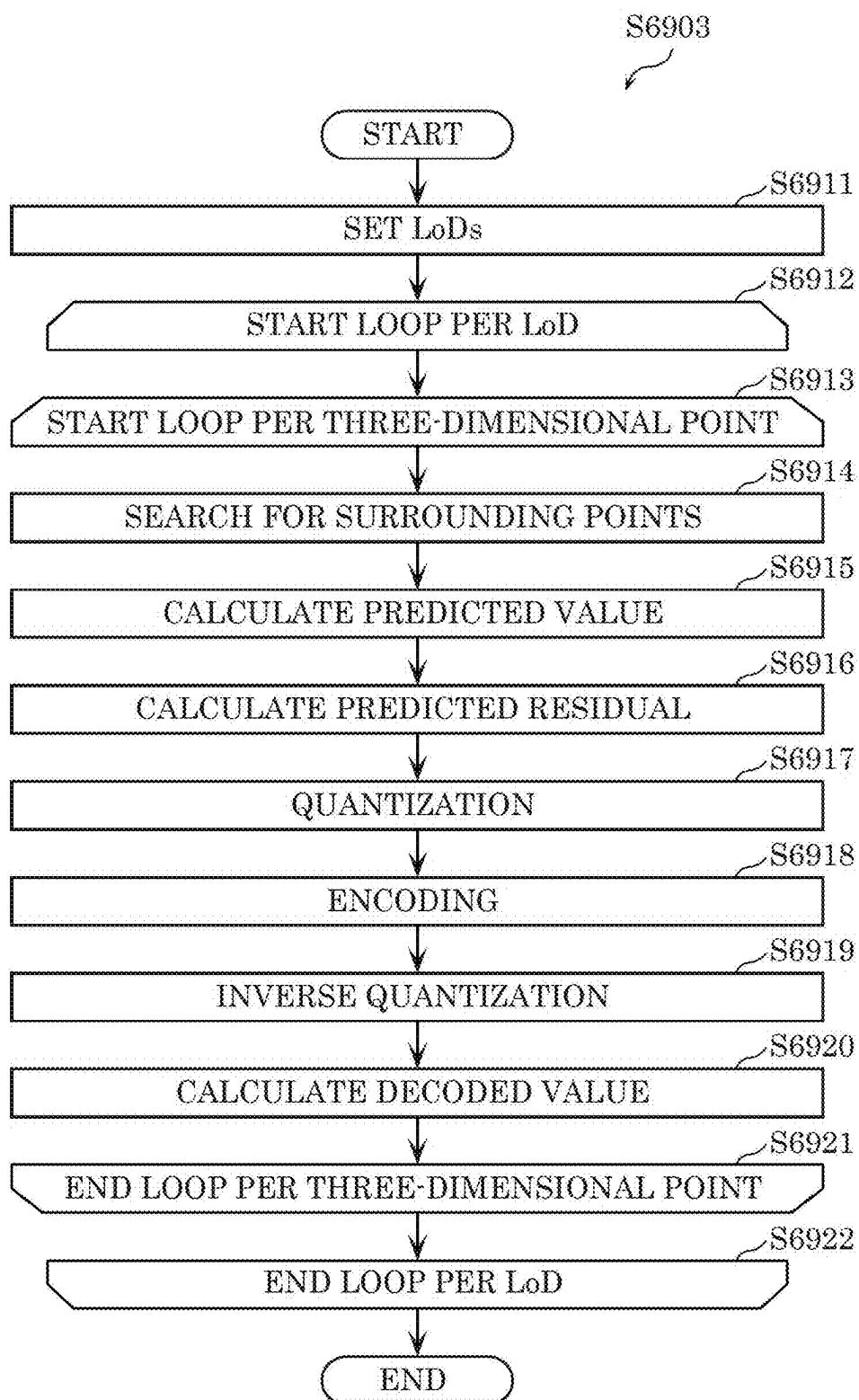


FIG. 84

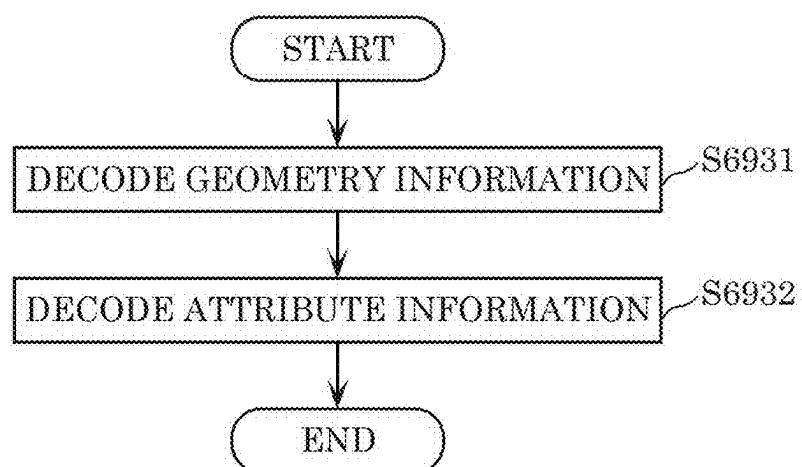


FIG. 85

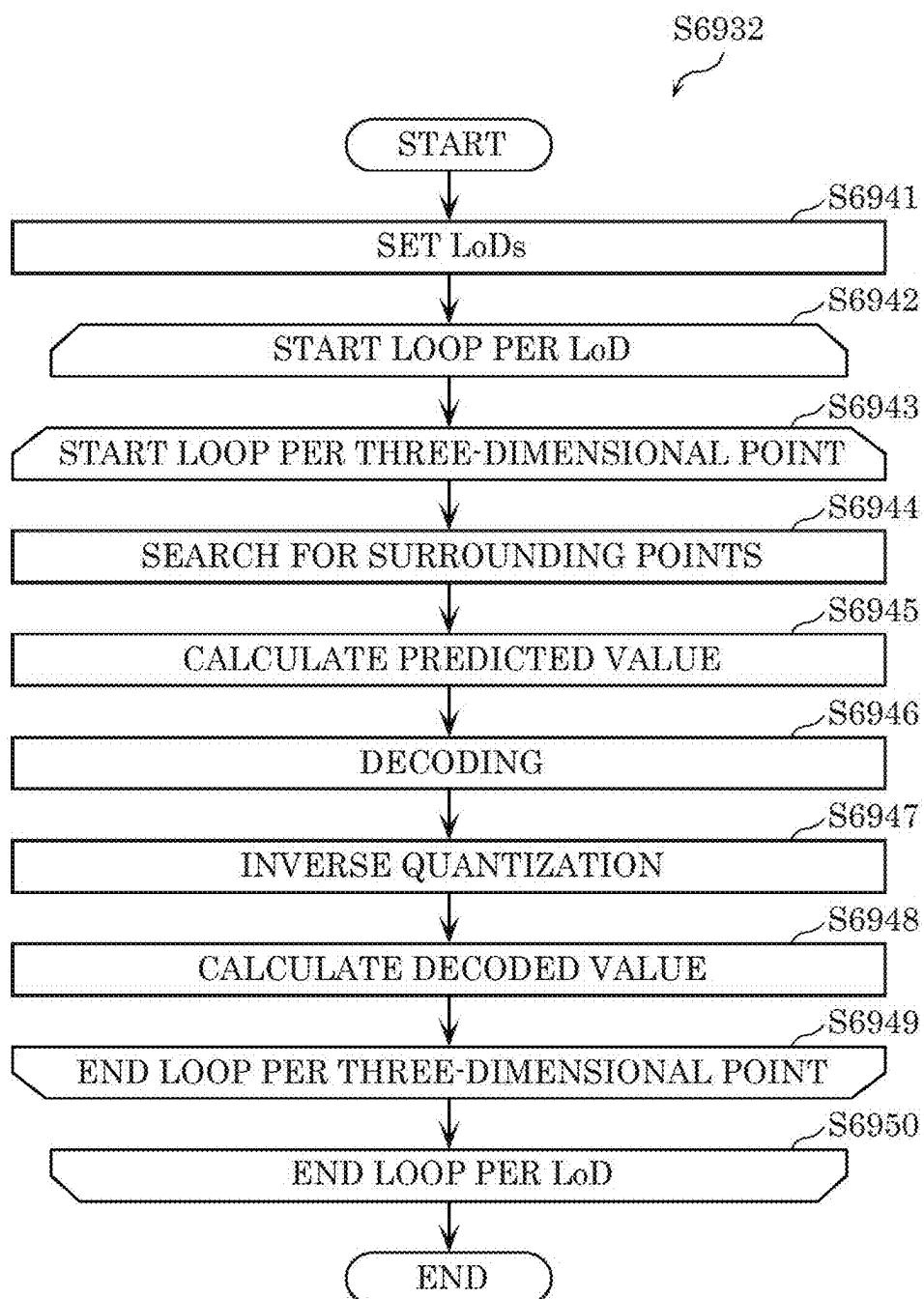


FIG. 86

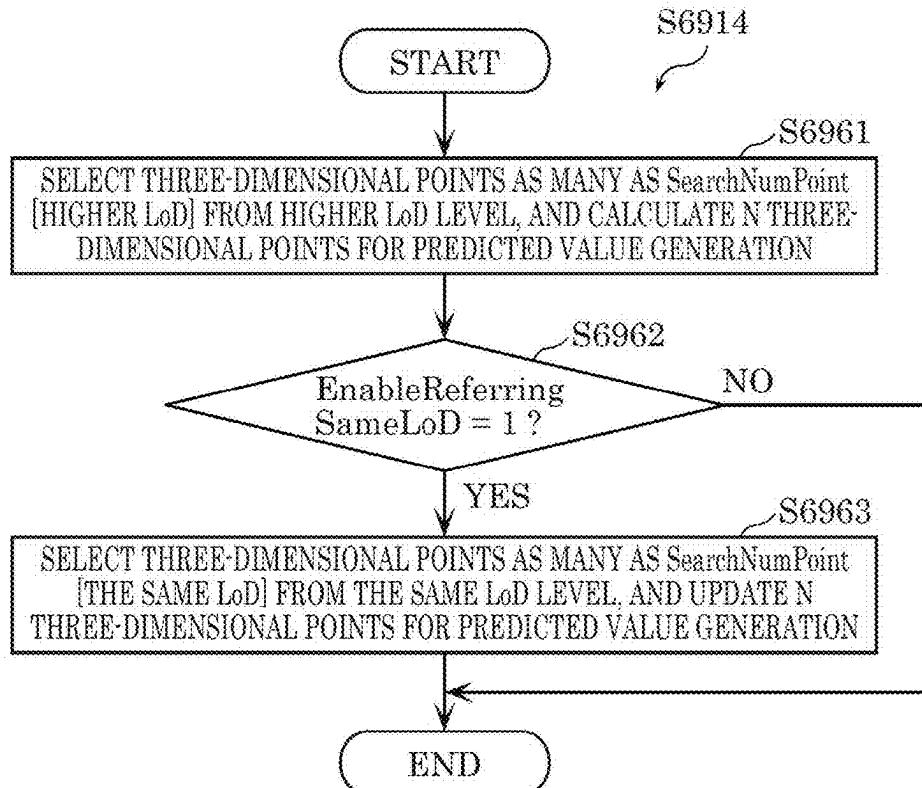


FIG. 87

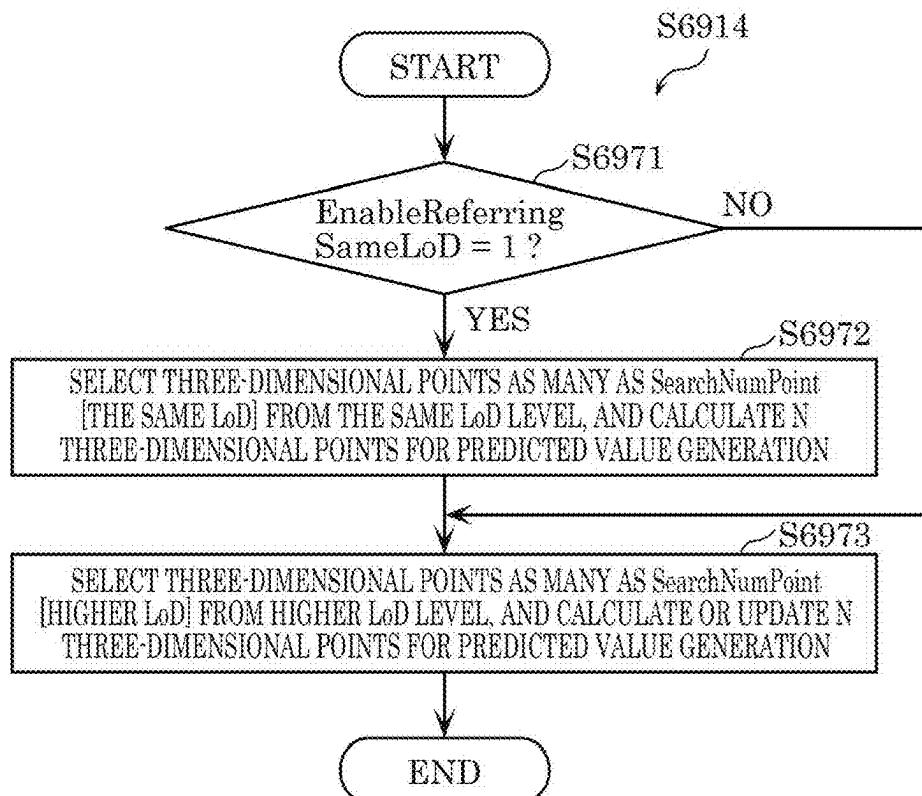


FIG. 88

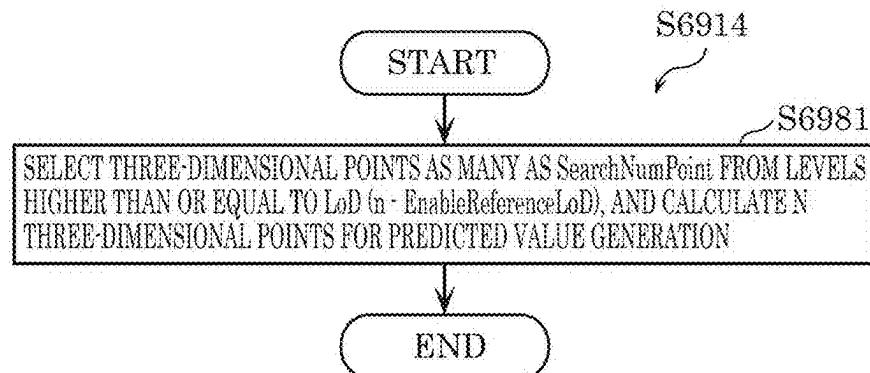


FIG. 89

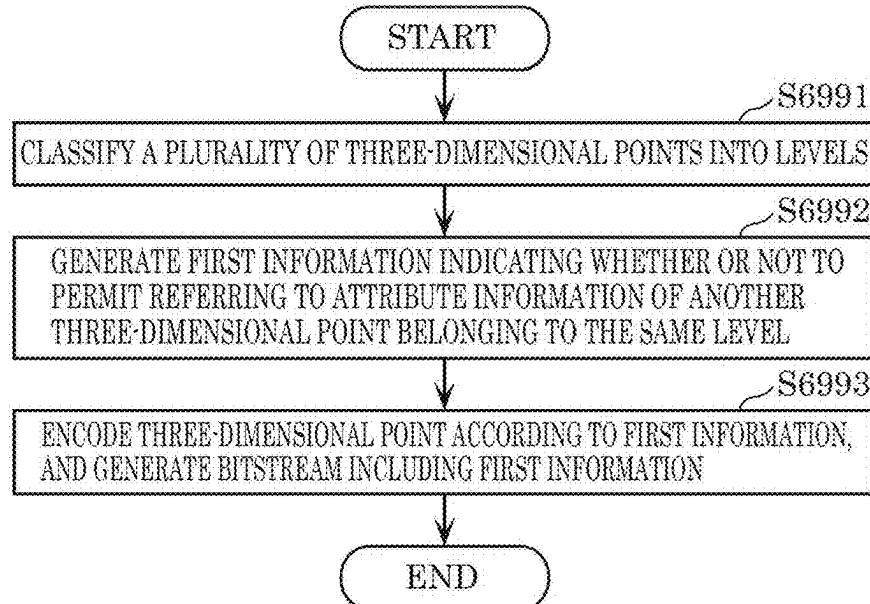


FIG. 90

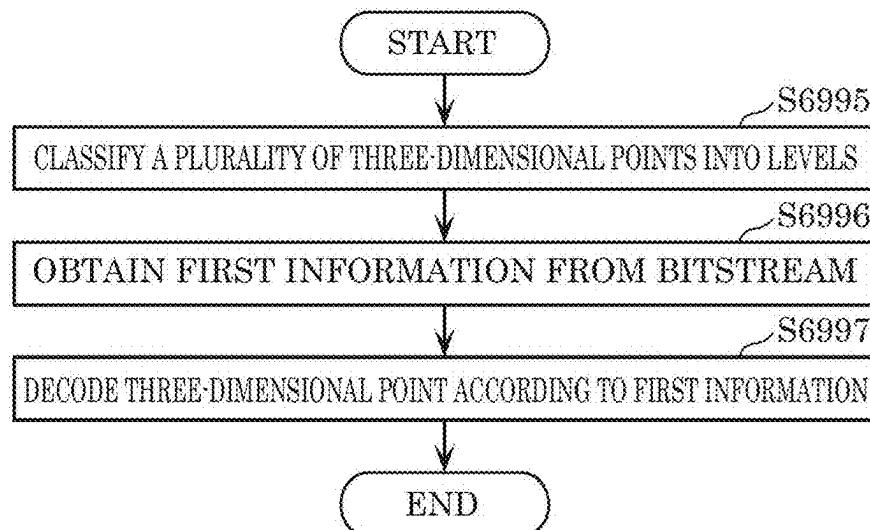
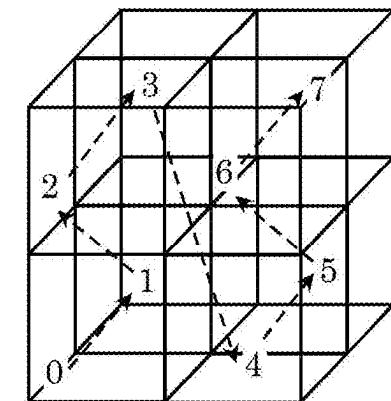


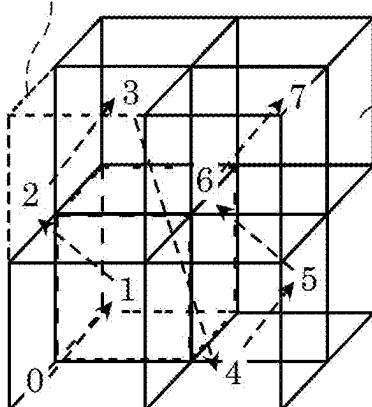
FIG. 91



0	1	2	3	4	5	6	7
---	---	---	---	---	---	---	---

(a)

NOT OCCUPIED



OCCUPIED

0	3	4	5	6	7
---	---	---	---	---	---

(b)

0	4	3	5	6	7
---	---	---	---	---	---

(c)

FIG. 92

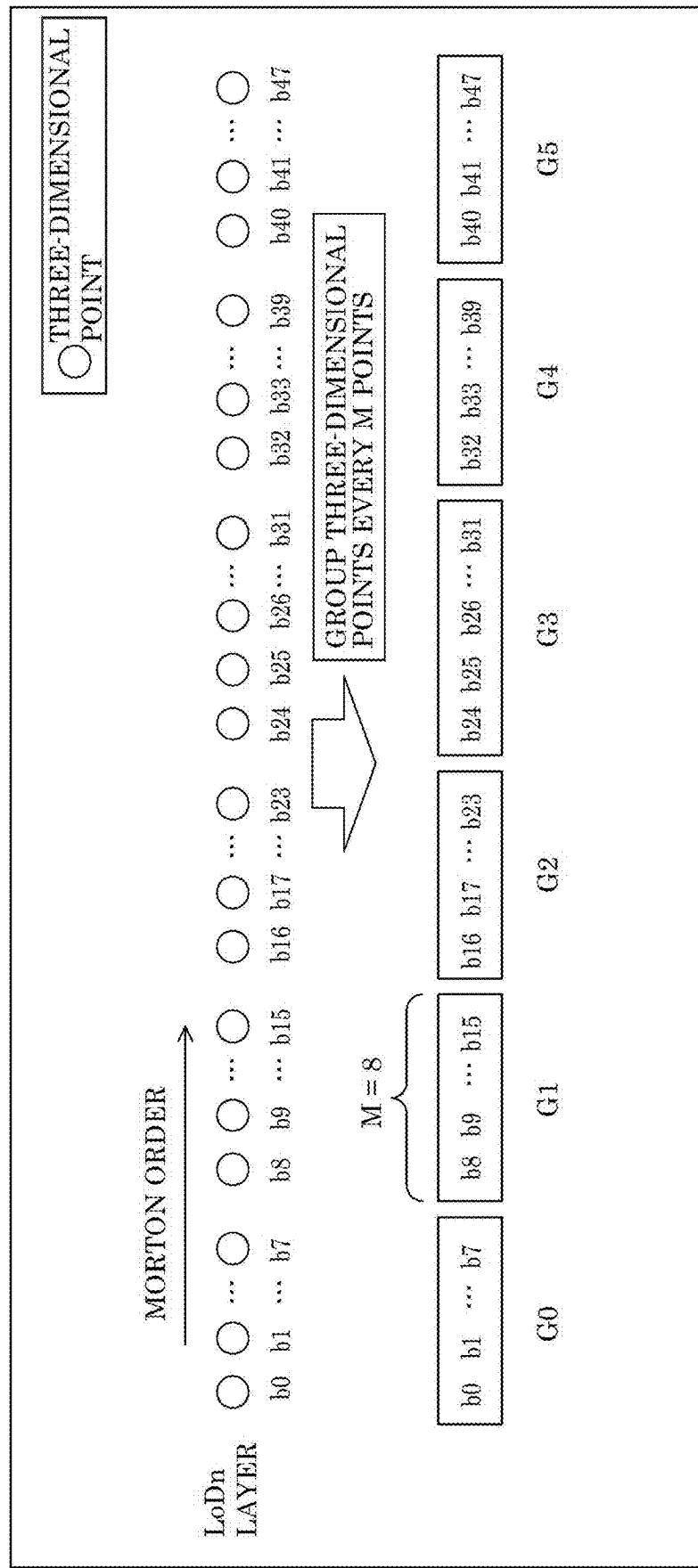


FIG. 93

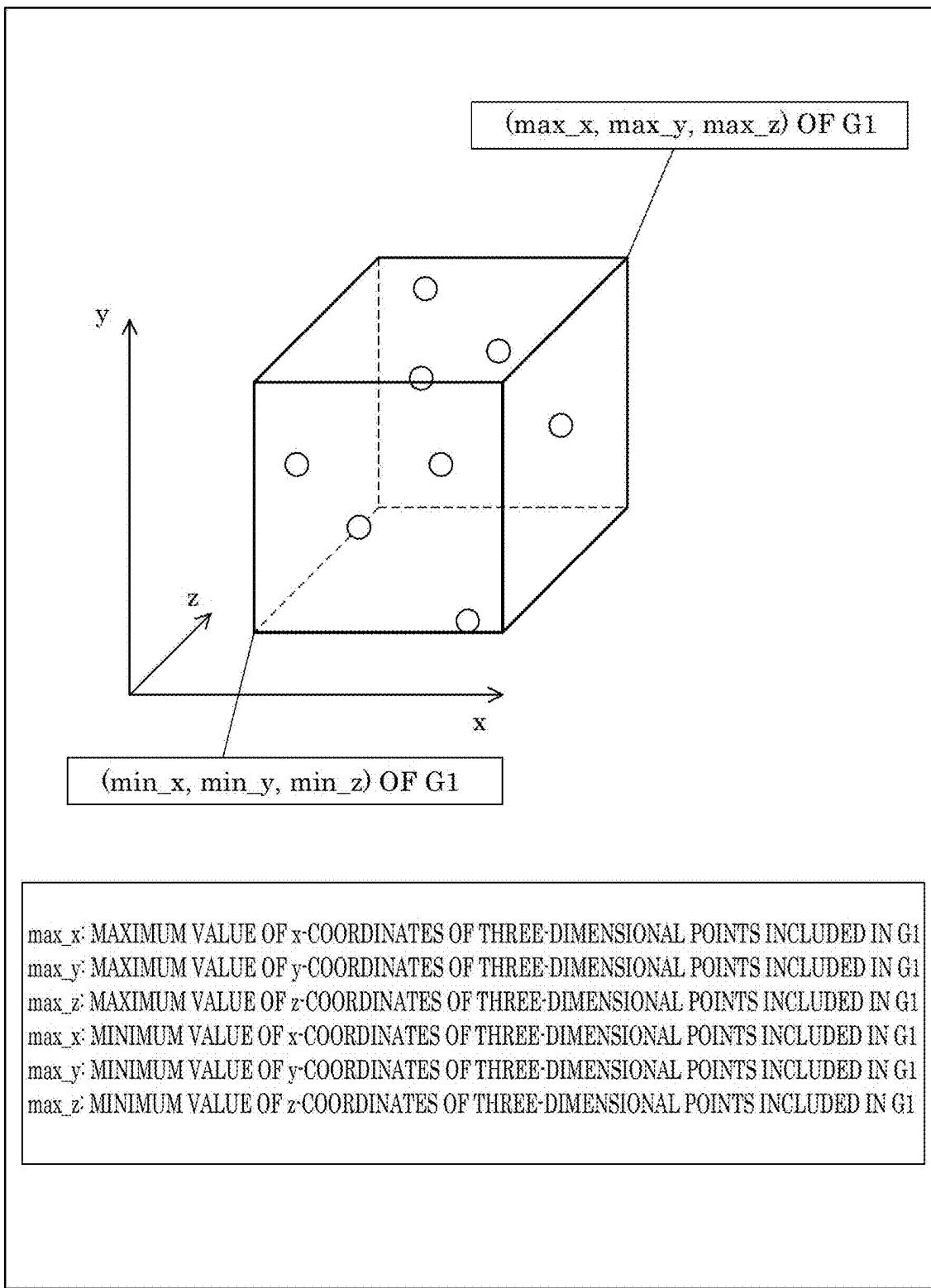


FIG. 94

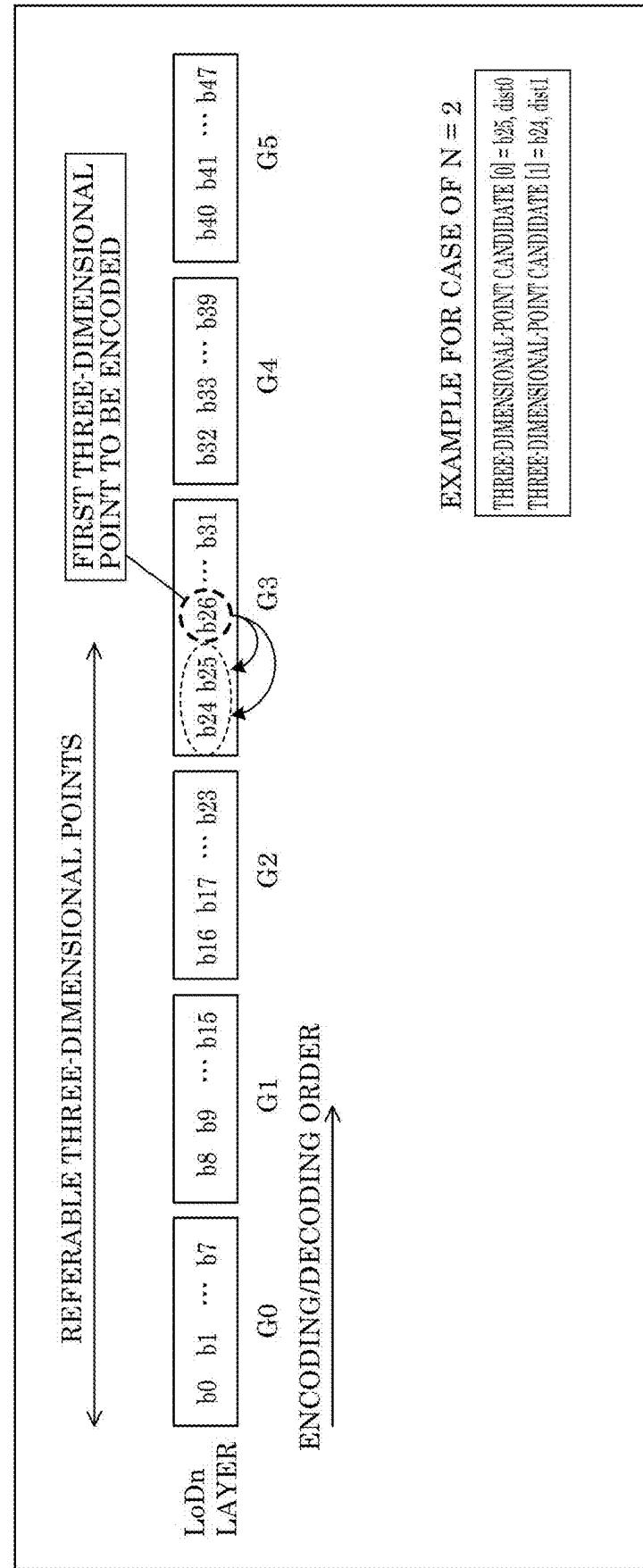


FIG. 95

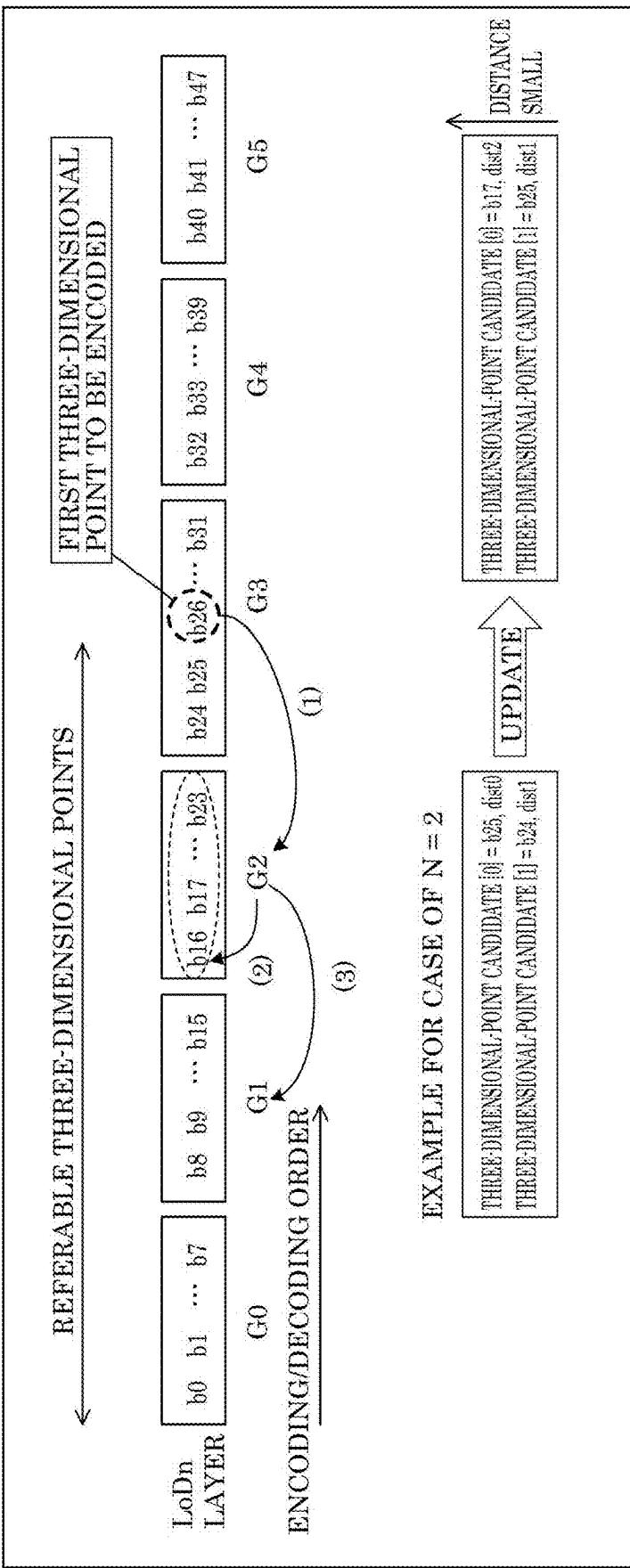


FIG. 96

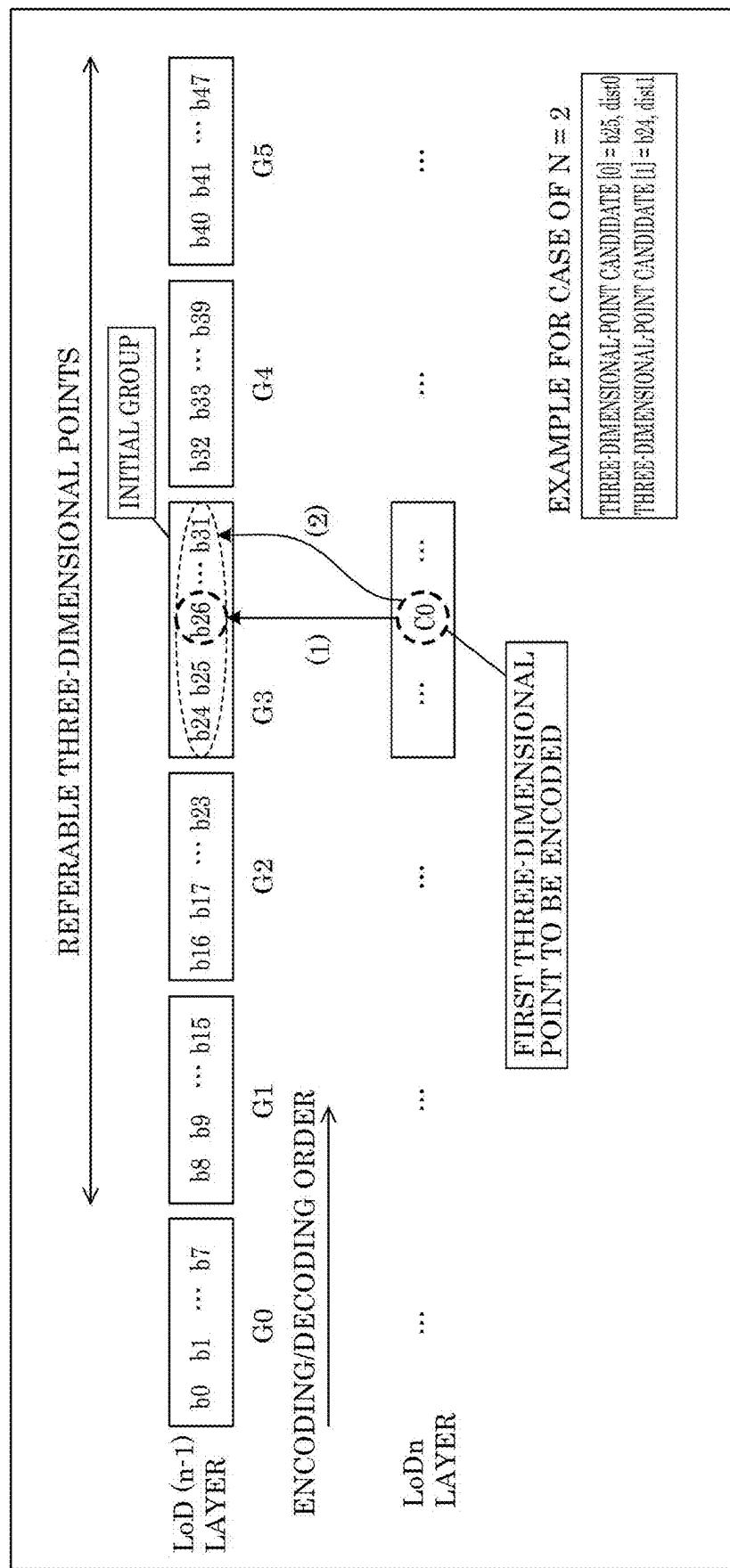


FIG. 97

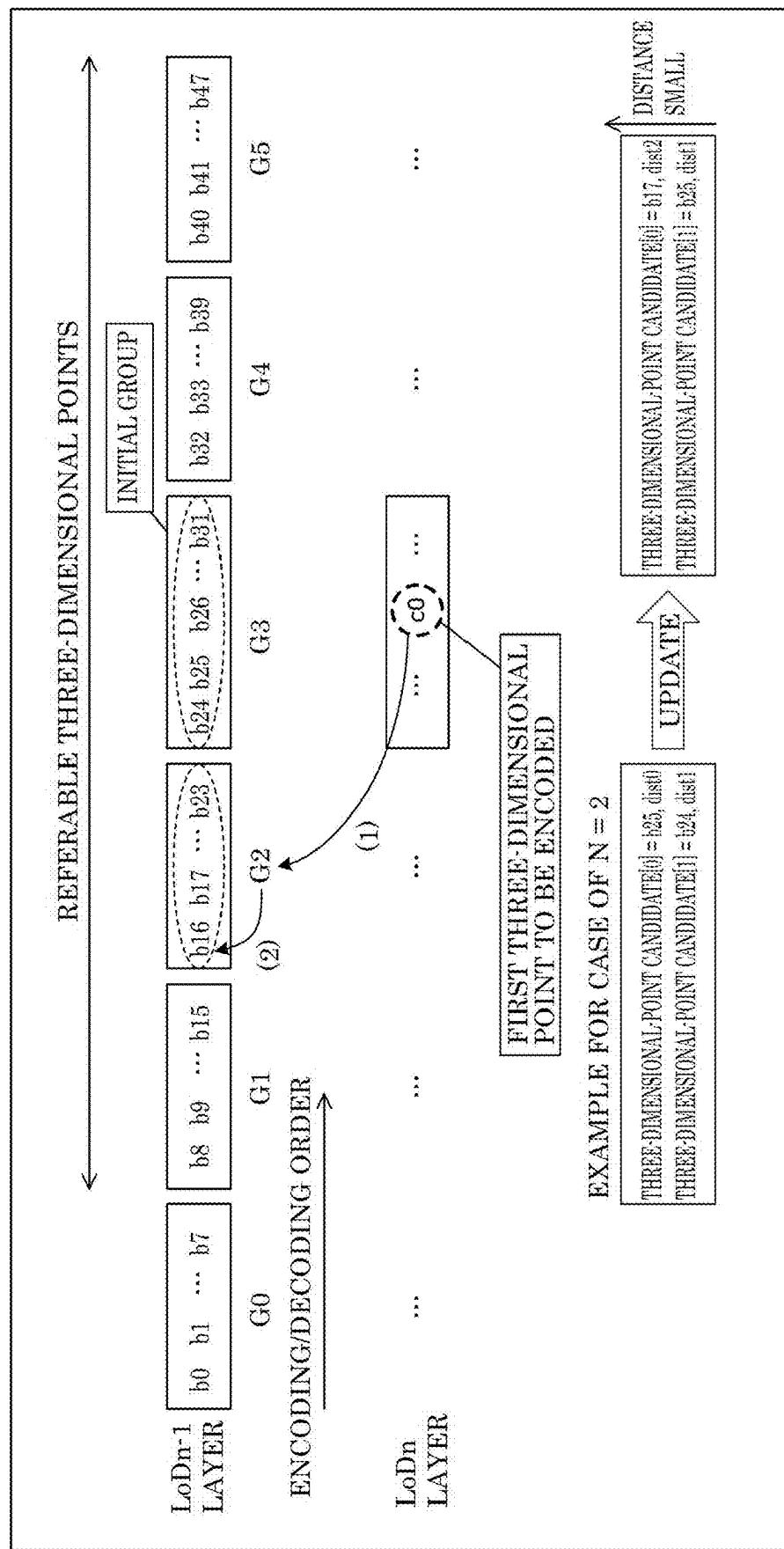


FIG. 98

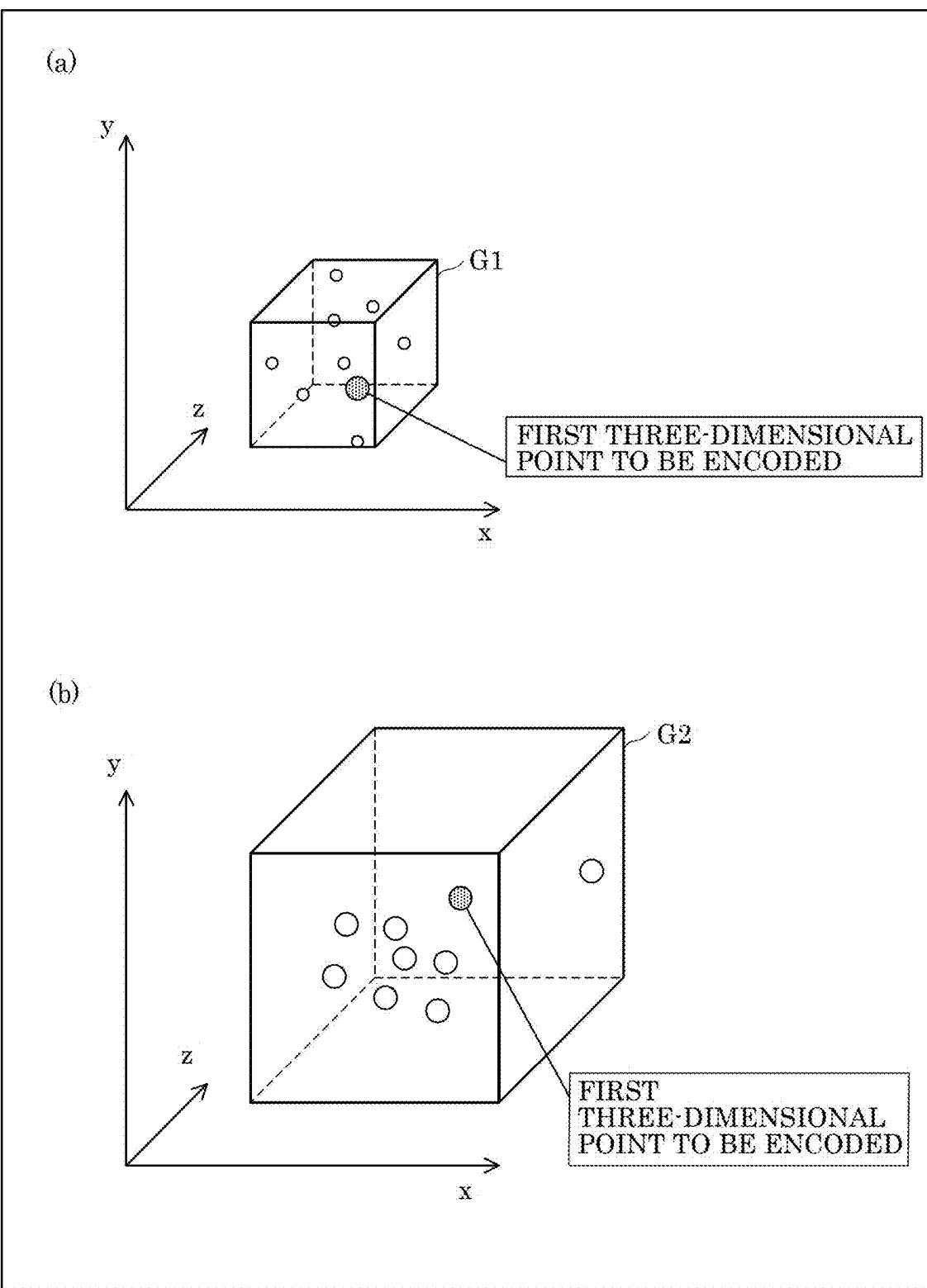


FIG. 99

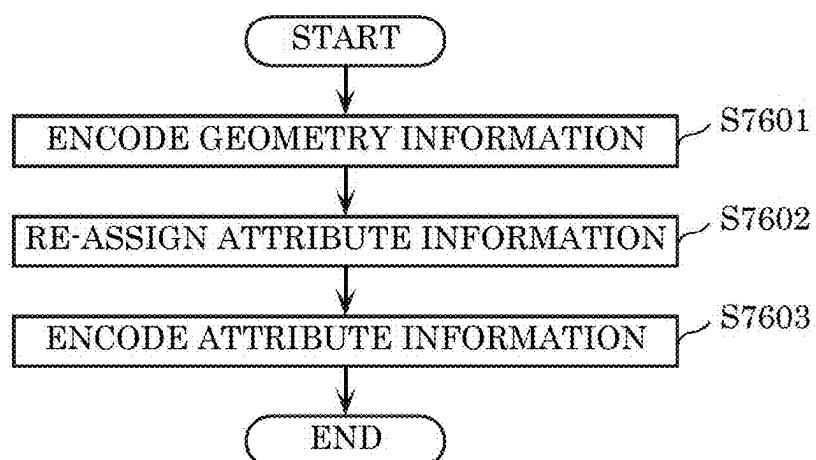


FIG. 100

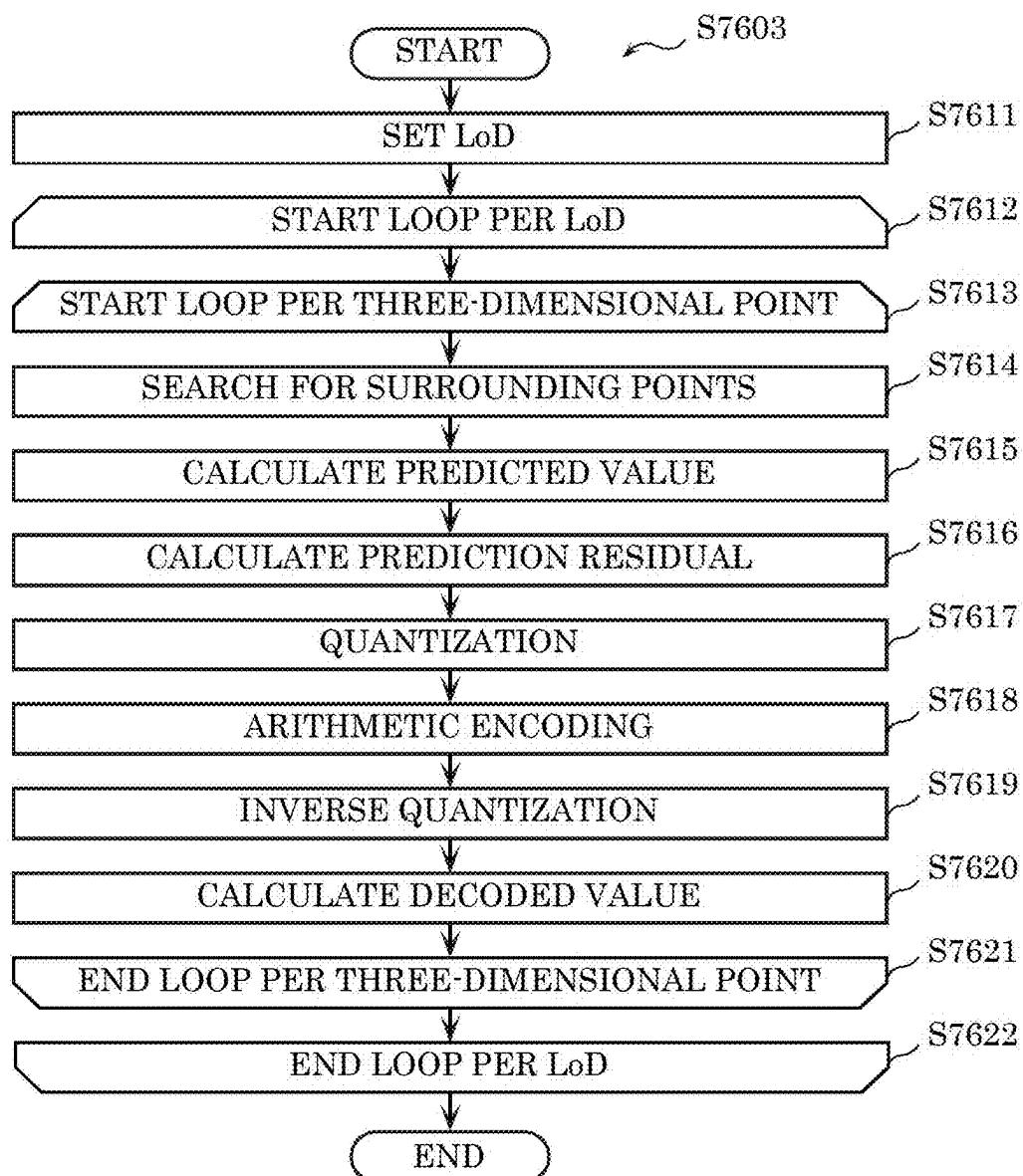


FIG. 101

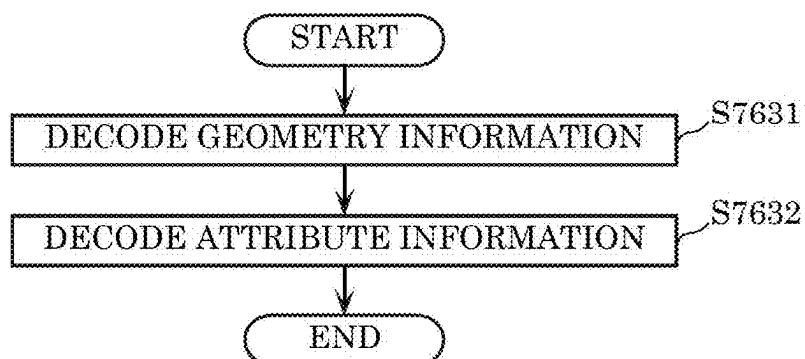


FIG. 102

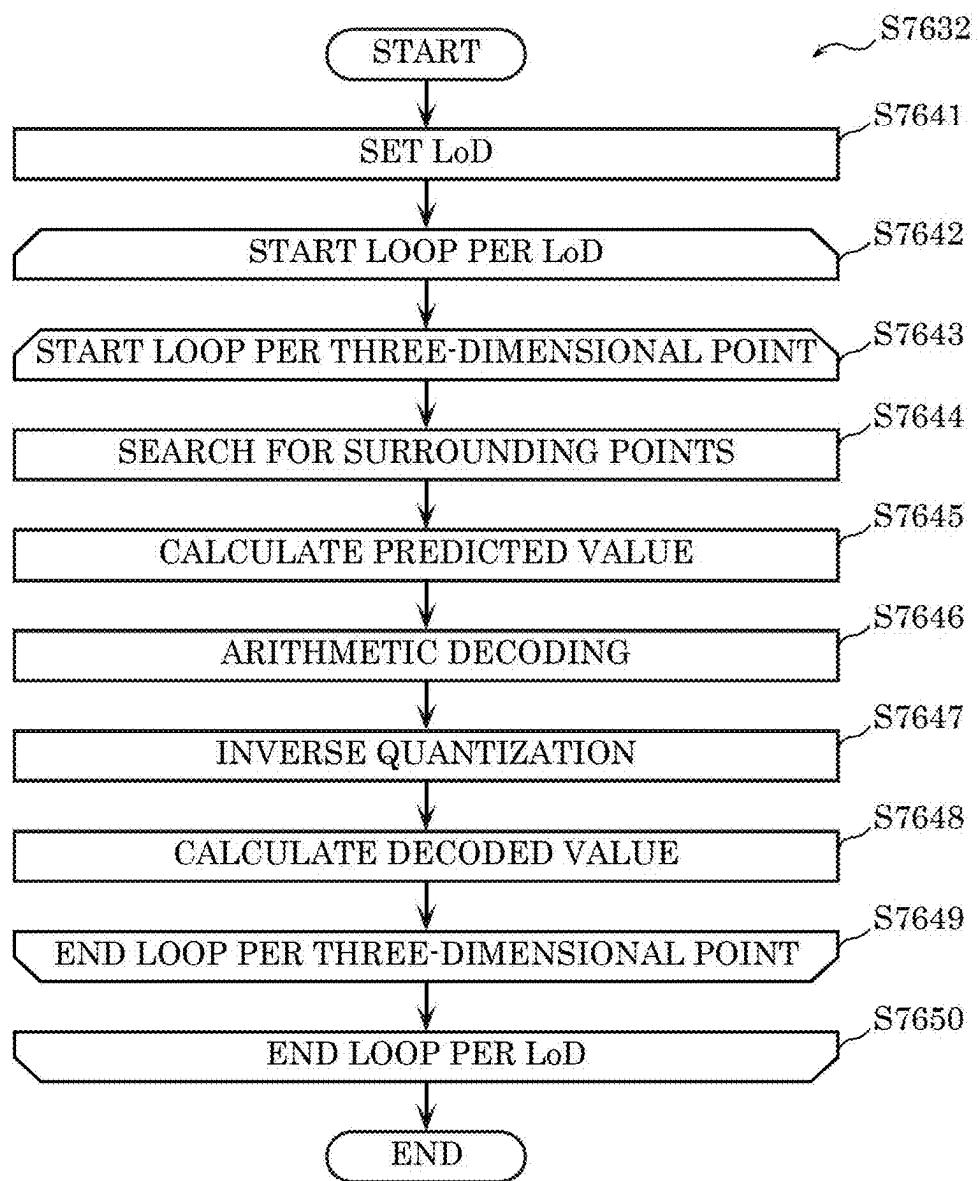


FIG. 103

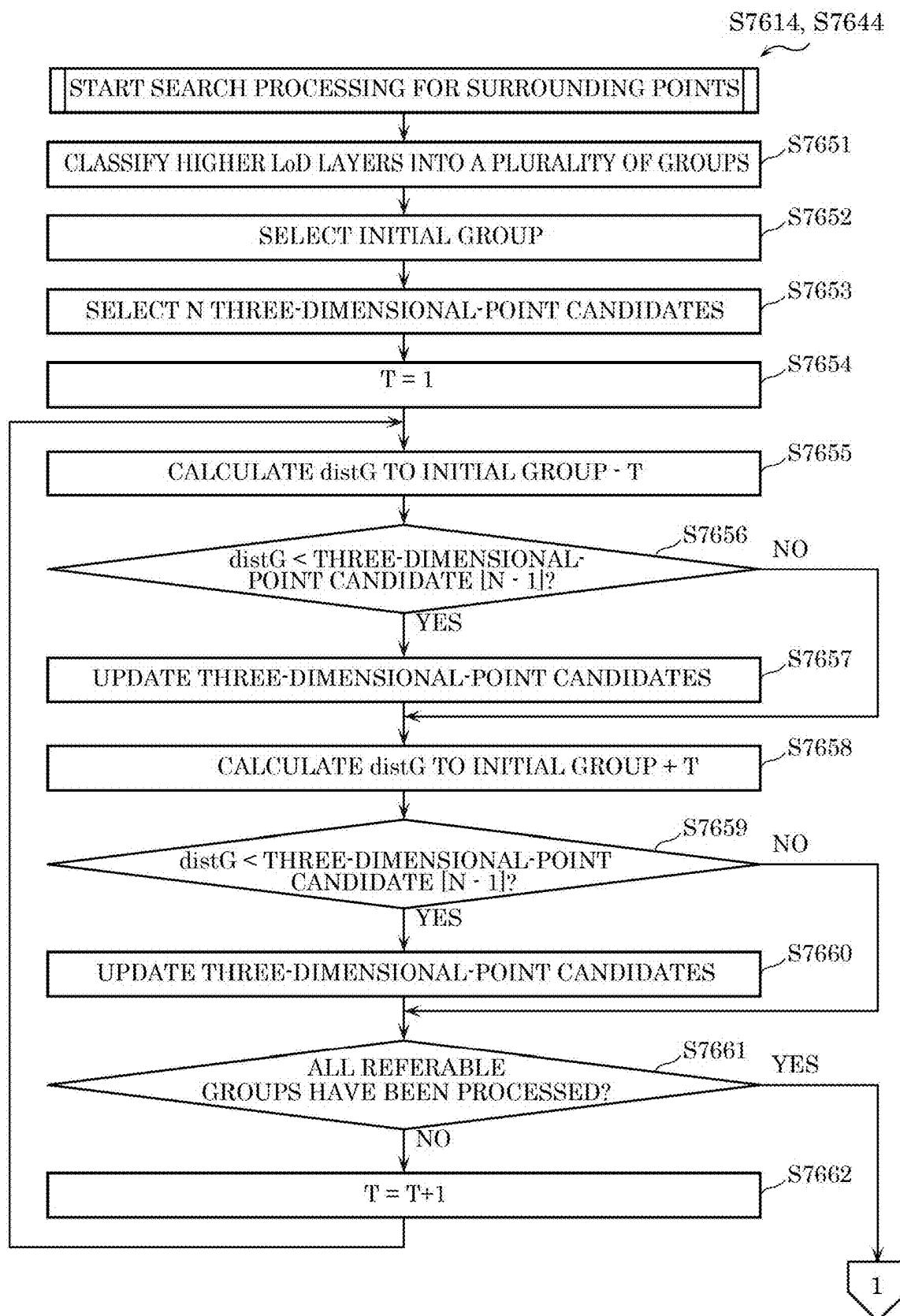


FIG. 104

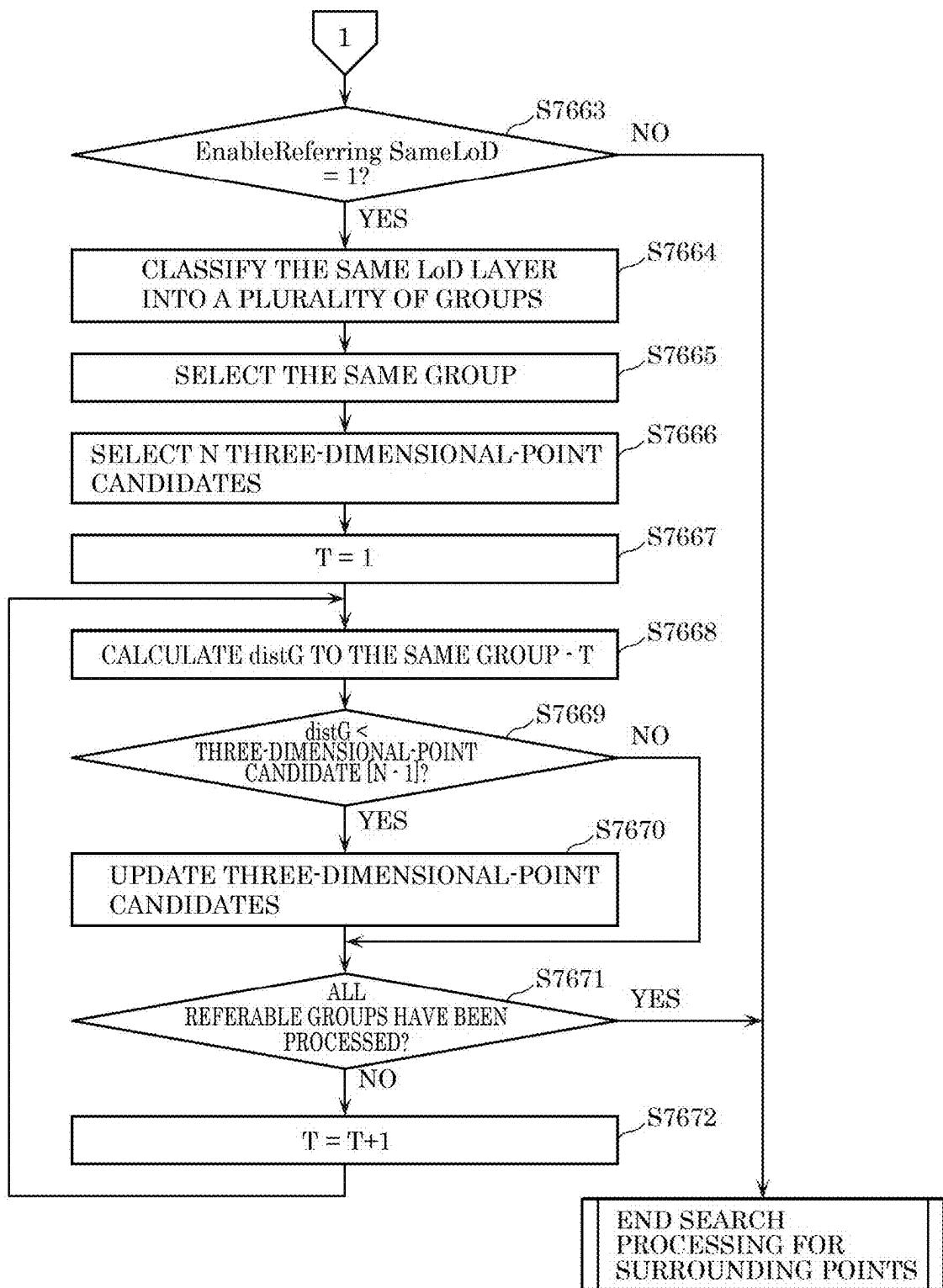


FIG. 105

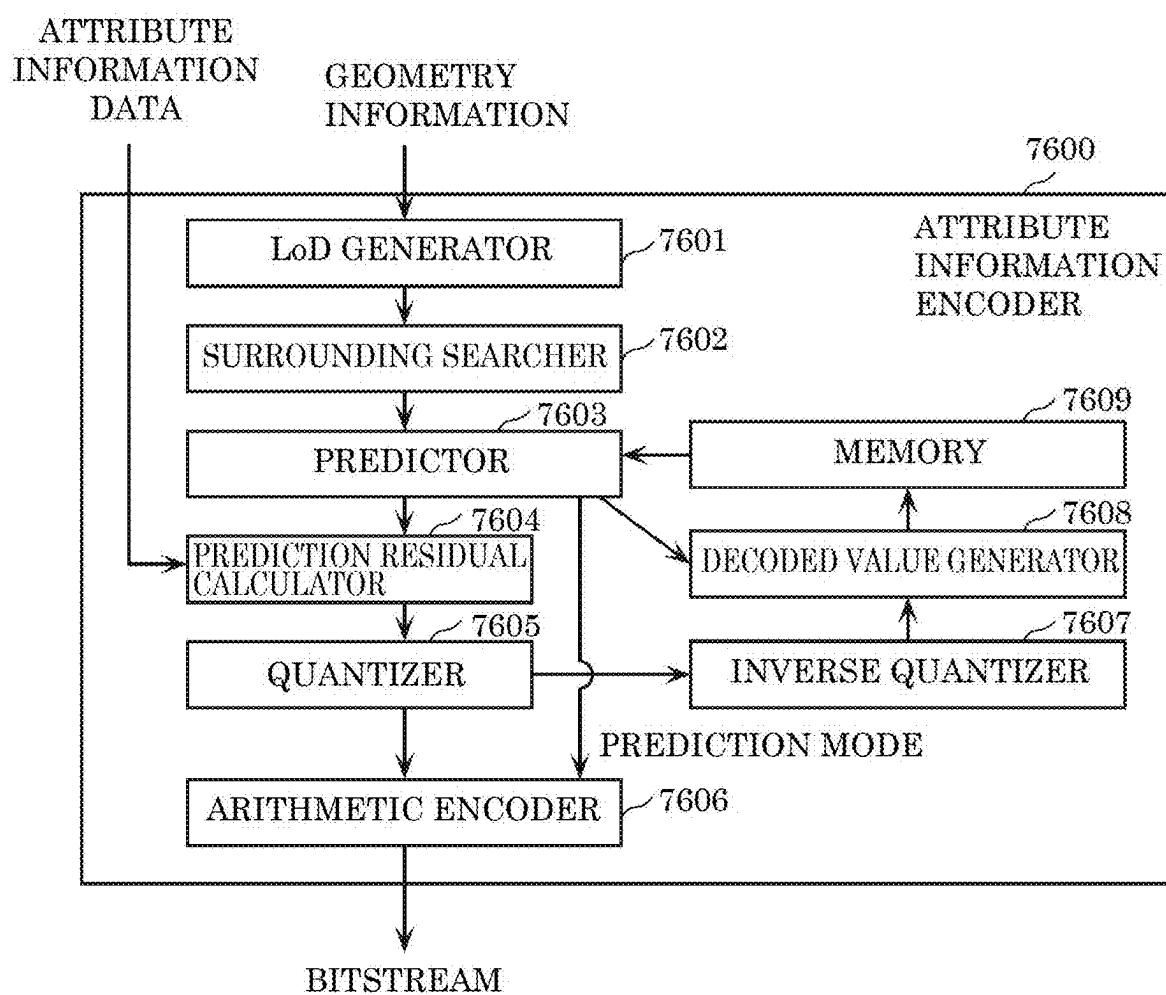


FIG. 106

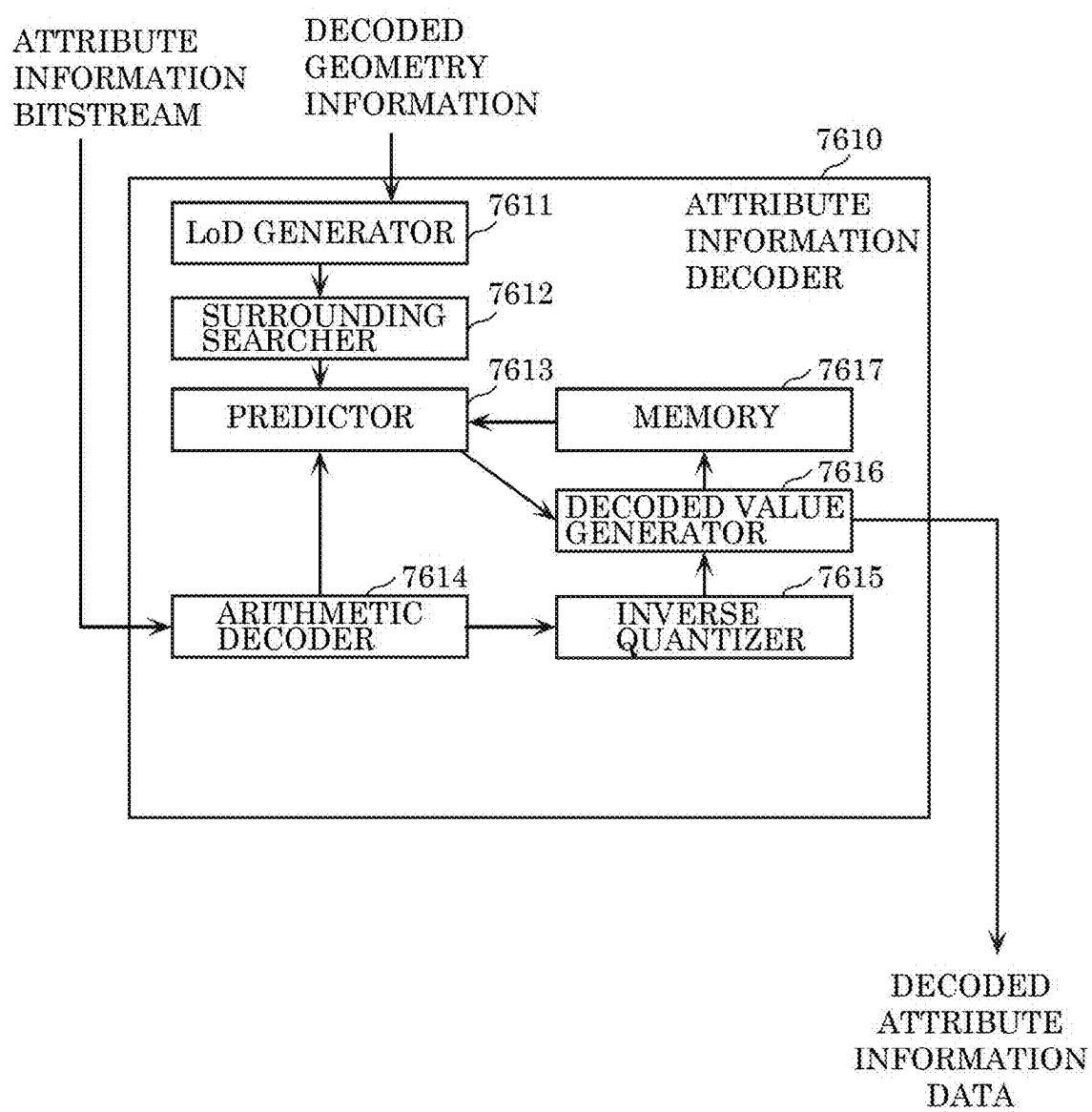


FIG. 107

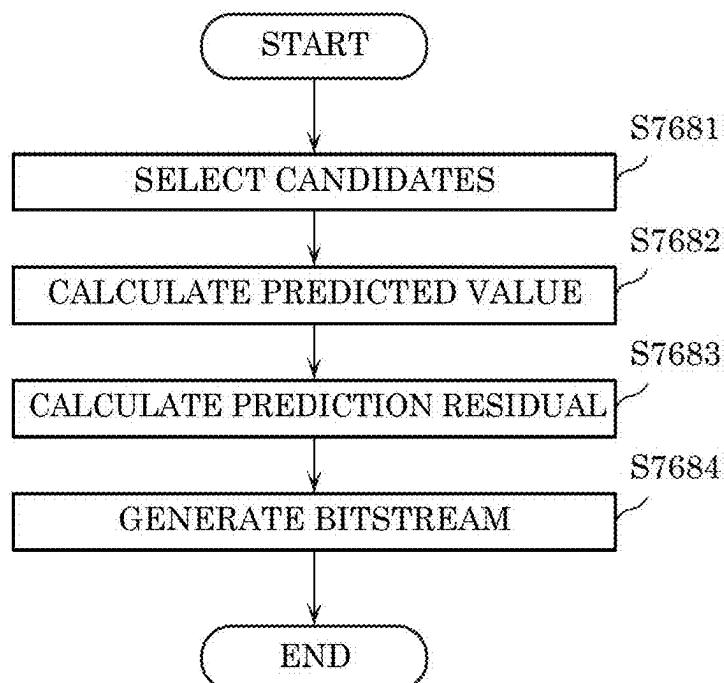


FIG. 108

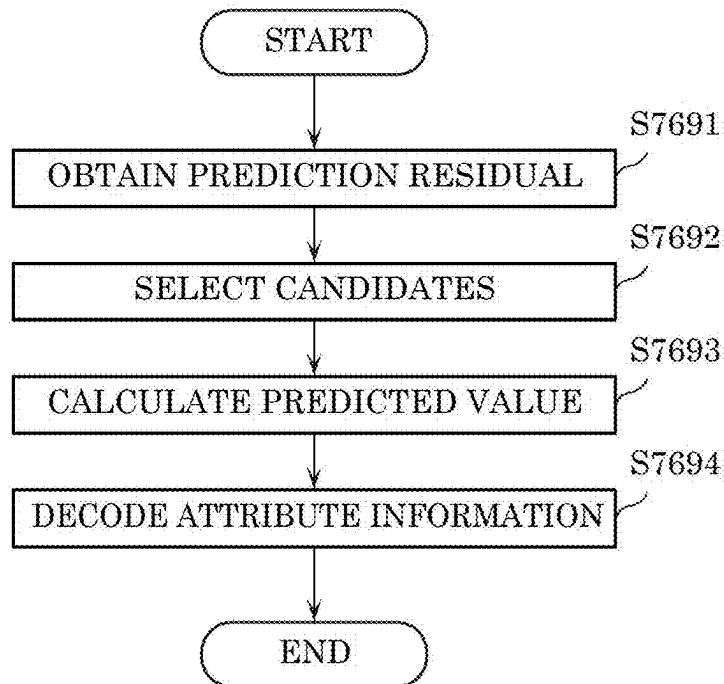


FIG. 109

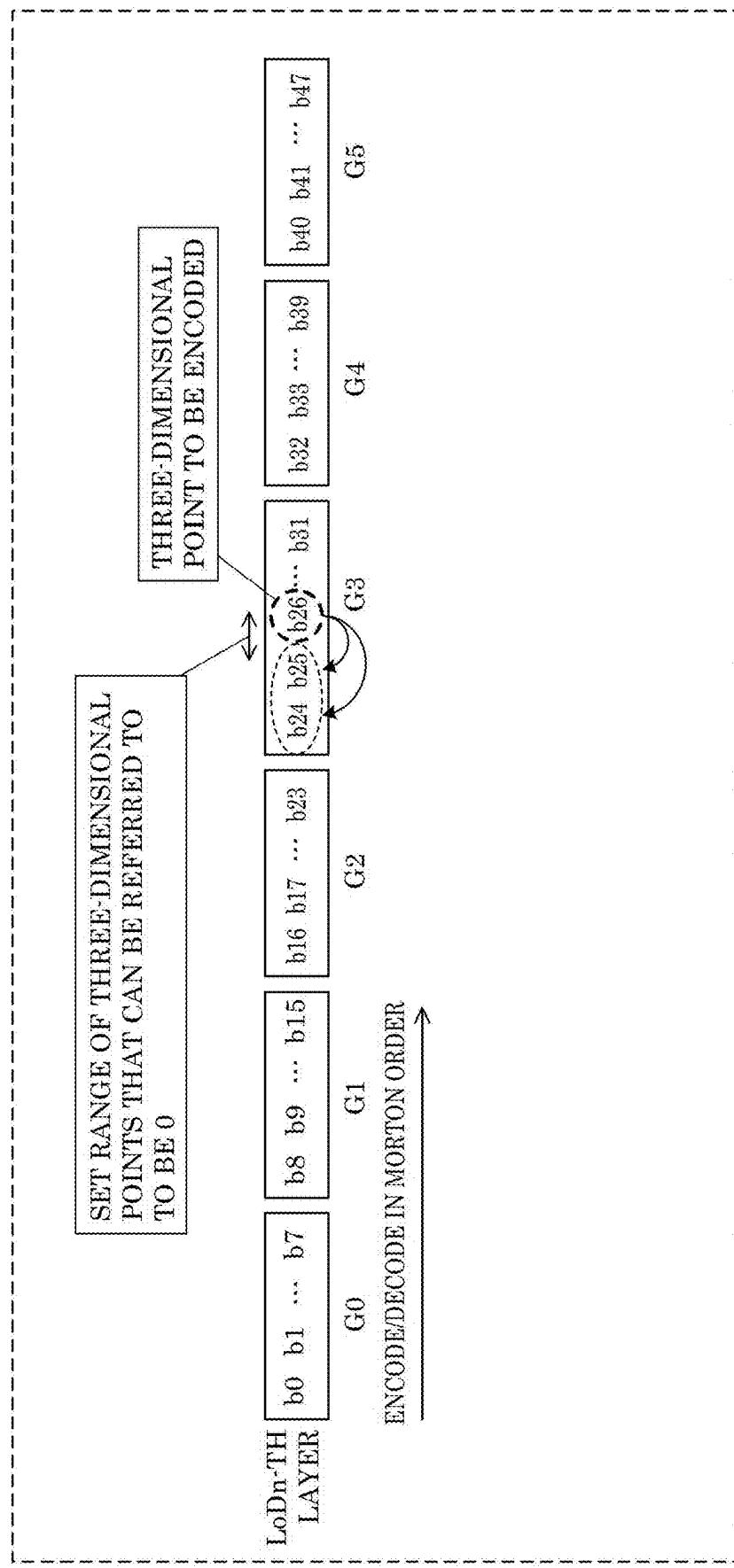


FIG. 110

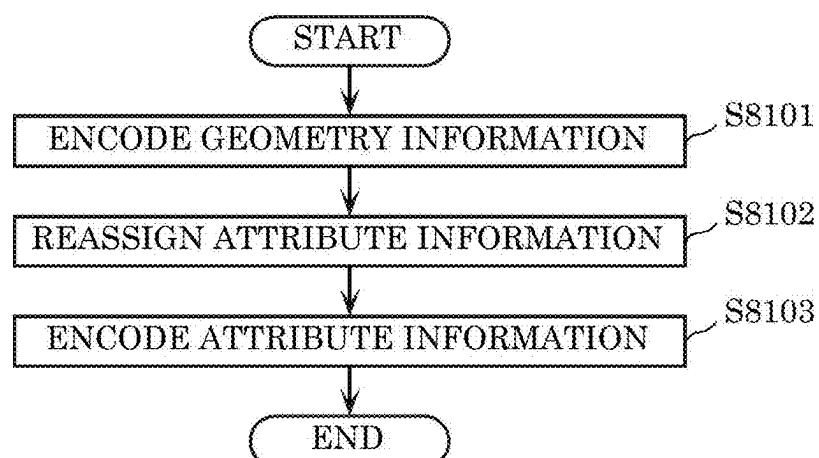


FIG. 111

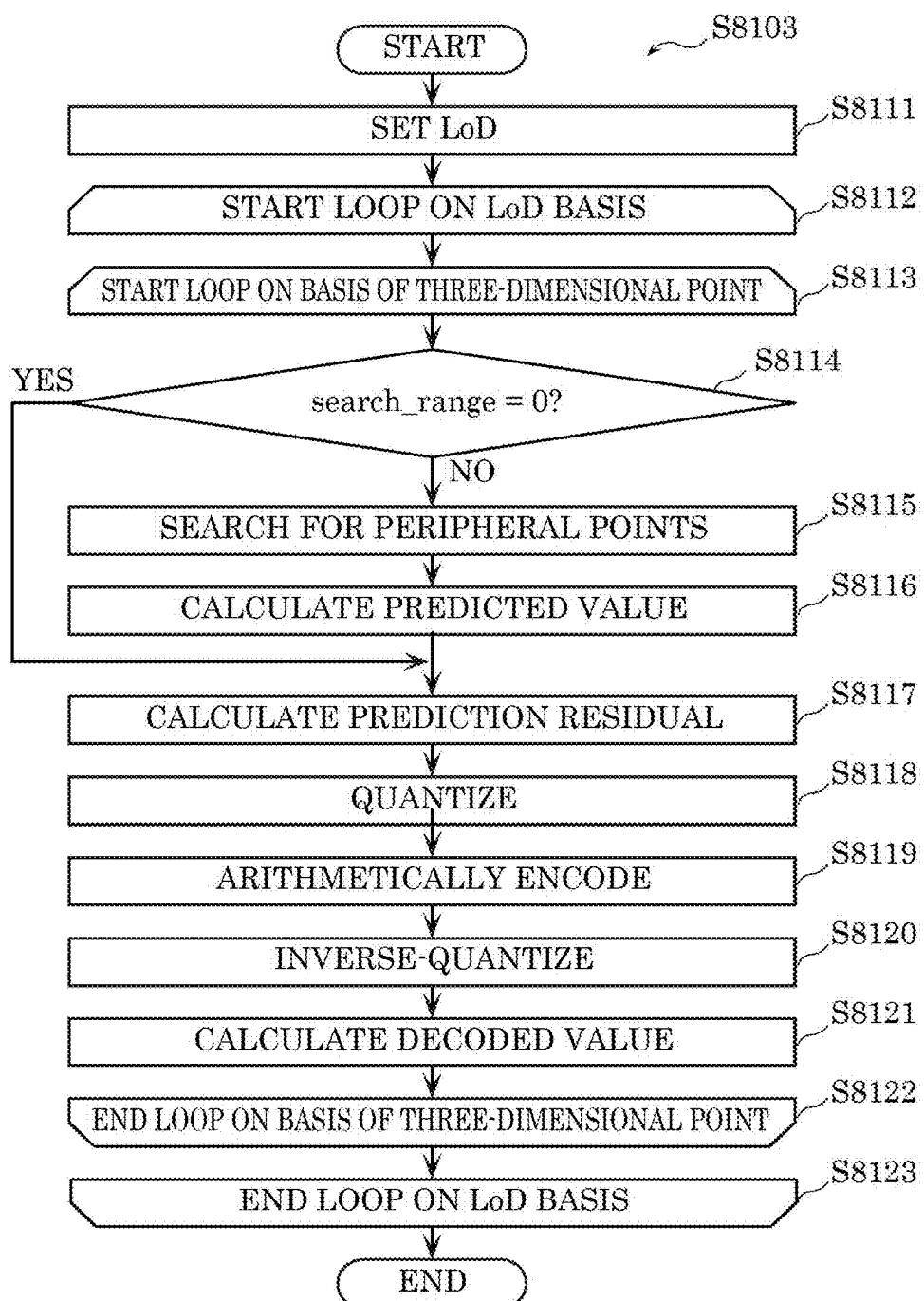


FIG. 112

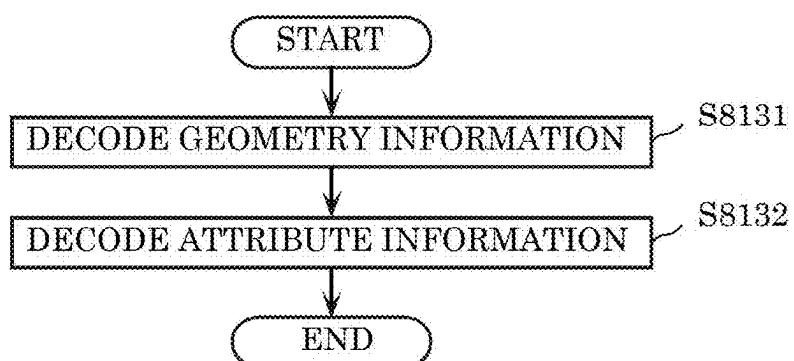


FIG. 113

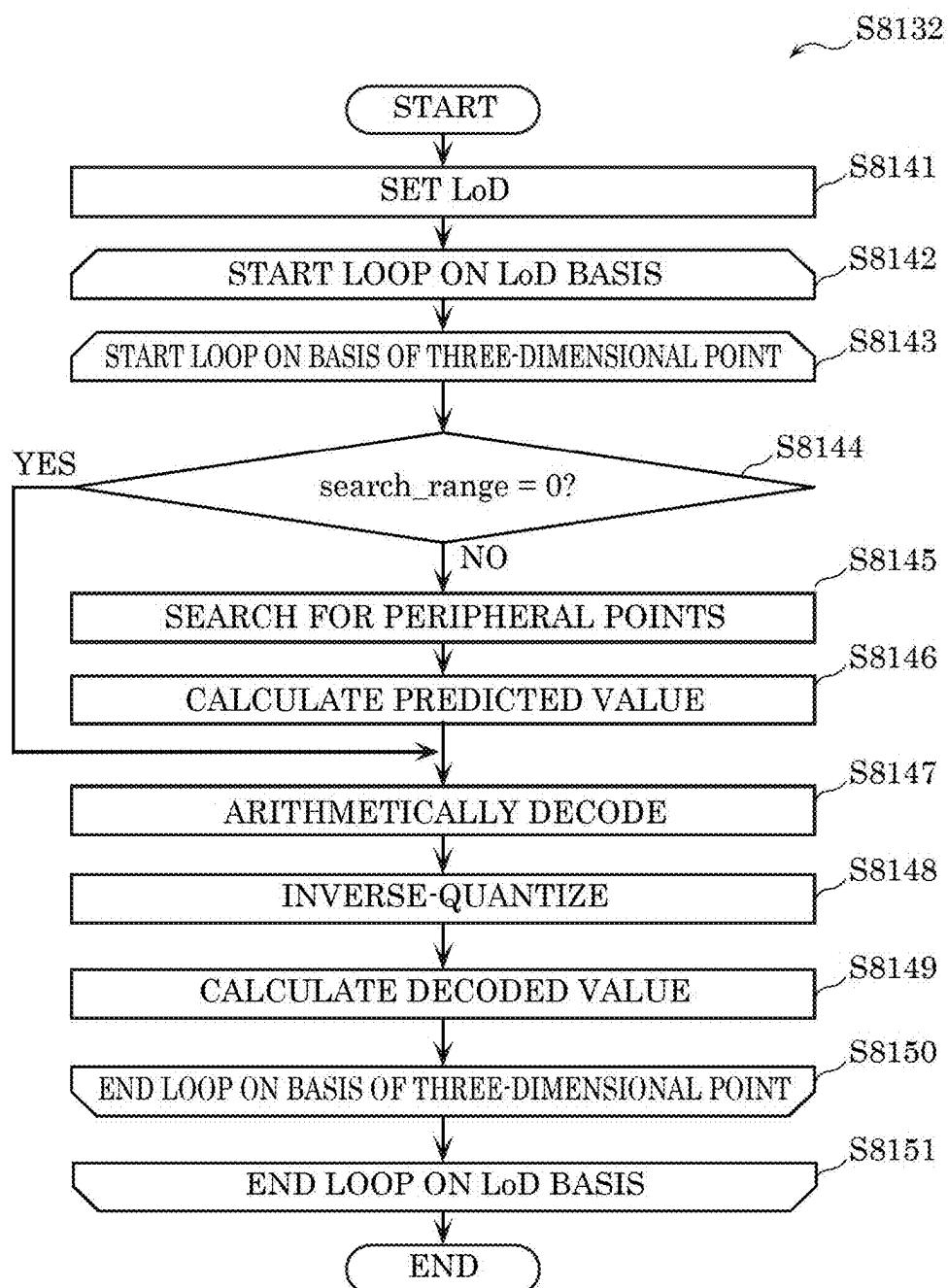


FIG. 114

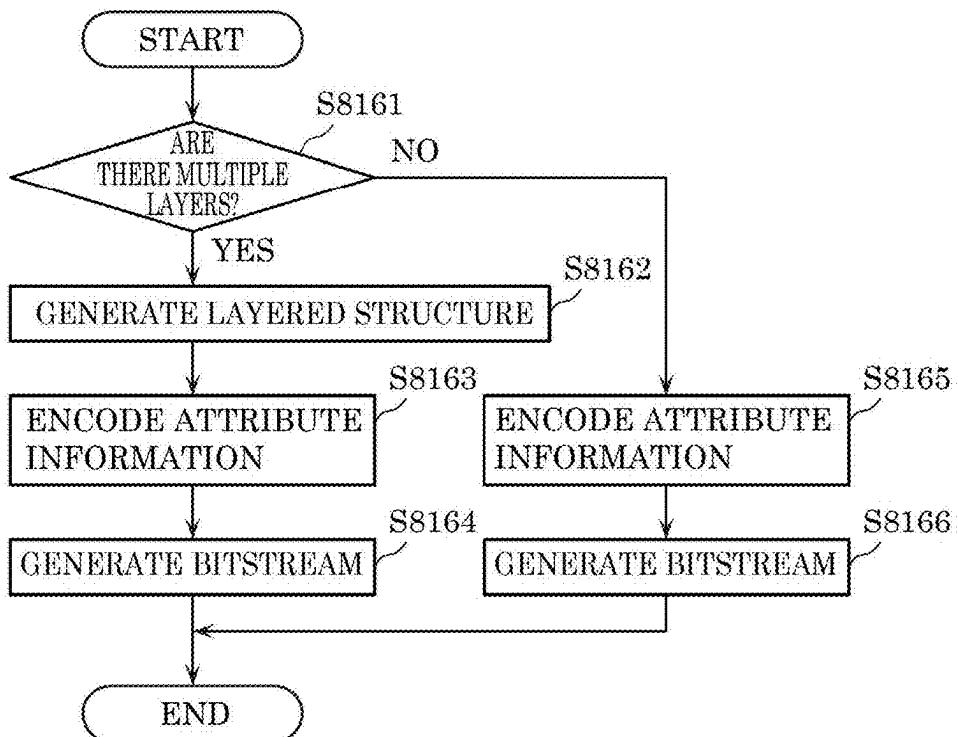


FIG. 115

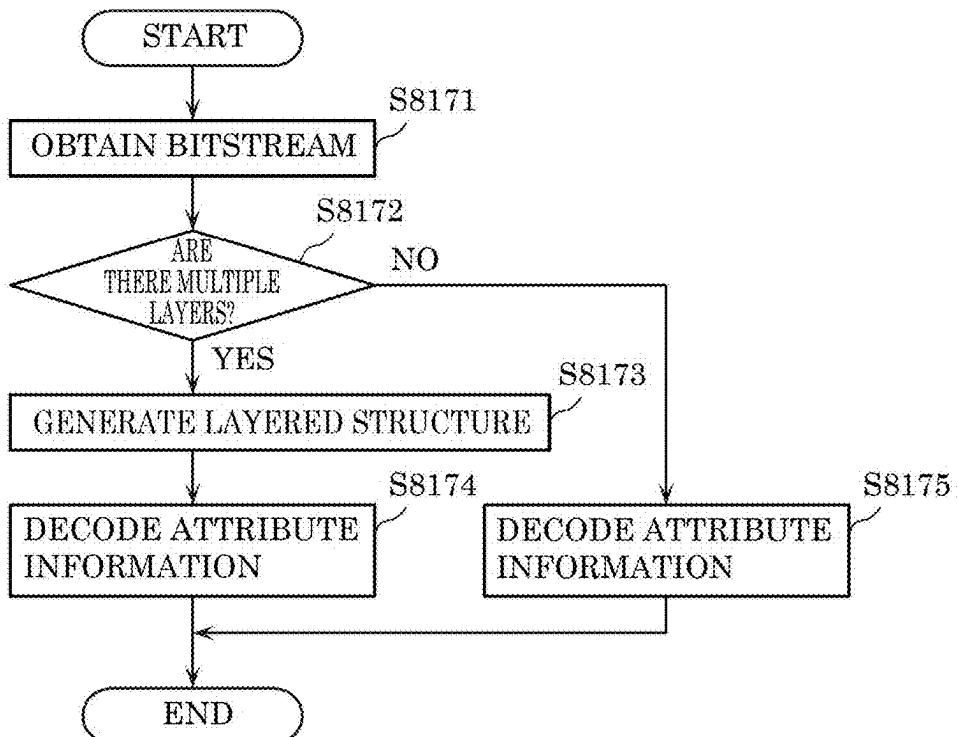


FIG. 116

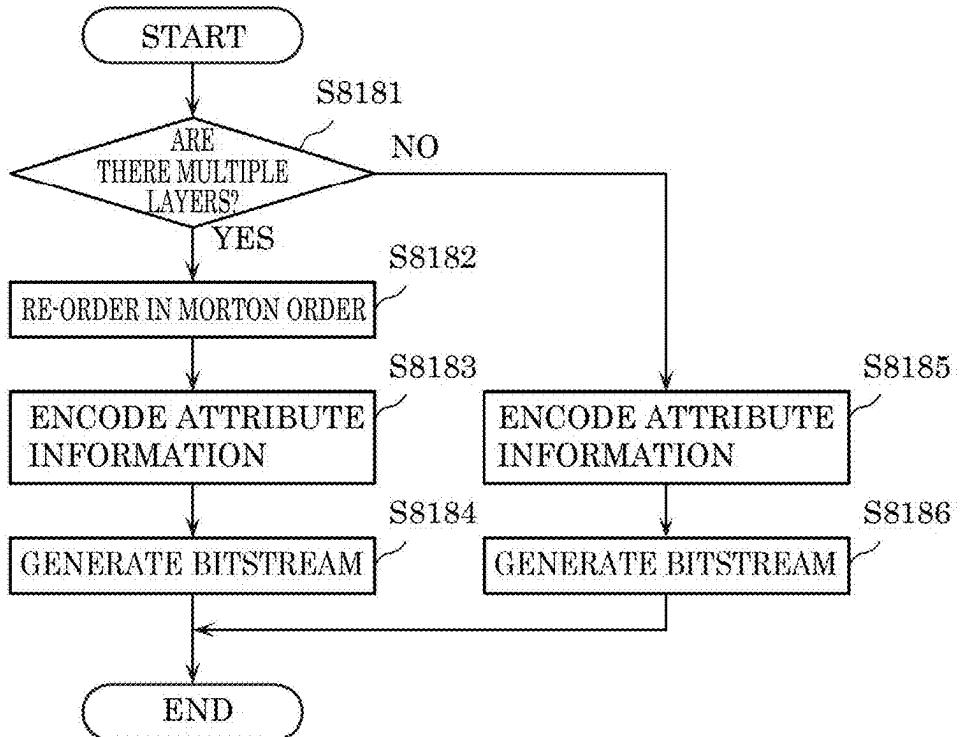
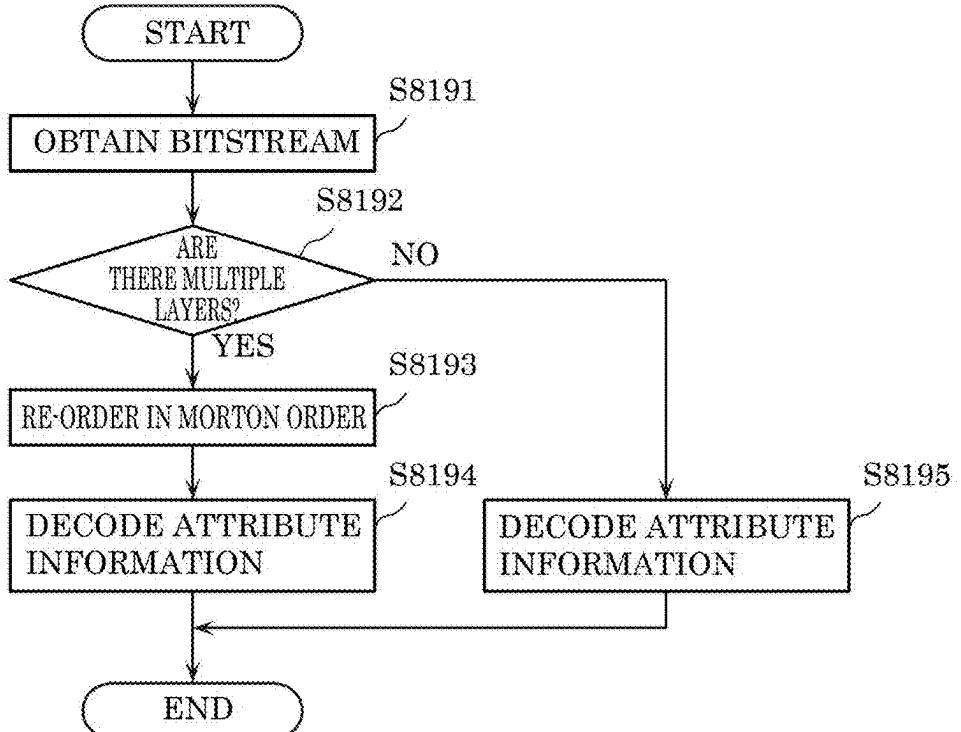


FIG. 117



**THREE-DIMENSIONAL DATA ENCODING METHOD, THREE-DIMENSIONAL DATA DECODING METHOD, THREE-DIMENSIONAL DATA ENCODING DEVICE, AND THREE-DIMENSIONAL DATA DECODING DEVICE**

**CROSS REFERENCE TO RELATED APPLICATIONS**

[0001] This application is a continuation of U.S. application Ser. No. 18/410,431 filed on Jan. 11, 2024, which is a continuation of U.S. application Ser. No. 17/474,940, now U.S. Pat. No. 11,949,869, filed on Sep. 14, 2021, which is a continuation application of PCT International Patent Application Number PCT/JP2020/013475 filed on Mar. 25, 2020, claiming the benefit of priority of U.S. Provisional Patent Application No. 62/823,267 filed on Mar. 25, 2019. The entire disclosures of the above-identified applications, including the specifications, drawings, and claims are incorporated herein by reference in their entirety.

**BACKGROUND**

1. Technical Field

[0002] The present disclosure relates to a three-dimensional data encoding method, a three-dimensional data decoding method, a three-dimensional data encoding device, and a three-dimensional data decoding device.

2. Description of the Related Art

[0003] Devices or services utilizing three-dimensional data are expected to find their widespread use in a wide range of fields, such as computer vision that enables autonomous operations of cars or robots, map information, monitoring, infrastructure inspection, and video distribution. Three-dimensional data is obtained through various means including a distance sensor such as a rangefinder, as well as a stereo camera and a combination of a plurality of monocular cameras.

[0004] Methods of representing three-dimensional data include a method known as a point cloud scheme that represents the shape of a three-dimensional structure by a point group in a three-dimensional space. In the point cloud scheme, the positions and colors of a point group are stored. While point cloud is expected to be a mainstream method of representing three-dimensional data, a massive amount of data of a point group necessitates compression of the amount of three-dimensional data by encoding for accumulation and transmission, as in the case of a two-dimensional moving picture (examples include MPEG-4 AVC and HEVC standardized by MPEG).

[0005] Meanwhile, point cloud compression is partially supported by, for example, an open-source library (Point Cloud Library) for point cloud-related processing.

[0006] Furthermore, a technique for searching for and displaying a facility located in the surroundings of the vehicle is known (for example, see International Publication WO 2014/020663).

**SUMMARY**

[0007] There has been a demand for reducing the processing load in three-dimensional data encoding.

[0008] The present disclosure provides a three-dimensional data encoding method, a three-dimensional data decoding method, a three-dimensional data encoding device, or a three-dimensional data decoding device that can reduce the processing load in three-dimensional data encoding.

[0009] A three-dimensional data encoding method according to an aspect of the present disclosure includes: (i) in a first case where a layered structure is generated by classifying three-dimensional points into layers: encoding attribute information for the three-dimensional points based on the layered structure; and generating a bitstream including layer information utilized for the generation of the layered structure; and (ii) in a second case where the three-dimensional points are not classified:

[0010] encoding attribute information for the three-dimensional points; and generating a bitstream not including the layer information.

[0011] A three-dimensional data encoding method according to another aspect of the present disclosure includes: (i) in a first case where a layered structure is generated by classifying three-dimensional points into layers: encoding attribute information for the three-dimensional points in Morton order; and (ii) in a second case where the three-dimensional points are not classified: encoding the attribute information for the three-dimensional points in a state where the three-dimensional points are not re-ordered in Morton order; and generating a bitstream including the attribute information encoded.

[0012] A three-dimensional data decoding method according to an aspect of the present disclosure includes: obtaining a bitstream including encoded three-dimensional points; and (i) in a case where the three-dimensional points are classified into layers: generating a layered structure using layer information included in the bitstream; and decoding the encoded three-dimensional points based on the layered structure; and (ii) in a case where the encoded three-dimensional points are not classified: decoding the encoded three-dimensional points without using the layer information.

[0013] A three-dimensional data decoding method according to another aspect of the present disclosure includes: obtaining a bitstream including encoded three-dimensional points; and (i) in a case where the encoded three-dimensional points are classified into layers: encoding attribute information for the encoded three-dimensional points in Morton order; and (ii) in a second case where the three-dimensional points are not classified: encoding the attribute information for the three-dimensional points in a state where the three-dimensional points are not re-ordered in Morton order.

[0014] Note that these general and specific aspects may be implemented as a system, a method, an integrated circuit, a computer program, or a computer-readable recording medium such as a CD-ROM, or as any combination of a system, a method, an integrated circuit, a computer program, and a computer-readable recording medium.

[0015] The present disclosure can provide a three-dimensional data encoding method, a three-dimensional data decoding method, a three-dimensional data encoding device, or a three-dimensional data decoding device that can reduce the processing load in three-dimensional data encoding.

**BRIEF DESCRIPTION OF DRAWINGS**

[0016] These and other objects, advantages and features of the disclosure will become apparent from the following

description thereof taken in conjunction with the accompanying drawings that illustrate a specific embodiment of the present disclosure.

[0017] FIG. 1 is a diagram showing the structure of encoded three-dimensional data according to Embodiment 1;

[0018] FIG. 2 is a diagram showing an example of prediction structures among SPCs that belong to the lowermost layer in a GOS according to Embodiment 1;

[0019] FIG. 3 is a diagram showing an example of prediction structures among layers according to Embodiment 1;

[0020] FIG. 4 is a diagram showing an example order of encoding GOSSs according to Embodiment 1;

[0021] FIG. 5 is a diagram showing an example order of encoding GOSSs according to Embodiment 1;

[0022] FIG. 6 is a block diagram of a three-dimensional data encoding device according to Embodiment 1;

[0023] FIG. 7 is a flowchart of encoding processes according to Embodiment 1;

[0024] FIG. 8 is a block diagram of a three-dimensional data decoding device according to Embodiment 1;

[0025] FIG. 9 is a flowchart of decoding processes according to Embodiment 1;

[0026] FIG. 10 is a diagram showing an example of meta information according to Embodiment 1;

[0027] FIG. 11 is a diagram showing an example structure of a SWLD according to Embodiment 2;

[0028] FIG. 12 is a diagram showing example operations performed by a server and a client according to Embodiment 2;

[0029] FIG. 13 is a diagram showing example operations performed by the server and a client according to Embodiment 2;

[0030] FIG. 14 is a diagram showing example operations performed by the server and the clients according to Embodiment 2;

[0031] FIG. 15 is a diagram showing example operations performed by the server and the clients according to Embodiment 2;

[0032] FIG. 16 is a block diagram of a three-dimensional data encoding device according to Embodiment 2;

[0033] FIG. 17 is a flowchart of encoding processes according to Embodiment 2;

[0034] FIG. 18 is a block diagram of a three-dimensional data decoding device according to Embodiment 2;

[0035] FIG. 19 is a flowchart of decoding processes according to Embodiment 2;

[0036] FIG. 20 is a diagram showing an example structure of a WLD according to Embodiment 2;

[0037] FIG. 21 is a diagram showing an example octree structure of the WLD according to Embodiment 2;

[0038] FIG. 22 is a diagram showing an example structure of a SWLD according to Embodiment 2;

[0039] FIG. 23 is a diagram showing an example octree structure of the SWLD according to Embodiment 2;

[0040] FIG. 24 is a block diagram of a three-dimensional data creation device according to Embodiment 3;

[0041] FIG. 25 is a block diagram of a three-dimensional data transmission device according to Embodiment 3;

[0042] FIG. 26 is a block diagram of a three-dimensional information processing device according to Embodiment 4;

[0043] FIG. 27 is a block diagram of a three-dimensional data creation device according to Embodiment 5;

[0044] FIG. 28 is a diagram showing a structure of a system according to Embodiment 6;

[0045] FIG. 29 is a block diagram of a client device according to Embodiment 6;

[0046] FIG. 30 is a block diagram of a server according to Embodiment 6;

[0047] FIG. 31 is a flowchart of a three-dimensional data creation process performed by the client device according to Embodiment 6;

[0048] FIG. 32 is a flowchart of a sensor information transmission process performed by the client device according to Embodiment 6;

[0049] FIG. 33 is a flowchart of a three-dimensional data creation process performed by the server according to Embodiment 6;

[0050] FIG. 34 is a flowchart of a three-dimensional map transmission process performed by the server according to Embodiment 6;

[0051] FIG. 35 is a diagram showing a structure of a variation of the system according to Embodiment 6;

[0052] FIG. 36 is a diagram showing a structure of the server and client devices according to Embodiment 6;

[0053] FIG. 37 is a block diagram of a three-dimensional data encoding device according to Embodiment 7;

[0054] FIG. 38 is a diagram showing an example of a prediction residual according to Embodiment 7;

[0055] FIG. 39 is a diagram showing an example of a volume according to Embodiment 7;

[0056] FIG. 40 is a diagram showing an example of an octree representation of the volume according to Embodiment 7;

[0057] FIG. 41 is a diagram showing an example of bit sequences of the volume according to Embodiment 7;

[0058] FIG. 42 is a diagram showing an example of an octree representation of a volume according to Embodiment 7;

[0059] FIG. 43 is a diagram showing an example of the volume according to Embodiment 7;

[0060] FIG. 44 is a diagram for describing an intra prediction process according to Embodiment 7;

[0061] FIG. 45 is a diagram for describing a rotation and translation process according to Embodiment 7;

[0062] FIG. 46 is a diagram showing an example syntax of an RT flag and RT information according to Embodiment 7;

[0063] FIG. 47 is a diagram for describing an inter prediction process according to Embodiment 7;

[0064] FIG. 48 is a block diagram of a three-dimensional data decoding device according to Embodiment 7;

[0065] FIG. 49 is a flowchart of a three-dimensional data encoding process performed by the three-dimensional data encoding device according to Embodiment 7;

[0066] FIG. 50 is a flowchart of a three-dimensional data decoding process performed by the three-dimensional data decoding device according to Embodiment 7;

[0067] FIG. 51 is a diagram illustrating an example of three-dimensional points according to Embodiment 8;

[0068] FIG. 52 is a diagram illustrating an example of setting LoDs according to Embodiment 8;

[0069] FIG. 53 is a diagram illustrating an example of setting LoDs according to Embodiment 8;

[0070] FIG. 54 is a diagram illustrating an example of attribute information to be used for predicted values according to Embodiment 8;

- [0071] FIG. 55 is a diagram illustrating examples of exponential-Golomb codes according to Embodiment 8;
- [0072] FIG. 56 is a diagram indicating a process on exponential-Golomb codes according to Embodiment 8;
- [0073] FIG. 57 is a diagram indicating an example of a syntax in attribute header according to Embodiment 8;
- [0074] FIG. 58 is a diagram indicating an example of a syntax in attribute data according to Embodiment 8;
- [0075] FIG. 59 is a flowchart of a three-dimensional data encoding process according to Embodiment 8;
- [0076] FIG. 60 is a flowchart of an attribute information encoding process according to Embodiment 8;
- [0077] FIG. 61 is a diagram indicating processing on exponential-Golomb codes according to Embodiment 8;
- [0078] FIG. 62 is a diagram indicating an example of a reverse lookup table indicating relationships between remaining codes and the values thereof according to Embodiment 8;
- [0079] FIG. 63 is a flowchart of a three-dimensional data decoding process according to Embodiment 8;
- [0080] FIG. 64 is a flowchart of an attribute information decoding process according to Embodiment 8;
- [0081] FIG. 65 is a block diagram of a three-dimensional data encoding device according to Embodiment 8;
- [0082] FIG. 66 is a block diagram of a three-dimensional data decoding device according to Embodiment 8;
- [0083] FIG. 67 is a flowchart of a three-dimensional data encoding process according to Embodiment 8;
- [0084] FIG. 68 is a flowchart of a three-dimensional data decoding process according to Embodiment 8;
- [0085] FIG. 69 is a diagram showing a first example of a table representing predicted values calculated in prediction modes according to Embodiment 9;
- [0086] FIG. 70 is a diagram showing examples of attribute information items (pieces of attribute information) used as the predicted values according to Embodiment 9;
- [0087] FIG. 71 is a diagram showing a second example of a table representing predicted values calculated in the prediction modes according to Embodiment 9;
- [0088] FIG. 72 is a diagram showing a third example of a table representing predicted values calculated in the prediction modes according to Embodiment 9;
- [0089] FIG. 73 is a diagram showing a fourth example of a table representing predicted values calculated in the prediction modes according to Embodiment 9;
- [0090] FIG. 74 is a diagram showing an example of the reference relationship according to Embodiment 10;
- [0091] FIG. 75 is a diagram showing an example of the reference relationship according to Embodiment 10;
- [0092] FIG. 76 is a diagram showing an example of setting the number of times of searching for each LoD according to Embodiment 10;
- [0093] FIG. 77 is a diagram showing an example of the reference relationship according to Embodiment 10;
- [0094] FIG. 78 is a diagram showing an example of the reference relationship according to Embodiment 10;
- [0095] FIG. 79 is a diagram showing an example of the reference relationship according to Embodiment 10;
- [0096] FIG. 80 is a diagram showing a syntax example of an attribute information header according to Embodiment 10;
- [0097] FIG. 81 is a diagram showing a syntax example of the attribute information header according to Embodiment 10;
- [0098] FIG. 82 is a flowchart of the three-dimensional data encoding processing according to Embodiment 10;
- [0099] FIG. 83 is a flowchart of the attribute information encoding processing according to Embodiment 10;
- [0100] FIG. 84 is a flowchart of the three-dimensional data decoding processing according to Embodiment 10;
- [0101] FIG. 85 is a flowchart of the attribute information decoding processing according to Embodiment 10;
- [0102] FIG. 86 is a flowchart of the surrounding point searching processing according to Embodiment 10;
- [0103] FIG. 87 is a flowchart of the surrounding point searching processing according to Embodiment 10;
- [0104] FIG. 88 is a flowchart of the surrounding point searching processing according to Embodiment 10;
- [0105] FIG. 89 is a flowchart of the three-dimensional data encoding processing according to Embodiment 10;
- [0106] FIG. 90 is a flowchart of the three-dimensional data decoding processing according to Embodiment 10;
- [0107] FIG. 91 is a diagram for illustrating a re-ordering process according to Embodiment 11;
- [0108] FIG. 92 is a diagram for describing a method of selecting N three-dimensional points according to Embodiment 11;
- [0109] FIG. 93 is a diagram illustrating an example of a bounding box of group Gk according to Embodiment 11;
- [0110] FIG. 94 is a diagram for describing processing of selecting the candidates of N three-dimensional points in a case where a first three-dimensional point and a plurality of second three-dimensional points belong to the same group, according to Embodiment 11;
- [0111] FIG. 95 is a diagram for describing processing of selecting the candidates of N three-dimensional points in a case where the first three-dimensional point and the plurality of second three-dimensional points belong to different groups, according to Embodiment 11;
- [0112] FIG. 96 is a diagram for describing processing of selecting a three-dimensional point candidate from a plurality of second three-dimensional points belonging to different layers, according to Embodiment 11;
- [0113] FIG. 97 is a diagram for describing the processing of selecting or updating three-dimensional point candidates from the groups before and after an initial group, according to Embodiment 11;
- [0114] FIG. 98 is a diagram for describing an example of giving preference to a group with a small bounding box according to Embodiment 11;
- [0115] FIG. 99 is a flowchart of three-dimensional data encoding processing by a three-dimensional data encoding device according to Embodiment 11;
- [0116] FIG. 100 is a flowchart of attribute information encoding processing according to Embodiment 11;
- [0117] FIG. 101 is a flowchart of three-dimensional data decoding processing by a three-dimensional data decoding device according to Embodiment 11;
- [0118] FIG. 102 is a flowchart of attribute information decoding processing according to Embodiment 11;
- [0119] FIG. 103 is a flowchart of search processing of a surrounding point according to Embodiment 11;
- [0120] FIG. 104 is a flowchart of the search processing of the surrounding point according to Embodiment 11;
- [0121] FIG. 105 is a block diagram illustrating the configuration of an attribute information encoder included in a three-dimensional data encoding device according to Embodiment 11;

[0122] FIG. 106 is a block diagram illustrating the configuration of an attribute information decoder included in a three-dimensional data decoding device according to Embodiment 11;

[0123] FIG. 107 is a flowchart of three-dimensional data encoding processing according to Embodiment 11;

[0124] FIG. 108 is a flowchart of three-dimensional data decoding processing according to Embodiment 11;

[0125] FIG. 109 is a diagram for illustrating an example of a process of encoding attribute information on a three-dimensional point according to Embodiment 12;

[0126] FIG. 110 is a flowchart of a three-dimensional data encoding process according to Embodiment 12;

[0127] FIG. 111 is a flowchart of a process of encoding attribute information according to Embodiment 12;

[0128] FIG. 112 is a flowchart of a three-dimensional data decoding process according to Embodiment 12;

[0129] FIG. 113 is a flowchart of a process of decoding attribute information according to Embodiment 12;

[0130] FIG. 114 is a flowchart of an example of the three-dimensional data encoding process according to Embodiment 12;

[0131] FIG. 115 is a flowchart of an example of the three-dimensional data decoding process according to Embodiment 12;

[0132] FIG. 116 is a flowchart of another example of the three-dimensional data encoding process according to Embodiment 12; and

[0133] FIG. 117 is a flowchart of another example of the three-dimensional data decoding process according to Embodiment 12.

#### DETAILED DESCRIPTION OF THE EMBODIMENTS

[0134] A three-dimensional data encoding method according to an aspect of the present disclosure is a three-dimensional data encoding method of encoding three-dimensional points each having attribute information, and includes: (i) when the three-dimensional points are classified into layers: generating a layered structure by classifying each of the three-dimensional points into the layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer; encoding the attribute information of each of the three-dimensional points, using the layered structure; and generating a bitstream including the attribute information encoded and layer information to be used in generating the layered structure; and (ii) when the three-dimensional points are not classified into the layers: encoding the attribute information of each of the three-dimensional points without classifying the three-dimensional points into the layers; and generating a bitstream including the attribute information encoded and not including the layer information.

[0135] With this, when three-dimensional points are not classified into layers, attribute information on each of the three-dimensional points is encoded without performing the process of classifying the three-dimensional points into layers, and thus, the processing load in the encoding can be reduced.

[0136] For example, the layer information may include a distance threshold value for classifying the three-dimen-

sional points into in such a way that the distance between the three-dimensional points falls within a distance range that is different between the layers.

[0137] For example, in the encoding when the three-dimensional points are not classified into layers, the attribute information of each of the three-dimensional points may be encoded without re-ordering the three-dimensional points in Morton order based on geometry information of the three-dimensional points.

[0138] With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the encoding can be further reduced.

[0139] Furthermore, a three-dimensional data encoding method according to another aspect of the present disclosure is a three-dimensional data encoding method of encoding three-dimensional points each having attribute information, and includes: encoding the attribute information of each of the three-dimensional points without re-ordering the three-dimensional points in Morton order based on geometry information of the three-dimensional points, when the three-dimensional points are not classified into layers; and generating a bitstream including the attribute information encoded.

[0140] With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the encoding can be reduced.

[0141] A three-dimensional data decoding method according to an aspect of the present disclosure is a three-dimensional data decoding method of decoding encoded three-dimensional points each having attribute information, and includes: obtaining a bitstream including the encoded three-dimensional points; and (i) when the encoded three-dimensional points are classified into layers: generating a layered structure using layer information included in the bitstream, for generating the layered structure by classifying the encoded three-dimensional points into the layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer; and decoding the encoded three-dimensional points using the layered structure; and (ii) when the encoded three-dimensional points are not classified into layers: decoding the encoded three-dimensional points without classifying the encoded three-dimensional points into the layers.

[0142] With this, when three-dimensional points are not classified into layers, three-dimensional points which have been encoded without performing the process of classifying the three-dimensional points into layers are decoded, and thus, the processing load in the decoding can be reduced.

[0143] For example, the layer information may include a distance threshold value for classifying the three-dimensional points in such a way that the distance between the three-dimensional points falls within a distance range that is different between the layers.

[0144] For example, in the decoding when the encoded three-dimensional points are not classified into layers, the encoded three-dimensional points may be decoded without re-ordering the encoded three-dimensional points in Morton order based on geometry information of the encoded three-dimensional points.

[0145] With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the decoding can be further reduced.

[0146] Furthermore, three-dimensional data decoding method according to another aspect of the present disclosure is a three-dimensional data decoding method of decoding encoded three-dimensional points each having attribute information, and includes: obtaining a bitstream including the encoded three-dimensional points; and decoding the encoded three-dimensional points without re-ordering the encoded three-dimensional points in Morton order based on geometry information of the encoded three-dimensional points, when the encoded three-dimensional points are not classified into layers.

[0147] With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the decoding can be reduced.

[0148] A three-dimensional data encoding device according to an aspect of the present disclosure is a three-dimensional data encoding device that encodes three-dimensional points each having attribute information, and includes: a processor; and memory. Using the memory, the processor: (i) when the three-dimensional points are classified into layers: generates a layered structure by classifying each of the three-dimensional points into the layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer; encodes the attribute information of each of the three-dimensional points, using the layered structure; and generates a bitstream including the attribute information encoded and layer information to be used in generating the layered structure; and (ii) when the three-dimensional points are not classified into the layers: encodes the attribute information of each of the three-dimensional points without classifying the three-dimensional points into the layers; and generates a bitstream including the attribute information encoded and not including the layer information.

[0149] With this, when three-dimensional points are not classified into layers, attribute information on each of the three-dimensional points is encoded without performing the process of classifying the plurality of three-dimensional points into layers, and thus, the processing load in the encoding can be reduced.

[0150] A three-dimensional data decoding device according to an aspect of the present disclosure is a three-dimensional data decoding device that decodes encoded three-dimensional points each having attribute information, and includes: a processor; and memory. Using the memory, the processor: obtains a bitstream including the encoded three-dimensional points; and (i) when the encoded three-dimensional points are classified into layers: generates a layered structure using layer information included in the bitstream, for generating the layered structure by classifying the encoded three-dimensional points into the layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer; and decodes the encoded three-dimensional points using the layered structure; and (ii) when the encoded three-dimensional points are not classified into layers: decodes the encoded three-dimensional points without classifying the encoded three-dimensional points into the layers.

[0151] With this, when three-dimensional points are not classified into layers, three-dimensional points which have been encoded without performing the process of classifying

the three-dimensional points into layers are decoded, and thus, the processing load in the decoding can be reduced.

[0152] Note that these generic or specific aspects may be implemented as a system, a method, an integrated circuit, a computer program, or a computer-readable recording medium such as a CD-ROM, or may be implemented as any combination of a system, a method, an integrated circuit, a computer program, and a recording medium.

[0153] The following describes embodiments with reference to the drawings. Note that the following embodiments show exemplary embodiments of the present disclosure. The numerical values, shapes, materials, structural components, the arrangement and connection of the structural components, steps, the processing order of the steps, etc. shown in the following embodiments are mere examples, and thus are not intended to limit the present disclosure. Of the structural components described in the following embodiments, structural components not recited in any one of the independent claims that indicate the broadest concepts will be described as optional structural components.

#### Embodiment 1

[0154] First, the data structure of encoded three-dimensional data (hereinafter also referred to as encoded data) according to the present embodiment will be described. FIG. 1 is a diagram showing the structure of encoded three-dimensional data according to the present embodiment.

[0155] In the present embodiment, a three-dimensional space is divided into spaces (SPCs), which correspond to pictures in moving picture encoding, and the three-dimensional data is encoded on a SPC-by-SPC basis. Each SPC is further divided into volumes (VLMs), which correspond to macroblocks, etc. in moving picture encoding, and predictions and transforms are performed on a VLM-by-VLM basis. Each volume includes a plurality of voxels (VXLs), each being a minimum unit in which position coordinates are associated. Note that prediction is a process of generating predictive three-dimensional data analogous to a current processing unit by referring to another processing unit, and encoding a differential between the predictive three-dimensional data and the current processing unit, as in the case of predictions performed on two-dimensional images. Such prediction includes not only spatial prediction in which another prediction unit corresponding to the same time is referred to, but also temporal prediction in which a prediction unit corresponding to a different time is referred to.

[0156] When encoding a three-dimensional space represented by point group data such as a point cloud, for example, the three-dimensional data encoding device (hereinafter also referred to as the encoding device) encodes the points in the point group or points included in the respective voxels in a collective manner, in accordance with a voxel size. Finer voxels enable a highly-precise representation of the three-dimensional shape of a point group, while larger voxels enable a rough representation of the three-dimensional shape of a point group.

[0157] Note that the following describes the case where three-dimensional data is a point cloud, but three-dimensional data is not limited to a point cloud, and thus three-dimensional data of any format may be employed.

[0158] Also note that voxels with a hierarchical structure may be used. In such a case, when the hierarchy includes n levels, whether a sampling point is included in the n-th level or lower levels (levels below the n-th level) may be

sequentially indicated. For example, when only the n-th level is decoded, and the n-1th level or lower levels include a sampling point, the n-th level can be decoded on the assumption that a sampling point is included at the center of a voxel in the n-th level.

[0159] Also, the encoding device obtains point group data, using, for example, a distance sensor, a stereo camera, a monocular camera, a gyroscope sensor, or an inertial sensor.

[0160] As in the case of moving picture encoding, each SPC is classified into one of at least the three prediction structures that include: intra SPC (I-SPC), which is individually decodable; predictive SPC (P-SPC) capable of only a unidirectional reference; and bidirectional SPC (B-SPC) capable of bidirectional references. Each SPC includes two types of time information: decoding time and display time.

[0161] Furthermore, as shown in FIG. 1, a processing unit that includes a plurality of SPCs is a group of spaces (GOS), which is a random access unit. Also, a processing unit that includes a plurality of GOSs is a world (WLD).

[0162] The spatial region occupied by each world is associated with an absolute position on earth, by use of, for example, GPS, or latitude and longitude information. Such position information is stored as meta-information. Note that meta-information may be included in encoded data, or may be transmitted separately from the encoded data.

[0163] Also, inside a GOS, all SPCs may be three-dimensionally adjacent to one another, or there may be a SPC that is not three-dimensionally adjacent to another SPC.

[0164] Note that the following also describes processes such as encoding, decoding, and reference to be performed on three-dimensional data included in processing units such as GOS, SPC, and VLM, simply as performing encoding/to encode, decoding/to decode, referring to, etc. on a processing unit. Also note that three-dimensional data included in a processing unit includes, for example, at least one pair of a spatial position such as three-dimensional coordinates and an attribute value such as color information.

[0165] Next, the prediction structures among SPCs in a GOS will be described. A plurality of SPCs in the same GOS or a plurality of VLMs in the same SPC occupy mutually different spaces, while having the same time information (the decoding time and the display time).

[0166] A SPC in a GOS that comes first in the decoding order is an I-SPC. GOSs come in two types: closed GOS and open GOS. A closed GOS is a GOS in which all SPCs in the GOS are decodable when decoding starts from the first I-SPC. Meanwhile, an open GOS is a GOS in which a different GOS is referred to in one or more SPCs preceding the first I-SPC in the GOS in the display time, and thus cannot be singly decoded.

[0167] Note that in the case of encoded data of map information, for example, a WLD is sometimes decoded in the backward direction, which is opposite to the encoding order, and thus backward reproduction is difficult when GOSs are interdependent. In such a case, a closed GOS is basically used.

[0168] Each GOS has a layer structure in height direction, and SPCs are sequentially encoded or decoded from SPCs in the bottom layer.

[0169] FIG. 2 is a diagram showing an example of prediction structures among SPCs that belong to the lowermost layer in a GOS. FIG. 3 is a diagram showing an example of prediction structures among layers.

[0170] A GOS includes at least one I-SPC. Of the objects in a three-dimensional space, such as a person, an animal, a car, a bicycle, a signal, and a building serving as a landmark, a small-sized object is especially effective when encoded as an I-SPC. When decoding a GOS at a low throughput or at a high speed, for example, the three-dimensional data decoding device (hereinafter also referred to as the decoding device) decodes only I-SPC(s) in the GOS.

[0171] The encoding device may also change the encoding interval or the appearance frequency of I-SPCs, depending on the degree of sparseness and denseness of the objects in a WLD.

[0172] In the structure shown in FIG. 3, the encoding device or the decoding device encodes or decodes a plurality of layers sequentially from the bottom layer (layer 1). This increases the priority of data on the ground and its vicinity, which involve a larger amount of information, when, for example, a self-driving car is concerned.

[0173] Regarding encoded data used for a drone, for example, encoding or decoding may be performed sequentially from SPCs in the top layer in a GOS in height direction.

[0174] The encoding device or the decoding device may also encode or decode a plurality of layers in a manner that the decoding device can have a rough grasp of a GOS first, and then the resolution is gradually increased. The encoding device or the decoding device may perform encoding or decoding in the order of layers 3, 8, 1, 9 . . . , for example.

[0175] Next, the handling of static objects and dynamic objects will be described.

[0176] A three-dimensional space includes scenes or still objects such as a building and a road (hereinafter collectively referred to as static objects), and objects with motion such as a car and a person (hereinafter collectively referred to as dynamic objects). Object detection is separately performed by, for example, extracting keypoints from point cloud data, or from video of a camera such as a stereo camera. In this description, an example method of encoding a dynamic object will be described.

[0177] A first method is a method in which a static object and a dynamic object are encoded without distinction. A second method is a method in which a distinction is made between a static object and a dynamic object on the basis of identification information.

[0178] For example, a GOS is used as an identification unit. In such a case, a distinction is made between a GOS that includes SPCs constituting a static object and a GOS that includes SPCs constituting a dynamic object, on the basis of identification information stored in the encoded data or stored separately from the encoded data.

[0179] Alternatively, a SPC may be used as an identification unit. In such a case, a distinction is made between a SPC that includes VLMs constituting a static object and a SPC that includes VLMs constituting a dynamic object, on the basis of the identification information thus described.

[0180] Alternatively, a VLM or a VXL may be used as an identification unit. In such a case, a distinction is made between a VLM or a VXL that includes a static object and a VLM or a VXL that includes a dynamic object, on the basis of the identification information thus described.

[0181] The encoding device may also encode a dynamic object as at least one VLM or SPC, and may encode a VLM or a SPC including a static object and a SPC including a dynamic object as mutually different GOSs. When the GOS

size is variable depending on the size of a dynamic object, the encoding device separately stores the GOS size as meta-information.

[0182] The encoding device may also encode a static object and a dynamic object separately from each other, and may superimpose the dynamic object onto a world constituted by static objects. In such a case, the dynamic object is constituted by at least one SPC, and each SPC is associated with at least one SPC constituting the static object onto which the each SPC is to be superimposed. Note that a dynamic object may be represented not by SPC(s) but by at least one VLM or VXL.

[0183] The encoding device may also encode a static object and a dynamic object as mutually different streams.

[0184] The encoding device may also generate a GOS that includes at least one SPC constituting a dynamic object. The encoding device may further set the size of a GOS including a dynamic object (GOS\_M) and the size of a GOS including a static object corresponding to the spatial region of GOS\_M at the same size (such that the same spatial region is occupied). This enables superimposition to be performed on a GOS-by-GOS basis.

[0185] SPC(s) included in another encoded GOS may be referred to in a P-SPC or a B-SPC constituting a dynamic object. In the case where the position of a dynamic object temporally changes, and the same dynamic object is encoded as an object in a GOS corresponding to a different time, referring to SPC(s) across GOSs is effective in terms of compression rate.

[0186] The first method and the second method may be selected in accordance with the intended use of encoded data. When encoded three-dimensional data is used as a map, for example, a dynamic object is desired to be separated, and thus the encoding device uses the second method. Meanwhile, the encoding device uses the first method when the separation of a dynamic object is not required such as in the case where three-dimensional data of an event such as a concert and a sports event is encoded.

[0187] The decoding time and the display time of a GOS or a SPC are storables in encoded data or as meta-information. All static objects may have the same time information. In such a case, the decoding device may determine the actual decoding time and display time. Alternatively, a different value may be assigned to each GOS or SPC as the decoding time, and the same value may be assigned as the display time. Furthermore, as in the case of the decoder model in moving picture encoding such as Hypothetical Reference Decoder (HRD) compliant with HEVC, a model may be employed that ensures that a decoder can perform decoding without fail by having a buffer of a predetermined size and by reading a bitstream at a predetermined bit rate in accordance with the decoding times.

[0188] Next, the topology of GOSs in a world will be described. The coordinates of the three-dimensional space in a world are represented by the three coordinate axes (x axis, y axis, and z axis) that are orthogonal to one another. A predetermined rule set for the encoding order of GOSs enables encoding to be performed such that spatially adjacent GOSs are contiguous in the encoded data. In an example shown in FIG. 4, for example, GOSs in the x and z planes are successively encoded. After the completion of encoding all GOSs in certain x and z planes, the value of the y axis is updated. Stated differently, the world expands in the

y axis direction as the encoding progresses. The GOS index numbers are set in accordance with the encoding order.

[0189] Here, the three-dimensional spaces in the respective worlds are previously associated one-to-one with absolute geographical coordinates such as GPS coordinates or latitude/longitude coordinates. Alternatively, each three-dimensional space may be represented as a position relative to a previously set reference position. The directions of the x axis, the y axis, and the z axis in the three-dimensional space are represented by directional vectors that are determined on the basis of the latitudes and the longitudes, etc. Such directional vectors are stored together with the encoded data as meta-information.

[0190] GOSs have a fixed size, and the encoding device stores such size as meta-information. The GOS size may be changed depending on, for example, whether it is an urban area or not, or whether it is inside or outside of a room. Stated differently, the GOS size may be changed in accordance with the amount or the attributes of objects with information values. Alternatively, in the same world, the encoding device may adaptively change the GOS size or the interval between I-SPCs in GOSs in accordance with the object density, etc. For example, the encoding device sets the GOS size to smaller and the interval between I-SPCs in GOSs to shorter, as the object density is higher.

[0191] In an example shown in FIG. 5, to enable random access with a finer granularity, a GOS with a high object density is partitioned into the regions of the third to tenth GOSs. Note that the seventh to tenth GOSs are located behind the third to sixth GOSs.

[0192] Next, the structure and the operation flow of the three-dimensional data encoding device according to the present embodiment will be described. FIG. 6 is a block diagram of three-dimensional data encoding device 100 according to the present embodiment. FIG. 7 is a flowchart of an example operation performed by three-dimensional data encoding device 100.

[0193] Three-dimensional data encoding device 100 shown in FIG. 6 encodes three-dimensional data 111, thereby generating encoded three-dimensional data 112. Such three-dimensional data encoding device 100 includes obtainer 101, encoding region determiner 102, divider 103, and encoder 104.

[0194] As shown in FIG. 7, first, obtainer 101 obtains three-dimensional data 111, which is point group data (S101).

[0195] Next, encoding region determiner 102 determines a current region for encoding from among spatial regions corresponding to the obtained point group data (S102). For example, in accordance with the position of a user or a vehicle, encoding region determiner 102 determines, as the current region, a spatial region around such position.

[0196] Next, divider 103 divides the point group data included in the current region into processing units. The processing units here means units such as GOSs and SPCs described above. The current region here corresponds to, for example, a world described above. More specifically, divider 103 divides the point group data into processing units on the basis of a predetermined GOS size, or the presence/absence/size of a dynamic object (S103). Divider 103 further determines the starting position of the SPC that comes first in the encoding order in each GOS.

[0197] Next, encoder 104 sequentially encodes a plurality of SPCs in each GOS, thereby generating encoded three-dimensional data 112 (S104).

[0198] Note that although an example is described here in which the current region is divided into GOSs and SPCs, after which each GOS is encoded, the processing steps are not limited to this order. For example, steps may be employed in which the structure of a single GOS is determined, which is followed by the encoding of such GOS, and then the structure of the subsequent GOS is determined.

[0199] As thus described, three-dimensional data encoding device 100 encodes three-dimensional data 111, thereby generating encoded three-dimensional data 112. More specifically, three-dimensional data encoding device 100 divides three-dimensional data into first processing units (GOSs), each being a random access unit and being associated with three-dimensional coordinates, divides each of the first processing units (GOSs) into second processing units (SPCs), and divides each of the second processing units (SPCs) into third processing units (VLMs). Each of the third processing units (VLMs) includes at least one voxel (VXL), which is the minimum unit in which position information is associated.

[0200] Next, three-dimensional data encoding device 100 encodes each of the first processing units (GOSs), thereby generating encoded three-dimensional data 112. More specifically, three-dimensional data encoding device 100 encodes each of the second processing units (SPCs) in each of the first processing units (GOSs). Three-dimensional data encoding device 100 further encodes each of the third processing units (VLMs) in each of the second processing units (SPCs).

[0201] When a current first processing unit (GOS) is a closed GOS, for example, three-dimensional data encoding device 100 encodes a current second processing unit (SPC) included in such current first processing unit (GOS) by referring to another second processing unit (SPC) included in the current first processing unit (GOS). Stated differently, three-dimensional data encoding device 100 refers to no second processing unit (SPC) included in a first processing unit (GOS) that is different from the current first processing unit (GOS).

[0202] Meanwhile, when a current first processing unit (GOS) is an open GOS, three-dimensional data encoding device 100 encodes a current second processing unit (SPC) included in such current first processing unit (GOS) by referring to another second processing unit (SPC) included in the current first processing unit (GOS) or a second processing unit (SPC) included in a first processing unit (GOS) that is different from the current first processing unit (GOS).

[0203] Also, three-dimensional data encoding device 100 selects, as the type of a current second processing unit (SPC), one of the following: a first type (I-SPC) in which another second processing unit (SPC) is not referred to; a second type (P-SPC) in which another single second processing unit (SPC) is referred to; and a third type in which other two second processing units (SPC) are referred to. Three-dimensional data encoding device 100 encodes the current second processing unit (SPC) in accordance with the selected type.

[0204] Next, the structure and the operation flow of the three-dimensional data decoding device according to the present embodiment will be described. FIG. 8 is a block

diagram of three-dimensional data decoding device 200 according to the present embodiment. FIG. 9 is a flowchart of an example operation performed by three-dimensional data decoding device 200.

[0205] Three-dimensional data decoding device 200 shown in FIG. 8 decodes encoded three-dimensional data 211, thereby generating decoded three-dimensional data 212. Encoded three-dimensional data 211 here is, for example, encoded three-dimensional data 112 generated by three-dimensional data encoding device 100. Such three-dimensional data decoding device 200 includes obtainer 201, decoding start GOS determiner 202, decoding SPC determiner 203, and decoder 204.

[0206] First, obtainer 201 obtains encoded three-dimensional data 211 (S201). Next, decoding start GOS determiner 202 determines a current GOS for decoding (S202). More specifically, decoding start GOS determiner 202 refers to meta-information stored in encoded three-dimensional data 211 or stored separately from the encoded three-dimensional data to determine, as the current GOS, a GOS that includes a SPC corresponding to the spatial position, the object, or the time from which decoding is to start.

[0207] Next, decoding SPC determiner 203 determines the type(s) (I, P, and/or B) of SPCs to be decoded in the GOS (S203). For example, decoding SPC determiner 203 determines whether to (1) decode only I-SPC(s), (2) to decode I-SPC(s) and P-SPCs, or (3) to decode SPCs of all types. Note that the present step may not be performed, when the type(s) of SPCs to be decoded are previously determined such as when all SPCs are previously determined to be decoded.

[0208] Next, decoder 204 obtains an address location within encoded three-dimensional data 211 from which a SPC that comes first in the GOS in the decoding order (the same as the encoding order) starts. Decoder 204 obtains the encoded data of the first SPC from the address location, and sequentially decodes the SPCs from such first SPC (S204). Note that the address location is stored in the meta-information, etc.

[0209] Three-dimensional data decoding device 200 decodes decoded three-dimensional data 212 as thus described. More specifically, three-dimensional data decoding device 200 decodes each encoded three-dimensional data 211 of the first processing units (GOSs), each being a random access unit and being associated with three-dimensional coordinates, thereby generating decoded three-dimensional data 212 of the first processing units (GOSs). Even more specifically, three-dimensional data decoding device 200 decodes each of the second processing units (SPCs) in each of the first processing units (GOSs). Three-dimensional data decoding device 200 further decodes each of the third processing units (VLMs) in each of the second processing units (SPCs).

[0210] The following describes meta-information for random access. Such meta-information is generated by three-dimensional data encoding device 100, and included in encoded three-dimensional data 112 (211).

[0211] In the conventional random access for a two-dimensional moving picture, decoding starts from the first frame in a random access unit that is close to a specified time. Meanwhile, in addition to times, random access to spaces (coordinates, objects, etc.) is assumed to be performed in a world.

[0212] To enable random access to at least three elements of coordinates, objects, and times, tables are prepared that associate the respective elements with the GOS index numbers. Furthermore, the GOS index numbers are associated with the addresses of the respective first I-SPCs in the GOSs. FIG. 10 is a diagram showing example tables included in the meta-information. Note that not all the tables shown in FIG. 10 are required to be used, and thus at least one of the tables is used.

[0213] The following describes an example in which random access is performed from coordinates as a starting point. To access the coordinates (x2, y2, and z2), the coordinates-GOS table is first referred to, which indicates that the point corresponding to the coordinates (x2, y2, and z2) is included in the second GOS. Next, the GOS-address table is referred to, which indicates that the address of the first I-SPC in the second GOS is addr(2). As such, decoder 204 obtains data from this address to start decoding.

[0214] Note that the addresses may either be logical addresses or physical addresses of an HDD or a memory. Alternatively, information that identifies file segments may be used instead of addresses. File segments are, for example, units obtained by segmenting at least one GOS, etc.

[0215] When an object spans across a plurality of GOSs, the object-GOS table may show a plurality of GOSs to which such object belongs. When such plurality of GOSs are closed GOSs, the encoding device and the decoding device can perform encoding or decoding in parallel. Meanwhile, when such plurality of GOSs are open GOSs, a higher compression efficiency is achieved by the plurality of GOSs referring to each other.

[0216] Example objects include a person, an animal, a car, a bicycle, a signal, and a building serving as a landmark. For example, three-dimensional data encoding device 100 extracts keypoints specific to an object from a three-dimensional point cloud, etc., when encoding a world, and detects the object on the basis of such keypoints to set the detected object as a random access point.

[0217] As thus described, three-dimensional data encoding device 100 generates first information indicating a plurality of first processing units (GOSs) and the three-dimensional coordinates associated with the respective first processing units (GOSs). Encoded three-dimensional data 112 (211) includes such first information. The first information further indicates at least one of objects, times, and data storage locations that are associated with the respective first processing units (GOSs).

[0218] Three-dimensional data decoding device 200 obtains the first information from encoded three-dimensional data 211. Using such first information, three-dimensional data decoding device 200 identifies encoded three-dimensional data 211 of the first processing unit that corresponds to the specified three-dimensional coordinates, object, or time, and decodes encoded three-dimensional data 211.

[0219] The following describes an example of other meta-information. In addition to the meta-information for random access, three-dimensional data encoding device 100 may also generate and store meta-information as described below, and three-dimensional data decoding device 200 may use such meta-information at the time of decoding.

[0220] When three-dimensional data is used as map information, for example, a profile is defined in accordance with the intended use, and information indicating such profile

may be included in meta-information. For example, a profile is defined for an urban or a suburban area, or for a flying object, and the maximum or minimum size, etc. of a world, a SPC or a VLM, etc. is defined in each profile. For example, more detailed information is required for an urban area than for a suburban area, and thus the minimum VLM size is set to small.

[0221] The meta-information may include tag values indicating object types. Each of such tag values is associated with VLMs, SPCs, or GOSs that constitute an object. For example, a tag value may be set for each object type in a manner, for example, that the tag value “0” indicates “person,” the tag value “1” indicates “car,” and the tag value “2” indicates “signal”. Alternatively, when an object type is hard to judge, or such judgment is not required, a tag value may be used that indicates the size or the attribute indicating, for example, whether an object is a dynamic object or a static object.

[0222] The meta-information may also include information indicating a range of the spatial region occupied by a world.

[0223] The meta-information may also store the SPC or VXL size as header information common to the whole stream of the encoded data or to a plurality of SPCs, such as SPCs in a GOS.

[0224] The meta-information may also include identification information on a distance sensor or a camera that has been used to generate a point cloud, or information indicating the positional accuracy of a point group in the point cloud.

[0225] The meta-information may also include information indicating whether a world is made only of static objects or includes a dynamic object.

[0226] The following describes variations of the present embodiment.

[0227] The encoding device or the decoding device may encode or decode two or more mutually different SPCs or GOSs in parallel. GOSs to be encoded or decoded in parallel can be determined on the basis of meta-information, etc. indicating the spatial positions of the GOSs.

[0228] When three-dimensional data is used as a spatial map for use by a car or a flying object, etc. in traveling, or for creation of such a spatial map, for example, the encoding device or the decoding device may encode or decode GOSs or SPCs included in a space that is identified on the basis of GPS information, the route information, the zoom magnification, etc.

[0229] The decoding device may also start decoding sequentially from a space that is close to the self-location or the traveling route. The encoding device or the decoding device may give a lower priority to a space distant from the self-location or the traveling route than the priority of a nearby space to encode or decode such distant place. To “give a lower priority” means here, for example, to lower the priority in the processing sequence, to decrease the resolution (to apply decimation in the processing), or to lower the image quality (to increase the encoding efficiency by, for example, setting the quantization step to larger).

[0230] When decoding encoded data that is hierarchically encoded in a space, the decoding device may decode only the bottom layer in the hierarchy.

[0231] The decoding device may also start decoding preferentially from the bottom layer of the hierarchy in accordance with the zoom magnification or the intended use of the map.

[0232] For self-location estimation or object recognition, etc. involved in the self-driving of a car or a robot, the encoding device or the decoding device may encode or decode regions at a lower resolution, except for a region that is lower than or at a specified height from the ground (the region to be recognized).

[0233] The encoding device may also encode point clouds representing the spatial shapes of a room interior and a room exterior separately. For example, the separation of a GOS representing a room interior (interior GOS) and a GOS representing a room exterior (exterior GOS) enables the decoding device to select a GOS to be decoded in accordance with a viewpoint location, when using the encoded data.

[0234] The encoding device may also encode an interior GOS and an exterior GOS having close coordinates so that such GOSs come adjacent to each other in an encoded stream. For example, the encoding device associates the identifiers of such GOSs with each other, and stores information indicating the associated identifiers into the meta-information that is stored in the encoded stream or stored separately. This enables the decoding device to refer to the information in the meta-information to identify an interior GOS and an exterior GOS having close coordinates.

[0235] The encoding device may also change the GOS size or the SPC size depending on whether a GOS is an interior GOS or an exterior GOS. For example, the encoding device sets the size of an interior GOS to smaller than the size of an exterior GOS. The encoding device may also change the accuracy of extracting keypoints from a point cloud, or the accuracy of detecting objects, for example, depending on whether a GOS is an interior GOS or an exterior GOS.

[0236] The encoding device may also add, to encoded data, information by which the decoding device displays objects with a distinction between a dynamic object and a static object. This enables the decoding device to display a dynamic object together with, for example, a red box or letters for explanation. Note that the decoding device may display only a red box or letters for explanation, instead of a dynamic object. The decoding device may also display more particular object types. For example, a red box may be used for a car, and a yellow box may be used for a person.

[0237] The encoding device or the decoding device may also determine whether to encode or decode a dynamic object and a static object as a different SPC or GOS, in accordance with, for example, the appearance frequency of dynamic objects or a ratio between static objects and dynamic objects. For example, when the appearance frequency or the ratio of dynamic objects exceeds a threshold, a SPC or a GOS including a mixture of a dynamic object and a static object is accepted, while when the appearance frequency or the ratio of dynamic objects is below a threshold, a SPC or GOS including a mixture of a dynamic object and a static object is unaccepted.

[0238] When detecting a dynamic object not from a point cloud but from two-dimensional image information of a camera, the encoding device may separately obtain information for identifying a detection result (box or letters) and the object position, and encode these items of information as

part of the encoded three-dimensional data. In such a case, the decoding device superimposes auxiliary information (box or letters) indicating the dynamic object onto a resultant of decoding a static object to display it.

[0239] The encoding device may also change the sparseness and denseness of VXLs or VLMs in a SPC in accordance with the degree of complexity of the shape of a static object. For example, the encoding device sets VXLs or VLMs at a higher density as the shape of a static object is more complex. The encoding device may further determine a quantization step, etc. for quantizing spatial positions or color information in accordance with the sparseness and denseness of VXLs or VLMs. For example, the encoding device sets the quantization step to smaller as the density of VXLs or VLMs is higher.

[0240] As described above, the encoding device or the decoding device according to the present embodiment encodes or decodes a space on a SPC-by-SPC basis that includes coordinate information.

[0241] Furthermore, the encoding device and the decoding device perform encoding or decoding on a volume-by-volume basis in a SPC. Each volume includes a voxel, which is the minimum unit in which position information is associated.

[0242] Also, using a table that associates the respective elements of spatial information including coordinates, objects, and times with GOSs or using a table that associates these elements with each other, the encoding device and the decoding device associate any ones of the elements with each other to perform encoding or decoding. The decoding device uses the values of the selected elements to determine the coordinates, and identifies a volume, a voxel, or a SPC from such coordinates to decode a SPC including such volume or voxel, or the identified SPC.

[0243] Furthermore, the encoding device determines a volume, a voxel, or a SPC that is selectable in accordance with the elements, through extraction of keypoints and object recognition, and encodes the determined volume, voxel, or SPC, as a volume, a voxel, or a SPC to which random access is possible.

[0244] SPCs are classified into three types: I-SPC that is singly encodable or decodable; P-SPC that is encoded or decoded by referring to any one of the processed SPCs; and B-SPC that is encoded or decoded by referring to any two of the processed SPCs.

[0245] At least one volume corresponds to a static object or a dynamic object. A SPC including a static object and a SPC including a dynamic object are encoded or decoded as mutually different GOSs. Stated differently, a SPC including a static object and a SPC including a dynamic object are assigned to different GOSs.

[0246] Dynamic objects are encoded or decoded on an object-by-object basis, and are associated with at least one SPC including a static object. Stated differently, a plurality of dynamic objects are individually encoded, and the obtained encoded data of the dynamic objects is associated with a SPC including a static object.

[0247] The encoding device and the decoding device give an increased priority to I-SPC(s) in a GOS to perform encoding or decoding. For example, the encoding device performs encoding in a manner that prevents the degradation of I-SPCs (in a manner that enables the original three-

dimensional data to be reproduced with a higher fidelity after decoded). The decoding device decodes, for example, only I-SPCs.

[0248] The encoding device may change the frequency of using I-SPCs depending on the sparseness and denseness or the number (amount) of the objects in a world to perform encoding. Stated differently, the encoding device changes the frequency of selecting I-SPCs depending on the number or the sparseness and denseness of the objects included in the three-dimensional data. For example, the encoding device uses I-SPCs at a higher frequency as the density of the objects in a world is higher.

[0249] The encoding device also sets random access points on a GOS-by-GOS basis, and stores information indicating the spatial regions corresponding to the GOSSs into the header information.

[0250] The encoding device uses, for example, a default value as the spatial size of a GOS. Note that the encoding device may change the GOS size depending on the number (amount) or the sparseness and denseness of objects or dynamic objects. For example, the encoding device sets the spatial size of a GOS to smaller as the density of objects or dynamic objects is higher or the number of objects or dynamic objects is greater.

[0251] Also, each SPC or volume includes a keypoint group that is derived by use of information obtained by a sensor such as a depth sensor, a gyroscope sensor, or a camera sensor. The coordinates of the keypoints are set at the central positions of the respective voxels. Furthermore, finer voxels enable highly accurate position information.

[0252] The keypoint group is derived by use of a plurality of pictures. A plurality of pictures include at least two types of time information: the actual time information and the same time information common to a plurality of pictures that are associated with SPCs (for example, the encoding time used for rate control, etc.).

[0253] Also, encoding or decoding is performed on a GOS-by-GOS basis that includes at least one SPC.

[0254] The encoding device and the decoding device predict P-SPCs or B-SPCs in a current GOS by referring to SPCs in a processed GOS.

[0255] Alternatively, the encoding device and the decoding device predict P-SPCs or B-SPCs in a current GOS, using the processed SPCs in the current GOS, without referring to a different GOS.

[0256] Furthermore, the encoding device and the decoding device transmit or receive an encoded stream on a world-by-world basis that includes at least one GOS.

[0257] Also, a GOS has a layer structure in one direction at least in a world, and the encoding device and the decoding device start encoding or decoding from the bottom layer. For example, a random accessible GOS belongs to the lower-most layer. A GOS that belongs to the same layer or a lower layer is referred to in a GOS that belongs to an upper layer. Stated differently, a GOS is spatially divided in a predetermined direction in advance to have a plurality of layers, each including at least one SPC. The encoding device and the decoding device encode or decode each SPC by referring to a SPC included in the same layer as the each SPC or a SPC included in a layer lower than that of the each SPC.

[0258] Also, the encoding device and the decoding device successively encode or decode GOSSs on a world-by-world basis that includes such GOSSs. In so doing, the encoding device and the decoding device write or read out information

indicating the order (direction) of encoding or decoding as metadata. Stated differently, the encoded data includes information indicating the order of encoding a plurality of GOSSs.

[0259] The encoding device and the decoding device also encode or decode mutually different two or more SPCs or GOSSs in parallel.

[0260] Furthermore, the encoding device and the decoding device encode or decode the spatial information (coordinates, size, etc.) on a SPC or a GOS.

[0261] The encoding device and the decoding device encode or decode SPCs or GOSSs included in an identified space that is identified on the basis of external information on the self-location or/and region size, such as GPS information, route information, or magnification.

[0262] The encoding device or the decoding device gives a lower priority to a space distant from the self-location than the priority of a nearby space to perform encoding or decoding.

[0263] The encoding device sets a direction at one of the directions in a world, in accordance with the magnification or the intended use, to encode a GOS having a layer structure in such direction. Also, the decoding device decodes a GOS having a layer structure in one of the directions in a world that has been set in accordance with the magnification or the intended use, preferentially from the bottom layer.

[0264] The encoding device changes the accuracy of extracting keypoints, the accuracy of recognizing objects, or the size of spatial regions, etc. included in a SPC, depending on whether an object is an interior object or an exterior object. Note that the encoding device and the decoding device encode or decode an interior GOS and an exterior GOS having close coordinates in a manner that these GOSSs come adjacent to each other in a world, and associate their identifiers with each other for encoding and decoding.

## Embodiment 2

[0265] When using encoded data of a point cloud in an actual device or service, it is desirable that necessary information be transmitted/received in accordance with the intended use to reduce the network bandwidth. However, there has been no such functionality in the structure of encoding three-dimensional data, nor an encoding method therefor.

[0266] The present embodiment describes a three-dimensional data encoding method and a three-dimensional data encoding device for providing the functionality of transmitting/receiving only necessary information in encoded data of a three-dimensional point cloud in accordance with the intended use, as well as a three-dimensional data decoding method and a three-dimensional data decoding device for decoding such encoded data.

[0267] A voxel (VXL) with a feature greater than or equal to a given amount is defined as a feature voxel (FVXL), and a world (WLD) constituted by FVXLs is defined as a sparse world (SWLD). FIG. 11 is a diagram showing example structures of a sparse world and a world. A SWLD includes: FGOSs, each being a GOS constituted by FVXLs; FSPCs, each being a SPC constituted by FVXLs; and FVLMs, each being a VLM constituted by FVXLs. The data structure and prediction structure of a FGOS, a FSPC, and a FVLM may be the same as those of a GOS, a SPC, and a VLM.

[0268] A feature represents the three-dimensional position information on a VXL or the visible-light information on the position of a VXL. A large number of features are detected

especially at a corner, an edge, etc. of a three-dimensional object. More specifically, such a feature is a three-dimensional feature or a visible-light feature as described below, but may be any feature that represents the position, luminance, or color information, etc. on a VXL.

[0269] Used as three-dimensional features are signature of histograms of orientations (SHOT) features, point feature histograms (PFH) features, or point pair feature (PPF) features.

[0270] SHOT features are obtained by dividing the periphery of a VXL, and calculating an inner product of the reference point and the normal vector of each divided region to represent the calculation result as a histogram. SHOT features are characterized by a large number of dimensions and high-level feature representation.

[0271] PFH features are obtained by selecting a large number of two point pairs in the vicinity of a VXL, and calculating the normal vector, etc. from each two point pair to represent the calculation result as a histogram. PFH features are histogram features, and thus are characterized by robustness against a certain extent of disturbance and also high-level feature representation.

[0272] PPF features are obtained by using a normal vector, etc. for each two points of VXLs. PPF features, for which all VXLs are used, has robustness against occlusion.

[0273] Used as visible-light features are scale-invariant feature transform (SIFT), speeded up robust features (SURF), or histogram of oriented gradients (HOG), etc. that use information on an image such as luminance gradient information.

[0274] A SWLD is generated by calculating the above-described features of the respective VXLs in a WLD to extract FVXLs. Here, the SWLD may be updated every time the WLD is updated, or may be regularly updated after the elapse of a certain period of time, regardless of the timing at which the WLD is updated.

[0275] A SWLD may be generated for each type of features. For example, different SWLDs may be generated for the respective types of features, such as SWLD1 based on SHOT features and SWLD2 based on SIFT features so that SWLDs are selectively used in accordance with the intended use. Also, the calculated feature of each FVXL may be held in each FVXL as feature information.

[0276] Next, the usage of a sparse world (SWLD) will be described. A SWLD includes only feature voxels (FVXLs), and thus its data size is smaller in general than that of a WLD that includes all VXLs.

[0277] In an application that utilizes features for a certain purpose, the use of information on a SWLD instead of a WLD reduces the time required to read data from a hard disk, as well as the bandwidth and the time required for data transfer over a network. For example, a WLD and a SWLD are held in a server as map information so that map information to be sent is selected between the WLD and the SWLD in accordance with a request from a client. This reduces the network bandwidth and the time required for data transfer. More specific examples will be described below.

[0278] FIG. 12 and FIG. 13 are diagrams showing usage examples of a SWLD and a WLD. As FIG. 12 shows, when client 1, which is a vehicle-mounted device, requires map information to use it for self-location determination, client 1 sends to a server a request for obtaining map data for self-location estimation (S301). The server sends to client 1

the SWLD in response to the obtainment request (S302). Client 1 uses the received SWLD to determine the self-location (S303). In so doing, client 1 obtains VXL information on the periphery of client 1 through various means including a distance sensor such as a rangefinder, as well as a stereo camera and a combination of a plurality of monocular cameras. Client 1 then estimates the self-location information from the obtained VXL information and the SWLD. Here, the self-location information includes three-dimensional position information, orientation, etc. of client 1.

[0279] As FIG. 13 shows, when client 2, which is a vehicle-mounted device, requires map information to use it for rendering a map such as a three-dimensional map, client 2 sends to the server a request for obtaining map data for map rendering (S311). The server sends to client 2 the WLD in response to the obtainment request (S312). Client 2 uses the received WLD to render a map (S313). In so doing, client 2 uses, for example, image client 2 has captured by a visible-light camera, etc. and the WLD obtained from the server to create a rendering image, and renders such created image onto a screen of a car navigation system, etc.

[0280] As described above, the server sends to a client a SWLD when the features of the respective VXLs are mainly required such as in the case of self-location estimation, and sends to a client a WLD when detailed VXL information is required such as in the case of map rendering. This allows for an efficient sending/receiving of map data.

[0281] Note that a client may self-judge which one of a SWLD and a WLD is necessary, and request the server to send a SWLD or a WLD. Also, the server may judge which one of a SWLD and a WLD to send in accordance with the status of the client or a network.

[0282] Next, a method will be described of switching the sending/receiving between a sparse world (SWLD) and a world (WLD).

[0283] Whether to receive a WLD or a SWLD may be switched in accordance with the network bandwidth. FIG. 14 is a diagram showing an example operation in such case. For example, when a low-speed network is used that limits the usable network bandwidth, such as in a Long-Term Evolution (LTE) environment, a client accesses the server over a low-speed network (S321), and obtains the SWLD from the server as map information (S322). Meanwhile, when a high-speed network is used that has an adequately broad network bandwidth, such as in a WiFi environment, a client accesses the server over a high-speed network (S323), and obtains the WLD from the server (S324). This enables the client to obtain appropriate map information in accordance with the network bandwidth such client is using.

[0284] More specifically, a client receives the SWLD over an LTE network when in outdoors, and obtains the WLD over a WiFi network when in indoors such as in a facility. This enables the client to obtain more detailed map information on indoor environment.

[0285] As described above, a client may request for a WLD or a SWLD in accordance with the bandwidth of a network such client is using. Alternatively, the client may send to the server information indicating the bandwidth of a network such client is using, and the server may send to the client data (the WLD or the SWLD) suitable for such client in accordance with the information. Alternatively, the server

may identify the network bandwidth the client is using, and send to the client data (the WLD or the SWLD) suitable for such client.

[0286] Also, whether to receive a WLD or a SWLD may be switched in accordance with the speed of traveling. FIG. 15 is a diagram showing an example operation in such case. For example, when traveling at a high speed (S331), a client receives the SWLD from the server (S332). Meanwhile, when traveling at a low speed (S333), the client receives the WLD from the server (S334). This enables the client to obtain map information suitable to the speed, while reducing the network bandwidth. More specifically, when traveling on an expressway, the client receives the SWLD with a small data amount, which enables the update of rough map information at an appropriate speed. Meanwhile, when traveling on a general road, the client receives the WLD, which enables the obtainment of more detailed map information.

[0287] As described above, the client may request the server for a WLD or a SWLD in accordance with the traveling speed of such client. Alternatively, the client may send to the server information indicating the traveling speed of such client, and the server may send to the client data (the WLD or the SWLD) suitable to such client in accordance with the information. Alternatively, the server may identify the traveling speed of the client to send data (the WLD or the SWLD) suitable to such client.

[0288] Also, the client may obtain, from the server, a SWLD first, from which the client may obtain a WLD of an important region. For example, when obtaining map information, the client first obtains a SWLD for rough map information, from which the client narrows to a region in which features such as buildings, signals, or persons appear at high frequency so that the client can later obtain a WLD of such narrowed region. This enables the client to obtain detailed information on a necessary region, while reducing the amount of data received from the server.

[0289] The server may also create from a WLD different SWLDs for the respective objects, and the client may receive SWLDs in accordance with the intended use. This reduces the network bandwidth. For example, the server recognizes persons or cars in a WLD in advance, and creates a SWLD of persons and a SWLD of cars. The client, when wishing to obtain information on persons around the client, receives the SWLD of persons, and when wishing to obtain information on cars, receives the SWLD of cars. Such types of SWLDs may be distinguished by information (flag, or type, etc.) added to the header, etc.

[0290] Next, the structure and the operation flow of the three-dimensional data encoding device (e.g., a server) according to the present embodiment will be described. FIG. 16 is a block diagram of three-dimensional data encoding device 400 according to the present embodiment. FIG. 17 is a flowchart of three-dimensional data encoding processes performed by three-dimensional data encoding device 400.

[0291] Three-dimensional data encoding device 400 shown in FIG. 16 encodes input three-dimensional data 411, thereby generating encoded three-dimensional data 413 and encoded three-dimensional data 414, each being an encoded stream. Here, encoded three-dimensional data 413 is encoded three-dimensional data corresponding to a WLD, and encoded three-dimensional data 414 is encoded three-dimensional data corresponding to a SWLD. Such three-dimensional data encoding device 400 includes, obtainer

401, encoding region determiner 402, SWLD extractor 403, WLD encoder 404, and SWLD encoder 405.

[0292] First, as FIG. 17 shows, obtainer 401 obtains input three-dimensional data 411, which is point group data in a three-dimensional space (S401).

[0293] Next, encoding region determiner 402 determines a current spatial region for encoding on the basis of a spatial region in which the point cloud data is present (S402).

[0294] Next, SWLD extractor 403 defines the current spatial region as a WLD, and calculates the feature from each VXL included in the WLD. Then, SWLD extractor 403 extracts VXLs having an amount of features greater than or equal to a predetermined threshold, defines the extracted VXLs as FVXLs, and adds such FVXLs to a SWLD, thereby generating extracted three-dimensional data 412 (S403). Stated differently, extracted three-dimensional data 412 having an amount of features greater than or equal to the threshold is extracted from input three-dimensional data 411.

[0295] Next, WLD encoder 404 encodes input three-dimensional data 411 corresponding to the WLD, thereby generating encoded three-dimensional data 413 corresponding to the WLD (S404). In so doing, WLD encoder 404 adds to the header of encoded three-dimensional data 413 information that distinguishes that such encoded three-dimensional data 413 is a stream including a WLD.

[0296] SWLD encoder 405 encodes extracted three-dimensional data 412 corresponding to the SWLD, thereby generating encoded three-dimensional data 414 corresponding to the SWLD (S405). In so doing, SWLD encoder 405 adds to the header of encoded three-dimensional data 414 information that distinguishes that such encoded three-dimensional data 414 is a stream including a SWLD.

[0297] Note that the process of generating encoded three-dimensional data 413 and the process of generating encoded three-dimensional data 414 may be performed in the reverse order. Also note that a part or all of these processes may be performed in parallel.

[0298] A parameter “world\_type” is defined, for example, as information added to each header of encoded three-dimensional data 413 and encoded three-dimensional data 414. world\_type=0 indicates that a stream includes a WLD, and world\_type=1 indicates that a stream includes a SWLD. An increased number of values may be further assigned to define a larger number of types, e.g., world\_type=2. Also, one of encoded three-dimensional data 413 and encoded three-dimensional data 414 may include a specified flag. For example, encoded three-dimensional data 414 may be assigned with a flag indicating that such stream includes a SWLD. In such a case, the decoding device can distinguish whether such stream is a stream including a WLD or a stream including a SWLD in accordance with the presence/absence of the flag.

[0299] Also, an encoding method used by WLD encoder 404 to encode a WLD may be different from an encoding method used by SWLD encoder 405 to encode a SWLD.

[0300] For example, data of a SWLD is decimated, and thus can have a lower correlation with the neighboring data than that of a WLD. For this reason, of intra prediction and inter prediction, inter prediction may be more preferentially performed in an encoding method used for a SWLD than in an encoding method used for a WLD.

[0301] Also, an encoding method used for a SWLD and an encoding method used for a WLD may represent three-

dimensional positions differently. For example, three-dimensional coordinates may be used to represent the three-dimensional positions of FVXLs in a SWLD and an octree described below may be used to represent three-dimensional positions in a WLD, and vice versa.

[0302] Also, SWLD encoder 405 performs encoding in a manner that encoded three-dimensional data 414 of a SWLD has a smaller data size than the data size of encoded three-dimensional data 413 of a WLD. A SWLD can have a lower inter-data correlation, for example, than that of a WLD as described above. This can lead to a decreased encoding efficiency, and thus to encoded three-dimensional data 414 having a larger data size than the data size of encoded three-dimensional data 413 of a WLD. When the data size of the resulting encoded three-dimensional data 414 is larger than the data size of encoded three-dimensional data 413 of a WLD, SWLD encoder 405 performs encoding again to re-generate encoded three-dimensional data 414 having a reduced data size.

[0303] For example, SWLD extractor 403 re-generates extracted three-dimensional data 412 having a reduced number of keypoints to be extracted, and SWLD encoder 405 encodes such extracted three-dimensional data 412. Alternatively, SWLD encoder 405 may perform more coarse quantization. More coarse quantization is achieved, for example, by rounding the data in the lowermost level in an octree structure described below.

[0304] When failing to decrease the data size of encoded three-dimensional data 414 of the SWLD to smaller than the data size of encoded three-dimensional data 413 of the WLD, SWLD encoder 405 may not generate encoded three-dimensional data 414 of the SWLD. Alternatively, encoded three-dimensional data 413 of the WLD may be copied as encoded three-dimensional data 414 of the SWLD. Stated differently, encoded three-dimensional data 413 of the WLD may be used as it is as encoded three-dimensional data 414 of the SWLD.

[0305] Next, the structure and the operation flow of the three-dimensional data decoding device (e.g., a client) according to the present embodiment will be described. FIG. 18 is a block diagram of three-dimensional data decoding device 500 according to the present embodiment. FIG. 19 is a flowchart of three-dimensional data decoding processes performed by three-dimensional data decoding device 500.

[0306] Three-dimensional data decoding device 500 shown in FIG. 18 decodes encoded three-dimensional data 511, thereby generating decoded three-dimensional data 512 or decoded three-dimensional data 513. Encoded three-dimensional data 511 here is, for example, encoded three-dimensional data 413 or encoded three-dimensional data 414 generated by three-dimensional data encoding device 400.

[0307] Such three-dimensional data decoding device 500 includes obtainer 501, header analyzer 502, WLD decoder 503, and SWLD decoder 504.

[0308] First, as FIG. 19 shows, obtainer 501 obtains encoded three-dimensional data 511 (S501). Next, header analyzer 502 analyzes the header of encoded three-dimensional data 511 to identify whether encoded three-dimensional data 511 is a stream including a WLD or a stream including a SWLD (S502). For example, the above-described parameter world\_type is referred to in making such identification.

[0309] When encoded three-dimensional data 511 is a stream including a WLD (Yes in S503), WLD decoder 503

decodes encoded three-dimensional data 511, thereby generating decoded three-dimensional data 512 of the WLD (S504). Meanwhile, when encoded three-dimensional data 511 is a stream including a SWLD (No in S503), SWLD decoder 504 decodes encoded three-dimensional data 511, thereby generating decoded three-dimensional data 513 of the SWLD (S505).

[0310] Also, as in the case of the encoding device, a decoding method used by WLD decoder 503 to decode a WLD may be different from a decoding method used by SWLD decoder 504 to decode a SWLD. For example, of intra prediction and inter prediction, inter prediction may be more preferentially performed in a decoding method used for a SWLD than in a decoding method used for a WLD.

[0311] Also, a decoding method used for a SWLD and a decoding method used for a WLD may represent three-dimensional positions differently. For example, three-dimensional coordinates may be used to represent the three-dimensional positions of FVXLs in a SWLD and an octree described below may be used to represent three-dimensional positions in a WLD, and vice versa.

[0312] Next, an octree representation will be described, which is a method of representing three-dimensional positions. VXL data included in three-dimensional data is converted into an octree structure before encoded. FIG. 20 is a diagram showing example VXLs in a WLD. FIG. 21 is a diagram showing an octree structure of the WLD shown in FIG. 20. An example shown in FIG. 20 illustrates three VXLs 1 to 3 that include point groups (hereinafter referred to as effective VXLs). As FIG. 21 shows, the octree structure is made of nodes and leaves. Each node has a maximum of eight nodes or leaves. Each leaf has VXL information. Here, of the leaves shown in FIG. 21, leaf 1, leaf 2, and leaf 3 represent VXL1, VXL2, and VXL3 shown in FIG. 20, respectively.

[0313] More specifically, each node and each leaf correspond to a three-dimensional position. Node 1 corresponds to the entire block shown in FIG. 20. The block that corresponds to node 1 is divided into eight blocks. Of these eight blocks, blocks including effective VXLs are set as nodes, while the other blocks are set as leaves. Each block that corresponds to a node is further divided into eight nodes or leaves. These processes are repeated by the number of times that is equal to the number of levels in the octree structure. All blocks in the lowermost level are set as leaves.

[0314] FIG. 22 is a diagram showing an example SWLD generated from the WLD shown in FIG. 20. VXL1 and VXL2 shown in FIG. 20 are judged as FVXL1 and FVXL2 as a result of feature extraction, and thus are added to the SWLD. Meanwhile, VXL3 is not judged as a FVXL, and thus is not added to the SWLD. FIG. 23 is a diagram showing an octree structure of the SWLD shown in FIG. 22. In the octree structure shown in FIG. 23, leaf 3 corresponding to VXL3 shown in FIG. 21 is deleted. Consequently, node 3 shown in FIG. 21 has lost an effective VXL, and has changed to a leaf. As described above, a SWLD has a smaller number of leaves in general than a WLD does, and thus the encoded three-dimensional data of the SWLD is smaller than the encoded three-dimensional data of the WLD.

[0315] The following describes variations of the present embodiment.

[0316] For self-location estimation, for example, a client, being a vehicle-mounted device, etc., may receive a SWLD

from the server to use such SWLD to estimate the self-location. Meanwhile, for obstacle detection, the client may detect obstacles by use of three-dimensional information on the periphery obtained by such client through various means including a distance sensor such as a rangefinder, as well as a stereo camera and a combination of a plurality of monocular cameras.

[0317] In general, a SWLD is less likely to include VXL data on a flat region. As such, the server may hold a subsample world (subWLD) obtained by subsampling a WLD for detection of static obstacles, and send to the client the SWLD and the subWLD. This enables the client to perform self-location estimation and obstacle detection on the client's part, while reducing the network bandwidth.

[0318] When the client renders three-dimensional map data at a high speed, map information having a mesh structure is more useful in some cases. As such, the server may generate a mesh from a WLD to hold it beforehand as a mesh world (MWLD). For example, when wishing to perform coarse three-dimensional rendering, the client receives a MWLD, and when wishing to perform detailed three-dimensional rendering, the client receives a WLD. This reduces the network bandwidth.

[0319] In the above description, the server sets, as FVXLS, VXLs having an amount of features greater than or equal to the threshold, but the server may calculate FVXLS by a different method. For example, the server may judge that a VXL, a VLM, a SPC, or a GOS that constitutes a signal, or an intersection, etc. as necessary for self-location estimation, driving assist, or self-driving, etc., and incorporate such VXL, VLM, SPC, or GOS into a SWLD as a FVXL, a FVLM, a FSPLC, or a FGOS. Such judgment may be made manually. Also, FVXLS, etc. that have been set on the basis of an amount of features may be added to FVXLS, etc. obtained by the above method. Stated differently, SWLD extractor 403 may further extract, from input three-dimensional data 411, data corresponding to an object having a predetermined attribute as extracted three-dimensional data 412.

[0320] Also, that a VXL, a VLM, a SPC, or a GOS is necessary for such intended usage may be labeled separately from the features. The server may separately hold, as an upper layer of a SWLD (e.g., a lane world), FVXLS of a signal or an intersection, etc. necessary for self-location estimation, driving assist, or self-driving, etc.

[0321] The server may also add an attribute to VXLs in a WLD on a random access basis or on a predetermined unit basis. An attribute, for example, includes information indicating whether VXLs are necessary for self-location estimation, or information indicating whether VXLs are important as traffic information such as a signal, or an intersection, etc. An attribute may also include a correspondence between VXLs and features (intersection, or road, etc.) in lane information (geographic data files (GDF), etc.).

[0322] A method as described below may be used to update a WLD or a SWLD.

[0323] Update information indicating changes, etc. in a person, a roadwork, or a tree line (for trucks) is uploaded to the server as point groups or meta data. The server updates a WLD on the basis of such uploaded information, and then updates a SWLD by use of the updated WLD.

[0324] The client, when detecting a mismatch between the three-dimensional information such client has generated at the time of self-location estimation and the three-dimen-

sional information received from the server, may send to the server the three-dimensional information such client has generated, together with an update notification. In such a case, the server updates the SWLD by use of the WLD. When the SWLD is not to be updated, the server judges that the WLD itself is old.

[0325] In the above description, information that distinguishes whether an encoded stream is that of a WLD or a SWLD is added as header information of the encoded stream. However, when there are many types of worlds such as a mesh world and a lane world, information that distinguishes these types of the worlds may be added to header information. Also, when there are many SWLDs with different amounts of features, information that distinguishes the respective SWLDs may be added to header information.

[0326] In the above description, a SWLD is constituted by FVXLS, but a SWLD may include VXLs that have not been judged as FVXLS. For example, a SWLD may include an adjacent VXL used to calculate the feature of a FVXL. This enables the client to calculate the feature of a FVXL when receiving a SWLD, even in the case where feature information is not added to each FVXL of the SWLD. In such a case, the SWLD may include information that distinguishes whether each VXL is a FVXL or a VXL.

[0327] As described above, three-dimensional data encoding device 400 extracts, from input three-dimensional data 411 (first three-dimensional data), extracted three-dimensional data 412 (second three-dimensional data) having an amount of a feature greater than or equal to a threshold, and encodes extracted three-dimensional data 412 to generate encoded three-dimensional data 414 (first encoded three-dimensional data).

[0328] This three-dimensional data encoding device 400 generates encoded three-dimensional data 414 that is obtained by encoding data having an amount of a feature greater than or equal to the threshold. This reduces the amount of data compared to the case where input three-dimensional data 411 is encoded as it is. Three-dimensional data encoding device 400 is thus capable of reducing the amount of data to be transmitted.

[0329] Three-dimensional data encoding device 400 further encodes input three-dimensional data 411 to generate encoded three-dimensional data 413 (second encoded three-dimensional data).

[0330] This three-dimensional data encoding device 400 enables selective transmission of encoded three-dimensional data 413 and encoded three-dimensional data 414, in accordance, for example, with the intended use, etc.

[0331] Also, extracted three-dimensional data 412 is encoded by a first encoding method, and input three-dimensional data 411 is encoded by a second encoding method different from the first encoding method.

[0332] This three-dimensional data encoding device 400 enables the use of an encoding method suitable for each of input three-dimensional data 411 and extracted three-dimensional data 412.

[0333] Also, of intra prediction and inter prediction, the inter prediction is more preferentially performed in the first encoding method than in the second encoding method.

[0334] This three-dimensional data encoding device 400 enables inter prediction to be more preferentially performed on extracted three-dimensional data 412 in which adjacent data items are likely to have low correlation.

[0335] Also, the first encoding method and the second encoding method represent three-dimensional positions differently. For example, the second encoding method represents three-dimensional positions by octree, and the first encoding method represents three-dimensional positions by three-dimensional coordinates.

[0336] This three-dimensional data encoding device 400 enables the use of a more suitable method to represent the three-dimensional positions of three-dimensional data in consideration of the difference in the number of data items (the number of VXLs or FVXLs) included.

[0337] Also, at least one of encoded three-dimensional data 413 and encoded three-dimensional data 414 includes an identifier indicating whether the encoded three-dimensional data is encoded three-dimensional data obtained by encoding input three-dimensional data 411 or encoded three-dimensional data obtained by encoding part of input three-dimensional data 411. Stated differently, such identifier indicates whether the encoded three-dimensional data is encoded three-dimensional data 413 of a WLD or encoded three-dimensional data 414 of a SWLD.

[0338] This enables the decoding device to readily judge whether the obtained encoded three-dimensional data is encoded three-dimensional data 413 or encoded three-dimensional data 414.

[0339] Also, three-dimensional data encoding device 400 encodes extracted three-dimensional data 412 in a manner that encoded three-dimensional data 414 has a smaller data amount than a data amount of encoded three-dimensional data 413.

[0340] This three-dimensional data encoding device 400 enables encoded three-dimensional data 414 to have a smaller data amount than the data amount of encoded three-dimensional data 413.

[0341] Also, three-dimensional data encoding device 400 further extracts data corresponding to an object having a predetermined attribute from input three-dimensional data 411 as extracted three-dimensional data 412. The object having a predetermined attribute is, for example, an object necessary for self-location estimation, driving assist, or self-driving, etc., or more specifically, a signal, an intersection, etc.

[0342] This three-dimensional data encoding device 400 is capable of generating encoded three-dimensional data 414 that includes data required by the decoding device.

[0343] Also, three-dimensional data encoding device 400 (server) further sends, to a client, one of encoded three-dimensional data 413 and encoded three-dimensional data 414 in accordance with a status of the client.

[0344] This three-dimensional data encoding device 400 is capable of sending appropriate data in accordance with the status of the client.

[0345] Also, the status of the client includes one of a communication condition (e.g., network bandwidth) of the client and a traveling speed of the client.

[0346] Also, three-dimensional data encoding device 400 further sends, to a client, one of encoded three-dimensional data 413 and encoded three-dimensional data 414 in accordance with a request from the client.

[0347] This three-dimensional data encoding device 400 is capable of sending appropriate data in accordance with the request from the client.

[0348] Also, three-dimensional data decoding device 500 according to the present embodiment decodes encoded

three-dimensional data 413 or encoded three-dimensional data 414 generated by three-dimensional data encoding device 400 described above.

[0349] Stated differently, three-dimensional data decoding device 500 decodes, by a first decoding method, encoded three-dimensional data 414 obtained by encoding extracted three-dimensional data 412 having an amount of a feature greater than or equal to a threshold, extracted three-dimensional data 412 having been extracted from input three-dimensional data 411. Three-dimensional data decoding device 500 also decodes, by a second decoding method, encoded three-dimensional data 413 obtained by encoding input three-dimensional data 411, the second decoding method being different from the first decoding method.

[0350] This three-dimensional data decoding device 500 enables selective reception of encoded three-dimensional data 414 obtained by encoding data having an amount of a feature greater than or equal to the threshold and encoded three-dimensional data 413, in accordance, for example, with the intended use, etc. Three-dimensional data decoding device 500 is thus capable of reducing the amount of data to be transmitted. Such three-dimensional data decoding device 500 further enables the use of a decoding method suitable for each of input three-dimensional data 411 and extracted three-dimensional data 412.

[0351] Also, of intra prediction and inter prediction, the inter prediction is more preferentially performed in the first decoding method than in the second decoding method.

[0352] This three-dimensional data decoding device 500 enables inter prediction to be more preferentially performed on the extracted three-dimensional data in which adjacent data items are likely to have low correlation.

[0353] Also, the first decoding method and the second decoding method represent three-dimensional positions differently. For example, the second decoding method represents three-dimensional positions by octree, and the first decoding method represents three-dimensional positions by three-dimensional coordinates.

[0354] This three-dimensional data decoding device 500 enables the use of a more suitable method to represent the three-dimensional positions of three-dimensional data in consideration of the difference in the number of data items (the number of VXLs or FVXLs) included.

[0355] Also, at least one of encoded three-dimensional data 413 and encoded three-dimensional data 414 includes an identifier indicating whether the encoded three-dimensional data is encoded three-dimensional data obtained by encoding input three-dimensional data 411 or encoded three-dimensional data obtained by encoding part of input three-dimensional data 411. Three-dimensional data decoding device 500 refers to such identifier in identifying between encoded three-dimensional data 413 and encoded three-dimensional data 414.

[0356] This three-dimensional data decoding device 500 is capable of readily judging whether the obtained encoded three-dimensional data is encoded three-dimensional data 413 or encoded three-dimensional data 414.

[0357] Three-dimensional data decoding device 500 further notifies a server of a status of the client (three-dimensional data decoding device 500). Three-dimensional data decoding device 500 receives one of encoded three-dimensional data 413 and encoded three-dimensional data 414 from the server, in accordance with the status of the client.

[0358] This three-dimensional data decoding device **500** is capable of receiving appropriate data in accordance with the status of the client.

[0359] Also, the status of the client includes one of a communication condition (e.g., network bandwidth) of the client and a traveling speed of the client.

[0360] Three-dimensional data decoding device **500** further makes a request of the server for one of encoded three-dimensional data **413** and encoded three-dimensional data **414**, and receives one of encoded three-dimensional data **413** and encoded three-dimensional data **414** from the server, in accordance with the request.

[0361] This three-dimensional data decoding device **500** is capable of receiving appropriate data in accordance with the intended use.

### Embodiment 3

[0362] The present embodiment will describe a method of transmitting/receiving three-dimensional data between vehicles. For example, the three-dimensional data is transmitted/received between the own vehicle and the nearby vehicle.

[0363] FIG. 24 is a block diagram of three-dimensional data creation device **620** according to the present embodiment. Such three-dimensional data creation device **620**, which is included, for example, in the own vehicle, merges first three-dimensional data **632** created by three-dimensional data creation device **620** with the received second three-dimensional data **635**, thereby creating third three-dimensional data **636** having a higher density.

[0364] Such three-dimensional data creation device **620** includes three-dimensional data creator **621**, request range determiner **622**, searcher **623**, receiver **624**, decoder **625**, and merger **626**.

[0365] First, three-dimensional data creator **621** creates first three-dimensional data **632** by use of sensor information **631** detected by the sensor included in the own vehicle. Next, request range determiner **622** determines a request range, which is the range of a three-dimensional space, the data on which is insufficient in the created first three-dimensional data **632**.

[0366] Next, searcher **623** searches for the nearby vehicle having the three-dimensional data of the request range, and sends request range information **633** indicating the request range to nearby vehicle **601** having been searched out (S623). Next, receiver **624** receives encoded three-dimensional data **634**, which is an encoded stream of the request range, from nearby vehicle **601** (S624). Note that searcher **623** may indiscriminately send requests to all vehicles included in a specified range to receive encoded three-dimensional data **634** from a vehicle that has responded to the request. Searcher **623** may send a request not only to vehicles but also to an object such as a signal and a sign, and receive encoded three-dimensional data **634** from the object.

[0367] Next, decoder **625** decodes the received encoded three-dimensional data **634**, thereby obtaining second three-dimensional data **635**. Next, merger **626** merges first three-dimensional data **632** with second three-dimensional data **635**, thereby creating three-dimensional data **636** having a higher density.

[0368] Next, the structure and operations of three-dimensional data transmission device **640** according to the present embodiment will be described. FIG. 25 is a block diagram of three-dimensional data transmission device **640**.

[0369] Three-dimensional data transmission device **640** is included, for example, in the above-described nearby vehicle. Three-dimensional data transmission device **640** processes fifth three-dimensional data **652** created by the nearby vehicle into sixth three-dimensional data **654** requested by the own vehicle, encodes sixth three-dimensional data **654** to generate encoded three-dimensional data **634**, and sends encoded three-dimensional data **634** to the own vehicle.

[0370] Three-dimensional data transmission device **640** includes three-dimensional data creator **641**, receiver **642**, extractor **643**, encoder **644**, and transmitter **645**.

[0371] First, three-dimensional data creator **641** creates fifth three-dimensional data **652** by use of sensor information **651** detected by the sensor included in the nearby vehicle. Next, receiver **642** receives request range information **633** from the own vehicle.

[0372] Next, extractor **643** extracts from fifth three-dimensional data **652** the three-dimensional data of the request range indicated by request range information **633**, thereby processing fifth three-dimensional data **652** into sixth three-dimensional data **654**. Next, encoder **644** encodes sixth three-dimensional data **654** to generate encoded three-dimensional data **643**, which is an encoded stream. Then, transmitter **645** sends encoded three-dimensional data **634** to the own vehicle.

[0373] Note that although an example case is described here in which the own vehicle includes three-dimensional data creation device **620** and the nearby vehicle includes three-dimensional data transmission device **640**, each of the vehicles may include the functionality of both three-dimensional data creation device **620** and three-dimensional data transmission device **640**.

### Embodiment 4

[0374] The present embodiment describes operations performed in abnormal cases when self-location estimation is performed on the basis of a three-dimensional map.

[0375] A three-dimensional map is expected to find its expanded use in self-driving of a vehicle and autonomous movement, etc. of a mobile object such as a robot and a flying object (e.g., a drone). Example means for enabling such autonomous movement include a method in which a mobile object travels in accordance with a three-dimensional map, while estimating its self-location on the map (self-location estimation).

[0376] The self-location estimation is enabled by matching a three-dimensional map with three-dimensional information on the surrounding of the own vehicle (hereinafter referred to as self-detected three-dimensional data) obtained by a sensor equipped in the own vehicle, such as a rangefinder (e.g., a LIDAR) and a stereo camera to estimate the location of the own vehicle on the three-dimensional map.

[0377] As in the case of an HD map suggested by HERE Technologies, for example, a three-dimensional map may include not only a three-dimensional point cloud, but also two-dimensional map data such as information on the shapes of roads and intersections, or information that changes in real-time such as information on a traffic jam and an accident. A three-dimensional map includes a plurality of layers such as layers of three-dimensional data, two-dimen-

sional data, and meta-data that changes in real-time, from among which the device can obtain or refer to only necessary data.

[0378] Point cloud data may be a SWLD as described above, or may include point group data that is different from keypoints. The transmission/reception of point cloud data is basically carried out in one or more random access units.

[0379] A method described below is used as a method of matching a three-dimensional map with self-detected three-dimensional data. For example, the device compares the shapes of the point groups in each other's point clouds, and determines that portions having a high degree of similarity among keypoints correspond to the same position. When the three-dimensional map is formed by a SWLD, the device also performs matching by comparing the keypoints that form the SWLD with three-dimensional keypoints extracted from the self-detected three-dimensional data.

[0380] Here, to enable highly accurate self-location estimation, the following needs to be satisfied: (A) the three-dimensional map and the self-detected three-dimensional data have been already obtained; and (B) their accuracies satisfy a predetermined requirement. However, one of (A) and (B) cannot be satisfied in abnormal cases such as ones described below.

[0381] 1. A three-dimensional map is unobtainable over communication.

[0382] 2. A three-dimensional map is not present, or a three-dimensional map having been obtained is corrupt.

[0383] 3. A sensor of the own vehicle has trouble, or the accuracy of the generated self-detected three-dimensional data is inadequate due to bad weather.

[0384] The following describes operations to cope with such abnormal cases. The following description illustrates an example case of a vehicle, but the method described below is applicable to mobile objects on the whole that are capable of autonomous movement, such as a robot and a drone.

[0385] The following describes the structure of the three-dimensional information processing device and its operation according to the present embodiment capable of coping with abnormal cases regarding a three-dimensional map or self-detected three-dimensional data. FIG. 26 is a block diagram of an example structure of three-dimensional information processing device 700 according to the present embodiment.

[0386] Three-dimensional information processing device 700 is equipped, for example, in a mobile object such as a car. As shown in FIG. 26, three-dimensional information processing device 700 includes three-dimensional map obtainer 701, self-detected data obtainer 702, abnormal case judgment unit 703, coping operation determiner 704, and operation controller 705.

[0387] Note that three-dimensional information processing device 700 may include a non-illustrated two-dimensional or one-dimensional sensor that detects a structural object or a mobile object around the own vehicle, such as a camera capable of obtaining two-dimensional images and a sensor for one-dimensional data utilizing ultrasonic or laser. Three-dimensional information processing device 700 may also include a non-illustrated communication unit that obtains a three-dimensional map over a mobile communication network, such as 4G and 5G, or via inter-vehicle communication or road-to-vehicle communication.

[0388] Three-dimensional map obtainer 701 obtains three-dimensional map 711 of the surroundings of the traveling

route. For example, three-dimensional map obtainer 701 obtains three-dimensional map 711 over a mobile communication network, or via inter-vehicle communication or road-to-vehicle communication.

[0389] Next, self-detected data obtainer 702 obtains self-detected three-dimensional data 712 on the basis of sensor information. For example, self-detected data obtainer 702 generates self-detected three-dimensional data 712 on the basis of the sensor information obtained by a sensor equipped in the own vehicle.

[0390] Next, abnormal case judgment unit 703 conducts a predetermined check of at least one of obtained three-dimensional map 711 and self-detected three-dimensional data 712 to detect an abnormal case. Stated differently, abnormal case judgment unit 703 judges whether at least one of obtained three-dimensional map 711 and self-detected three-dimensional data 712 is abnormal.

[0391] When the abnormal case is detected, coping operation determiner 704 determines a coping operation to cope with such abnormal case. Next, operation controller 705 controls the operation of each of the processing units necessary to perform the coping operation.

[0392] Meanwhile, when no abnormal case is detected, three-dimensional information processing device 700 terminates the process.

[0393] Also, three-dimensional information processing device 700 estimates the location of the vehicle equipped with three-dimensional information processing device 700, using three-dimensional map 711 and self-detected three-dimensional data 712. Next, three-dimensional information processing device 700 performs the automatic operation of the vehicle by use of the estimated location of the vehicle.

[0394] As described above, three-dimensional information processing device 700 obtains, via a communication channel, map data (three-dimensional map 711) that includes first three-dimensional position information. The first three-dimensional position information includes, for example, a plurality of random access units, each of which is an assembly of at least one subspace and is individually decodable, the at least one subspace having three-dimensional coordinates information and serving as a unit in which each of the plurality of random access units is encoded. The first three-dimensional position information is, for example, data (SWLD) obtained by encoding keypoints, each of which has an amount of a three-dimensional feature greater than or equal to a predetermined threshold.

[0395] Three-dimensional information processing device 700 also generates second three-dimensional position information (self-detected three-dimensional data 712) from information detected by a sensor. Three-dimensional information processing device 700 then judges whether one of the first three-dimensional position information and the second three-dimensional position information is abnormal by performing, on one of the first three-dimensional position information and the second three-dimensional position information, a process of judging whether an abnormality is present.

[0396] Three-dimensional information processing device 700 determines a coping operation to cope with the abnormality when one of the first three-dimensional position information and the second three-dimensional position information is judged to be abnormal. Three-dimensional information processing device 700 then executes a control that is required to perform the coping operation.

[0397] This structure enables three-dimensional information processing device 700 to detect an abnormality regarding one of the first three-dimensional position information and the second three-dimensional position information, and to perform a coping operation therefor.

#### Embodiment 5

[0398] The present embodiment describes a method, etc. of transmitting three-dimensional data to a following vehicle.

[0399] FIG. 27 is a block diagram of an exemplary structure of three-dimensional data creation device 810 according to the present embodiment. Such three-dimensional data creation device 810 is equipped, for example, in a vehicle. Three-dimensional data creation device 810 transmits and receives three-dimensional data to and from an external cloud-based traffic monitoring system, a preceding vehicle, or a following vehicle, and creates and stores three-dimensional data.

[0400] Three-dimensional data creation device 810 includes data receiver 811, communication unit 812, reception controller 813, format converter 814, a plurality of sensors 815, three-dimensional data creator 816, three-dimensional data synthesizer 817, three-dimensional data storage 818, communication unit 819, transmission controller 820, format converter 821, and data transmitter 822.

[0401] Data receiver 811 receives three-dimensional data 831 from a cloud-based traffic monitoring system or a preceding vehicle. Three-dimensional data 831 includes, for example, information on a region undetectable by sensors 815 of the own vehicle, such as a point cloud, visible light video, depth information, sensor position information, and speed information.

[0402] Communication unit 812 communicates with the cloud-based traffic monitoring system or the preceding vehicle to transmit a data transmission request, etc. to the cloud-based traffic monitoring system or the preceding vehicle.

[0403] Reception controller 813 exchanges information, such as information on supported formats, with a communications partner via communication unit 812 to establish communication with the communications partner.

[0404] Format converter 814 applies format conversion, etc. on three-dimensional data 831 received by data receiver 811 to generate three-dimensional data 832. Format converter 814 also decompresses or decodes three-dimensional data 831 when three-dimensional data 831 is compressed or encoded.

[0405] A plurality of sensors 815 are a group of sensors, such as visible light cameras and infrared cameras, that obtain information on the outside of the vehicle and generate sensor information 833. Sensor information 833 is, for example, three-dimensional data such as a point cloud (point group data), when sensors 815 are laser sensors such as LIDARs. Note that a single sensor may serve as a plurality of sensors 815.

[0406] Three-dimensional data creator 816 generates three-dimensional data 834 from sensor information 833. Three-dimensional data 834 includes, for example, information such as a point cloud, visible light video, depth information, sensor position information, and speed information.

[0407] Three-dimensional data synthesizer 817 synthesizes three-dimensional data 834 created on the basis of sensor information 833 of the own vehicle with three-

dimensional data 832 created by the cloud-based traffic monitoring system or the preceding vehicle, etc., thereby forming three-dimensional data 835 of a space that includes the space ahead of the preceding vehicle undetectable by sensors 815 of the own vehicle.

[0408] Three-dimensional data storage 818 stores generated three-dimensional data 835, etc.

[0409] Communication unit 819 communicates with the cloud-based traffic monitoring system or the following vehicle to transmit a data transmission request, etc. to the cloud-based traffic monitoring system or the following vehicle.

[0410] Transmission controller 820 exchanges information such as information on supported formats with a communications partner via communication unit 819 to establish communication with the communications partner. Transmission controller 820 also determines a transmission region, which is a space of the three-dimensional data to be transmitted, on the basis of three-dimensional data 832 generated by three-dimensional data synthesizer 817 and the data transmission request from the communications partner.

[0411] More specifically, transmission controller 820 determines a transmission region that includes the space ahead of the own vehicle undetectable by a sensor of the following vehicle, in response to the data transmission request from the cloud-based traffic monitoring system or the following vehicle. Transmission controller 820 judges, for example, whether a space is transmittable or whether the already transmitted space includes an update, on the basis of the three-dimensional data formation information to determine a transmission region. For example, transmission controller 820 determines, as a transmission region, a region that is: a region specified by the data transmission request; and a region, corresponding three-dimensional data 835 of which is present. Transmission controller 820 then notifies format converter 821 of the format supported by the communications partner and the transmission region.

[0412] Of three-dimensional data 835 stored in three-dimensional data storage 818, format converter 821 converts three-dimensional data 836 of the transmission region into the format supported by the receiver end to generate three-dimensional data 837. Note that format converter 821 may compress or encode three-dimensional data 837 to reduce the data amount.

[0413] Data transmitter 822 transmits three-dimensional data 837 to the cloud-based traffic monitoring system or the following vehicle. Such three-dimensional data 837 includes, for example, information on a blind spot, which is a region hidden from view of the following vehicle, such as a point cloud ahead of the own vehicle, visible light video, depth information, and sensor position information.

[0414] Note that an example has been described in which format converter 814 and format converter 821 perform format conversion, etc., but format conversion may not be performed.

[0415] With the above structure, three-dimensional data creation device 810 obtains, from an external device, three-dimensional data 831 of a region undetectable by sensors 815 of the own vehicle, and synthesizes three-dimensional data 831 with three-dimensional data 834 that is based on sensor information 833 detected by sensors 815 of the own vehicle, thereby generating three-dimensional data 835. Three-dimensional data creation device 810 is thus capable

of generating three-dimensional data of a range undetectable by sensors **815** of the own vehicle.

**[0416]** Three-dimensional data creation device **810** is also capable of transmitting, to the cloud-based traffic monitoring system or the following vehicle, etc., three-dimensional data of a space that includes the space ahead of the own vehicle undetectable by a sensor of the following vehicle, in response to the data transmission request from the cloud-based traffic monitoring system or the following vehicle.

#### Embodiment 6

**[0417]** In embodiment 5, an example is described in which a client device of a vehicle or the like transmits three-dimensional data to another vehicle or a server such as a cloud-based traffic monitoring system. In the present embodiment, a client device transmits sensor information obtained through a sensor to a server or a client device.

**[0418]** A structure of a system according to the present embodiment will first be described. FIG. 28 is a diagram showing the structure of a transmission/reception system of a three-dimensional map and sensor information according to the present embodiment. This system includes server **901**, and client devices **902A** and **902B**. Note that client devices **902A** and **902B** are also referred to as client device **902** when no particular distinction is made therebetween.

**[0419]** Client device **902** is, for example, a vehicle-mounted device equipped in a mobile object such as a vehicle. Server **901** is, for example, a cloud-based traffic monitoring system, and is capable of communicating with the plurality of client devices **902**.

**[0420]** Server **901** transmits the three-dimensional map formed by a point cloud to client device **902**. Note that a structure of the three-dimensional map is not limited to a point cloud, and may also be another structure expressing three-dimensional data such as a mesh structure.

**[0421]** Client device **902** transmits the sensor information obtained by client device **902** to server **901**. The sensor information includes, for example, at least one of information obtained by LiDAR, a visible light image, an infrared image, a depth image, sensor position information, or sensor speed information.

**[0422]** The data to be transmitted and received between server **901** and client device **902** may be compressed in order to reduce data volume, and may also be transmitted uncompressed in order to maintain data precision. When compressing the data, it is possible to use a three-dimensional compression method on the point cloud based on, for example, an octree structure. It is possible to use a two-dimensional image compression method on the visible light image, the infrared image, and the depth image. The two-dimensional image compression method is, for example, MPEG-4 AVC or HEVC standardized by MPEG.

**[0423]** Server **901** transmits the three-dimensional map managed by server **901** to client device **902** in response to a transmission request for the three-dimensional map from client device **902**. Note that server **901** may also transmit the three-dimensional map without waiting for the transmission request for the three-dimensional map from client device **902**. For example, server **901** may broadcast the three-dimensional map to at least one client device **902** located in a predetermined space. Server **901** may also transmit the three-dimensional map suited to a position of client device **902** at fixed time intervals to client device **902** that has received the transmission request once. Server **901** may also

transmit the three-dimensional map managed by server **901** to client device **902** every time the three-dimensional map is updated.

**[0424]** Client device **902** sends the transmission request for the three-dimensional map to server **901**. For example, when client device **902** wants to perform the self-location estimation during traveling, client device **902** transmits the transmission request for the three-dimensional map to server **901**.

**[0425]** Note that in the following cases, client device **902** may send the transmission request for the three-dimensional map to server **901**. Client device **902** may send the transmission request for the three-dimensional map to server **901** when the three-dimensional map stored by client device **902** is old. For example, client device **902** may send the transmission request for the three-dimensional map to server **901** when a fixed period has passed since the three-dimensional map is obtained by client device **902**.

**[0426]** Client device **902** may also send the transmission request for the three-dimensional map to server **901** before a fixed time when client device **902** exits a space shown in the three-dimensional map stored by client device **902**. For example, client device **902** may send the transmission request for the three-dimensional map to server **901** when client device **902** is located within a predetermined distance from a boundary of the space shown in the three-dimensional map stored by client device **902**. When a movement path and a movement speed of client device **902** are understood, a time when client device **902** exits the space shown in the three-dimensional map stored by client device **902** may be predicted based on the movement path and the movement speed of client device **902**.

**[0427]** Client device **902** may also send the transmission request for the three-dimensional map to server **901** when an error during alignment of the three-dimensional data and the three-dimensional map created from the sensor information by client device **902** is at least at a fixed level.

**[0428]** Client device **902** transmits the sensor information to server **901** in response to a transmission request for the sensor information from server **901**. Note that client device **902** may transmit the sensor information to server **901** without waiting for the transmission request for the sensor information from server **901**. For example, client device **902** may periodically transmit the sensor information during a fixed period when client device **902** has received the transmission request for the sensor information from server **901** once. Client device **902** may determine that there is a possibility of a change in the three-dimensional map of a surrounding area of client device **902** having occurred, and transmit this information and the sensor information to server **901**, when the error during alignment of the three-dimensional data created by client device **902** based on the sensor information and the three-dimensional map obtained from server **901** is at least at the fixed level.

**[0429]** Server **901** sends a transmission request for the sensor information to client device **902**. For example, server **901** receives position information, such as GPS information, about client device **902** from client device **902**. Server **901** sends the transmission request for the sensor information to client device **902** in order to generate a new three-dimensional map, when it is determined that client device **902** is approaching a space in which the three-dimensional map managed by server **901** contains little information, based on the position information about client device **902**. Server **901**

may also send the transmission request for the sensor information, when wanting to (i) update the three-dimensional map, (ii) check road conditions during snowfall, a disaster, or the like, or (iii) check traffic congestion conditions, accident/incident conditions, or the like.

[0430] Client device 902 may set an amount of data of the sensor information to be transmitted to server 901 in accordance with communication conditions or bandwidth during reception of the transmission request for the sensor information to be received from server 901. Setting the amount of data of the sensor information to be transmitted to server 901 is, for example, increasing/reducing the data itself or appropriately selecting a compression method.

[0431] FIG. 29 is a block diagram showing an example structure of client device 902. Client device 902 receives the three-dimensional map formed by a point cloud and the like from server 901, and estimates a self-location of client device 902 using the three-dimensional map created based on the sensor information of client device 902. Client device 902 transmits the obtained sensor information to server 901.

[0432] Client device 902 includes data receiver 1011, communication unit 1012, reception controller 1013, format converter 1014, sensors 1015, three-dimensional data creator 1016, three-dimensional image processor 1017, three-dimensional data storage 1018, format converter 1019, communication unit 1020, transmission controller 1021, and data transmitter 1022.

[0433] Data receiver 1011 receives three-dimensional map 1031 from server 901. Three-dimensional map 1031 is data that includes a point cloud such as a WLD or a SWLD. Three-dimensional map 1031 may include compressed data or uncompressed data.

[0434] Communication unit 1012 communicates with server 901 and transmits a data transmission request (e.g., transmission request for three-dimensional map) to server 901.

[0435] Reception controller 1013 exchanges information, such as information on supported formats, with a communications partner via communication unit 1012 to establish communication with the communications partner.

[0436] Format converter 1014 performs a format conversion and the like on three-dimensional map 1031 received by data receiver 1011 to generate three-dimensional map 1032. Format converter 1014 also performs a decompression or decoding process when three-dimensional map 1031 is compressed or encoded. Note that format converter 1014 does not perform the decompression or decoding process when three-dimensional map 1031 is uncompressed data.

[0437] Sensors 815 are a group of sensors, such as LiDARs, visible light cameras, infrared cameras, or depth sensors that obtain information about the outside of a vehicle equipped with client device 902, and generate sensor information 1033. Sensor information 1033 is, for example, three-dimensional data such as a point cloud (point group data) when sensors 1015 are laser sensors such as LiDARs. Note that a single sensor may serve as sensors 1015.

[0438] Three-dimensional data creator 1016 generates three-dimensional data 1034 of a surrounding area of the own vehicle based on sensor information 1033. For example, three-dimensional data creator 1016 generates point cloud data with color information on the surrounding area of the own vehicle using information obtained by LiDAR and visible light video obtained by a visible light camera.

[0439] Three-dimensional image processor 1017 performs a self-location estimation process and the like of the own vehicle, using (i) the received three-dimensional map 1032 such as a point cloud, and (ii) three-dimensional data 1034 of the surrounding area of the own vehicle generated using sensor information 1033. Note that three-dimensional image processor 1017 may generate three-dimensional data 1035 about the surroundings of the own vehicle by merging three-dimensional map 1032 and three-dimensional data 1034, and may perform the self-location estimation process using the created three-dimensional data 1035.

[0440] Three-dimensional data storage 1018 stores three-dimensional map 1032, three-dimensional data 1034, three-dimensional data 1035, and the like.

[0441] Format converter 1019 generates sensor information 1037 by converting sensor information 1033 to a format supported by a receiver end. Note that format converter 1019 may reduce the amount of data by compressing or encoding sensor information 1037. Format converter 1019 may omit this process when format conversion is not necessary. Format converter 1019 may also control the amount of data to be transmitted in accordance with a specified transmission range.

[0442] Communication unit 1020 communicates with server 901 and receives a data transmission request (transmission request for sensor information) and the like from server 901.

[0443] Transmission controller 1021 exchanges information, such as information on supported formats, with a communications partner via communication unit 1020 to establish communication with the communications partner.

[0444] Data transmitter 1022 transmits sensor information 1037 to server 901. Sensor information 1037 includes, for example, information obtained through sensors 1015, such as information obtained by LiDAR, a luminance image obtained by a visible light camera, an infrared image obtained by an infrared camera, a depth image obtained by a depth sensor, sensor position information, and sensor speed information.

[0445] A structure of server 901 will be described next. FIG. 30 is a block diagram showing an example structure of server 901. Server 901 transmits sensor information from client device 902 and creates three-dimensional data based on the received sensor information. Server 901 updates the three-dimensional map managed by server 901 using the created three-dimensional data. Server 901 transmits the updated three-dimensional map to client device 902 in response to a transmission request for the three-dimensional map from client device 902.

[0446] Server 901 includes data receiver 1111, communication unit 1112, reception controller 1113, format converter 1114, three-dimensional data creator 1116, three-dimensional data merger 1117, three-dimensional data storage 1118, format converter 1119, communication unit 1120, transmission controller 1121, and data transmitter 1122.

[0447] Data receiver 1111 receives sensor information 1037 from client device 902. Sensor information 1037 includes, for example, information obtained by LiDAR, a luminance image obtained by a visible light camera, an infrared image obtained by an infrared camera, a depth image obtained by a depth sensor, sensor position information, sensor speed information, and the like.

[0448] Communication unit 1112 communicates with client device 902 and transmits a data transmission request (e.g. transmission request for sensor information) and the like to client device 902.

[0449] Reception controller 1113 exchanges information, such as information on supported formats, with a communications partner via communication unit 1112 to communication with the communications partner.

[0450] Format converter 1114 generates sensor information 1132 by performing a decompression or decoding process when received sensor information 1037 is compressed or encoded. Note that format converter 1114 does not perform the decompression or decoding process when sensor information 1037 is uncompressed data.

[0451] Three-dimensional data creator 1116 generates three-dimensional data 1134 of a surrounding area of client device 902 based on sensor information 1132. For example, three-dimensional data creator 1116 generates point cloud data with color information on the surrounding area of client device 902 using information obtained by LiDAR and visible light video obtained by a visible light camera.

[0452] Three-dimensional data merger 1117 updates three-dimensional map 1135 by merging three-dimensional data 1134 created based on sensor information 1132 with three-dimensional map 1135 managed by server 901.

[0453] Three-dimensional data storage 1118 stores three-dimensional map 1135 and the like.

[0454] Format converter 1119 generates three-dimensional map 1031 by converting three-dimensional map 1135 to a format supported by the receiver end. Note that format converter 1119 may reduce the amount of data by compressing or encoding three-dimensional map 1135. Format converter 1119 may omit this process when format conversion is not necessary. Format converter 1119 may also control the amount of data to be transmitted in accordance with a specified transmission range.

[0455] Communication unit 1120 communicates with client device 902 and receives a data transmission request (transmission request for three-dimensional map) and the like from client device 902.

[0456] Transmission controller 1121 exchanges information, such as information on supported formats, with a communications partner via communication unit 1120 to establish communication with the communications partner.

[0457] Data transmitter 1122 transmits three-dimensional map 1031 to client device 902. Three-dimensional map 1031 is data that includes a point cloud such as a WLD or a SWLD. Three-dimensional map 1031 may include one of compressed data and uncompressed data.

[0458] An operational flow of client device 902 will be described next. FIG. 31 is a flowchart of an operation when client device 902 obtains the three-dimensional map.

[0459] Client device 902 first requests server 901 to transmit the three-dimensional map (point cloud, etc.) (S1001). At this point, by also transmitting the position information about client device 902 obtained through GPS and the like, client device 902 may also request server 901 to transmit a three-dimensional map relating to this position information.

[0460] Client device 902 next receives the three-dimensional map from server 901 (S1002). When the received three-dimensional map is compressed data, client device 902 decodes the received three-dimensional map and generates an uncompressed three-dimensional map (S1003).

[0461] Client device 902 next creates three-dimensional data 1034 of the surrounding area of client device 902 using sensor information 1033 obtained by sensors 1015 (S1004). Client device 902 next estimates the self-location of client device 902 using three-dimensional map 1032 received from server 901 and three-dimensional data 1034 created using sensor information 1033 (S1005).

[0462] FIG. 32 is a flowchart of an operation when client device 902 transmits the sensor information. Client device 902 first receives a transmission request for the sensor information from server 901 (S1011). Client device 902 that has received the transmission request transmits sensor information 1037 to server 901 (S1012). Note that client device 902 may generate sensor information 1037 by compressing each piece of information using a compression method suited to each piece of information, when sensor information 1033 includes a plurality of pieces of information obtained by sensors 1015.

[0463] An operational flow of server 901 will be described next. FIG. 33 is a flowchart of an operation when server 901 obtains the sensor information. Server 901 first requests client device 902 to transmit the sensor information (S1021). Server 901 next receives sensor information 1037 transmitted from client device 902 in accordance with the request (S1022). Server 901 next creates three-dimensional data 1134 using the received sensor information 1037 (S1023). Server 901 next reflects the created three-dimensional data 1134 in three-dimensional map 1135 (S1024).

[0464] FIG. 34 is a flowchart of an operation when server 901 transmits the three-dimensional map. Server 901 first receives a transmission request for the three-dimensional map from client device 902 (S1031). Server 901 that has received the transmission request for the three-dimensional map transmits the three-dimensional map to client device 902 (S1032). At this point, server 901 may extract a three-dimensional map of a vicinity of client device 902 along with the position information about client device 902, and transmit the extracted three-dimensional map. Server 901 may compress the three-dimensional map formed by a point cloud using, for example, an octree structure compression method, and transmit the compressed three-dimensional map.

[0465] Hereinafter, variations of the present embodiment will be described.

[0466] Server 901 creates three-dimensional data 1134 of a vicinity of a position of client device 902 using sensor information 1037 received from client device 902. Server 901 next calculates a difference between three-dimensional data 1134 and three-dimensional map 1135, by matching the created three-dimensional data 1134 with three-dimensional map 1135 of the same area managed by server 901. Server 901 determines that a type of anomaly has occurred in the surrounding area of client device 902, when the difference is greater than or equal to a predetermined threshold. For example, it is conceivable that a large difference occurs between three-dimensional map 1135 managed by server 901 and three-dimensional data 1134 created based on sensor information 1037, when land subsidence and the like occurs due to a natural disaster such as an earthquake.

[0467] Sensor information 1037 may include information indicating at least one of a sensor type, a sensor performance, and a sensor model number. Sensor information 1037 may also be appended with a class ID and the like in accordance with the sensor performance. For example, when

sensor information **1037** is obtained by LiDAR, it is conceivable to assign identifiers to the sensor performance. A sensor capable of obtaining information with precision in units of several millimeters is class 1, a sensor capable of obtaining information with precision in units of several centimeters is class 2, and a sensor capable of obtaining information with precision in units of several meters is class 3. Server **901** may estimate sensor performance information and the like from a model number of client device **902**. For example, when client device **902** is equipped in a vehicle, server **901** may determine sensor specification information from a type of the vehicle. In this case, server **901** may obtain information on the type of the vehicle in advance, and the information may also be included in the sensor information. Server **901** may change a degree of correction with respect to three-dimensional data **1134** created using sensor information **1037**, using obtained sensor information **1037**. For example, when the sensor performance is high in precision (class 1), server **901** does not correct three-dimensional data **1134**. When the sensor performance is low in precision (class 3), server **901** corrects three-dimensional data **1134** in accordance with the precision of the sensor. For example, server **901** increases the degree (intensity) of correction with a decrease in the precision of the sensor.

**[0468]** Server **901** may simultaneously send the transmission request for the sensor information to the plurality of client devices **902** in a certain space. Server **901** does not need to use all of the sensor information for creating three-dimensional data **1134** and may, for example, select sensor information to be used in accordance with the sensor performance, when having received a plurality of pieces of sensor information from the plurality of client devices **902**. For example, when updating three-dimensional map **1135**, server **901** may select high-precision sensor information (class 1) from among the received plurality of pieces of sensor information, and create three-dimensional data **1134** using the selected sensor information.

**[0469]** Server **901** is not limited to only being a server such as a cloud-based traffic monitoring system, and may also be another (vehicle-mounted) client device. FIG. 35 is a diagram of a system structure in this case.

**[0470]** For example, client device **902C** sends a transmission request for sensor information to client device **902A** located nearby, and obtains the sensor information from client device **902A**. Client device **902C** then creates three-dimensional data using the obtained sensor information of client device **902A**, and updates a three-dimensional map of client device **902C**. This enables client device **902C** to generate a three-dimensional map of a space that can be obtained from client device **902A**, and fully utilize the performance of client device **902C**. For example, such a case is conceivable when client device **902C** has high performance.

**[0471]** In this case, client device **902A** that has provided the sensor information is given rights to obtain the high-precision three-dimensional map generated by client device **902C**. Client device **902A** receives the high-precision three-dimensional map from client device **902C** in accordance with these rights.

**[0472]** Server **901** may send the transmission request for the sensor information to the plurality of client devices **902** (client device **902A** and client device **902B**) located nearby client device **902C**. When a sensor of client device **902A** or client device **902B** has high performance, client device

**902C** is capable of creating the three-dimensional data using the sensor information obtained by this high-performance sensor.

**[0473]** FIG. 36 is a block diagram showing a functionality structure of server **901** and client device **902**. Server **901** includes, for example, three-dimensional map compression/decoding processor **1201** that compresses and decodes the three-dimensional map and sensor information compression/decoding processor **1202** that compresses and decodes the sensor information.

**[0474]** Client device **902** includes three-dimensional map decoding processor **1211** and sensor information compression processor **1212**. Three-dimensional map decoding processor **1211** receives encoded data of the compressed three-dimensional map, decodes the encoded data, and obtains the three-dimensional map. Sensor information compression processor **1212** compresses the sensor information itself instead of the three-dimensional data created using the obtained sensor information, and transmits the encoded data of the compressed sensor information to server **901**. With this structure, client device **902** does not need to internally store a processor that performs a process for compressing the three-dimensional data of the three-dimensional map (point cloud, etc.), as long as client device **902** internally stores a processor that performs a process for decoding the three-dimensional map (point cloud, etc.). This makes it possible to limit costs, power consumption, and the like of client device **902**.

**[0475]** As stated above, client device **902** according to the present embodiment is equipped in the mobile object, and creates three-dimensional data **1034** of a surrounding area of the mobile object using sensor information **1033** that is obtained through sensor **1015** equipped in the mobile object and indicates a surrounding condition of the mobile object. Client device **902** estimates a self-location of the mobile object using the created three-dimensional data **1034**. Client device **902** transmits obtained sensor information **1033** to server **901** or another mobile object.

**[0476]** This enables client device **902** to transmit sensor information **1033** to server **901** or the like. This makes it possible to further reduce the amount of transmission data compared to when transmitting the three-dimensional data. Since there is no need for client device **902** to perform processes such as compressing or encoding the three-dimensional data, it is possible to reduce the processing amount of client device **902**. As such, client device **902** is capable of reducing the amount of data to be transmitted or simplifying the structure of the device.

**[0477]** Client device **902** further transmits the transmission request for the three-dimensional map to server **901** and receives three-dimensional map **1031** from server **901**. In the estimating of the self-location, client device **902** estimates the self-location using three-dimensional data **1034** and three-dimensional map **1032**.

**[0478]** Sensor information **1034** includes at least one of information obtained by a laser sensor, a luminance image, an infrared image, a depth image, sensor position information, or sensor speed information.

**[0479]** Sensor information **1033** includes information that indicates a performance of the sensor.

**[0480]** Client device **902** encodes or compresses sensor information **1033**, and in the transmitting of the sensor information, transmits sensor information **1037** that has been encoded or compressed to server **901** or another mobile

object 902. This enables client device 902 to reduce the amount of data to be transmitted.

[0481] For example, client device 902 includes a processor and memory. The processor performs the above processes using the memory.

[0482] Server 901 according to the present embodiment is capable of communicating with client device 902 equipped in the mobile object, and receives sensor information 1037 that is obtained through sensor 1015 equipped in the mobile object and indicates a surrounding condition of the mobile object. Server 901 creates three-dimensional data 1134 of a surrounding area of the mobile object using received sensor information 1037.

[0483] With this, server 901 creates three-dimensional data 1134 using sensor information 1037 transmitted from client device 902. This makes it possible to further reduce the amount of transmission data compared to when client device 902 transmits the three-dimensional data. Since there is no need for client device 902 to perform processes such as compressing or encoding the three-dimensional data, it is possible to reduce the processing amount of client device 902. As such, server 901 is capable of reducing the amount of data to be transmitted or simplifying the structure of the device.

[0484] Server 901 further transmits a transmission request for the sensor information to client device 902.

[0485] Server 901 further updates three-dimensional map 1135 using the created three-dimensional data 1134, and transmits three-dimensional map 1135 to client device 902 in response to the transmission request for three-dimensional map 1135 from client device 902.

[0486] Sensor information 1037 includes at least one of information obtained by a laser sensor, a luminance image, an infrared image, a depth image, sensor position information, or sensor speed information.

[0487] Sensor information 1037 includes information that indicates a performance of the sensor.

[0488] Server 901 further corrects the three-dimensional data in accordance with the performance of the sensor. This enables the three-dimensional data creation method to improve the quality of the three-dimensional data.

[0489] In the receiving of the sensor information, server 901 receives a plurality of pieces of sensor information 1037 received from a plurality of client devices 902, and selects sensor information 1037 to be used in the creating of three-dimensional data 1134, based on a plurality of pieces of information that each indicates the performance of the sensor included in the plurality of pieces of sensor information 1037. This enables server 901 to improve the quality of three-dimensional data 1134.

[0490] Server 901 decodes or decompresses received sensor information 1037, and creates three-dimensional data 1134 using sensor information 1132 that has been decoded or decompressed. This enables server 901 to reduce the amount of data to be transmitted.

[0491] For example, server 901 includes a processor and memory. The processor performs the above processes using the memory.

#### Embodiment 7

[0492] In the present embodiment, three-dimensional data encoding and decoding methods using an inter prediction process will be described.

[0493] FIG. 37 is a block diagram of three-dimensional data encoding device 1300 according to the present embodiment. This three-dimensional data encoding device 1300 generates an encoded bitstream (hereinafter, also simply referred to as bitstream) that is an encoded signal, by encoding three-dimensional data. As illustrated in FIG. 37, three-dimensional data encoding device 1300 includes divider 1301, subtractor 1302, transformer 1303, quantizer 1304, inverse quantizer 1305, inverse transformer 1306, adder 1307, reference volume memory 1308, intra predictor 1309, reference space memory 1310, inter predictor 1311, prediction controller 1312, and entropy encoder 1313.

[0494] Divider 1301 divides a plurality of volumes (VLMs) that are encoding units of each space (SPC) included in the three-dimensional data. Divider 1301 makes an octree representation (make into an octree) of voxels in each volume. Note that divider 1301 may make the spaces into an octree representation with the spaces having the same size as the volumes. Divider 1301 may also append information (depth information, etc.) necessary for making the octree representation to a header and the like of a bitstream.

[0495] Subtractor 1302 calculates a difference between a volume (encoding target volume) outputted by divider 1301 and a predicted volume generated through intra prediction or inter prediction, which will be described later, and outputs the calculated difference to transformer 1303 as a prediction residual. FIG. 38 is a diagram showing an example calculation of the prediction residual. Note that bit sequences of the encoding target volume and the predicted volume shown here are, for example, position information indicating positions of three-dimensional points included in the volumes.

[0496] Hereinafter, a scan order of an octree representation and voxels will be described. A volume is encoded after being converted into an octree structure (made into an octree). The octree structure includes nodes and leaves. Each node has eight nodes or leaves, and each leaf has voxel (VXL) information. FIG. 39 is a diagram showing an example structure of a volume including voxels. FIG. 40 is a diagram showing an example of the volume shown in FIG. 39 having been converted into the octree structure. Among the leaves shown in FIG. 40, leaves 1, 2, and 3 respectively represent VXL 1, VXL 2, and VXL 3, and represent VXLs including a point group (hereinafter, active VXLs).

[0497] An octree is represented by, for example, binary sequences of 1s and 0s. For example, when giving the nodes or the active VXLs a value of 1 and everything else a value of 0, each node and leaf is assigned with the binary sequence shown in FIG. 40. Thus, this binary sequence is scanned in accordance with a breadth-first or a depth-first scan order. For example, when scanning breadth-first, the binary sequence shown in A of FIG. 41 is obtained. When scanning depth-first, the binary sequence shown in B of FIG. 41 is obtained. The binary sequences obtained through this scanning are encoded through entropy encoding, which reduces an amount of information.

[0498] Depth information in the octree representation will be described next. Depth in the octree representation is used in order to control up to how fine a granularity point cloud information included in a volume is stored. Upon setting a great depth, it is possible to reproduce the point cloud information to a more precise level, but an amount of data for representing the nodes and leaves increases. Upon setting a small depth, however, the amount of data decreases,

but some information that the point cloud information originally held is lost, since pieces of point cloud information including different positions and different colors are now considered as pieces of point cloud information including the same position and the same color.

[0499] For example, FIG. 42 is a diagram showing an example in which the octree with a depth of 2 shown in FIG. 40 is represented with a depth of 1. The octree shown in FIG. 42 has a lower amount of data than the octree shown in FIG. 40. In other words, the binarized octree shown in FIG. 42 has a lower bit count than the octree shown in FIG. 40. Leaf 1 and leaf 2 shown in FIG. 40 are represented by leaf 1 shown in FIG. 41. In other words, the information on leaf 1 and leaf 2 being in different positions is lost.

[0500] FIG. 43 is a diagram showing a volume corresponding to the octree shown in FIG. 42. VXL 1 and VXL 2 shown in FIG. 39 correspond to VXL 12 shown in FIG. 43. In this case, three-dimensional data encoding device 1300 generates color information of VXL 12 shown in FIG. 43 using color information of VXL 1 and VXL 2 shown in FIG. 39. For example, three-dimensional data encoding device 1300 calculates an average value, a median, a weighted average value, or the like of the color information of VXL 1 and VXL 2 as the color information of VXL 12. In this manner, three-dimensional data encoding device 1300 may control a reduction of the amount of data by changing the depth of the octree.

[0501] Three-dimensional data encoding device 1300 may set the depth information of the octree to units of worlds, units of spaces, or units of volumes. In this case, three-dimensional data encoding device 1300 may append the depth information to header information of the world, header information of the space, or header information of the volume. In all worlds, spaces, and volumes associated with different times, the same value may be used as the depth information. In this case, three-dimensional data encoding device 1300 may append the depth information to header information managing the worlds associated with all times.

[0502] When the color information is included in the voxels, transformer 1303 applies frequency transformation, e.g. orthogonal transformation, to a prediction residual of the color information of the voxels in the volume. For example, transformer 1303 creates a one-dimensional array by scanning the prediction residual in a certain scan order. Subsequently, transformer 1303 transforms the one-dimensional array to a frequency domain by applying one-dimensional orthogonal transformation to the created one-dimensional array. With this, when a value of the prediction residual in the volume is similar, a value of a low-frequency component increases and a value of a high-frequency component decreases. As such, it is possible to more efficiently reduce a code amount in quantizer 1304.

[0503] Transformer 1303 does not need to use orthogonal transformation in one dimension, but may also use orthogonal transformation in two or more dimensions. For example, transformer 1303 maps the prediction residual to a two-dimensional array in a certain scan order, and applies two-dimensional orthogonal transformation to the obtained two-dimensional array. Transformer 1303 may select an orthogonal transformation method to be used from a plurality of orthogonal transformation methods. In this case, three-dimensional data encoding device 1300 appends, to the bitstream, information indicating which orthogonal transformation method is used. Transformer 1303 may select

an orthogonal transformation method to be used from a plurality of orthogonal transformation methods in different dimensions. In this case, three-dimensional data encoding device 1300 appends, to the bitstream, in how many dimensions the orthogonal transformation method is used.

[0504] For example, transformer 1303 matches the scan order of the prediction residual to a scan order (breadth-first, depth-first, or the like) in the octree in the volume. This makes it possible to reduce overhead, since information indicating the scan order of the prediction residual does not need to be appended to the bitstream. Transformer 1303 may apply a scan order different from the scan order of the octree. In this case, three-dimensional data encoding device 1300 appends, to the bitstream, information indicating the scan order of the prediction residual. This enables three-dimensional data encoding device 1300 to efficiently encode the prediction residual. Three-dimensional data encoding device 1300 may append, to the bitstream, information (flag, etc.) indicating whether to apply the scan order of the octree, and may also append, to the bitstream, information indicating the scan order of the prediction residual when the scan order of the octree is not applied.

[0505] Transformer 1303 does not only transform the prediction residual of the color information, and may also transform other attribute information included in the voxels. For example, transformer 1303 may transform and encode information, such as reflectance information, obtained when obtaining a point cloud through LiDAR and the like.

[0506] Transformer 1303 may skip these processes when the spaces do not include attribute information such as color information. Three-dimensional data encoding device 1300 may append, to the bitstream, information (flag) indicating whether to skip the processes of transformer 1303.

[0507] Quantizer 1304 generates a quantized coefficient by performing quantization using a quantization control parameter on a frequency component of the prediction residual generated by transformer 1303. With this, the amount of information is further reduced. The generated quantized coefficient is outputted to entropy encoder 1313. Quantizer 1304 may control the quantization control parameter in units of worlds, units of spaces, or units of volumes. In this case, three-dimensional data encoding device 1300 appends the quantization control parameter to each header information and the like. Quantizer 1304 may perform quantization control by changing a weight per frequency component of the prediction residual. For example, quantizer 1304 may precisely quantize a low-frequency component and roughly quantize a high-frequency component. In this case, three-dimensional data encoding device 1300 may append, to a header, a parameter expressing a weight of each frequency component.

[0508] Quantizer 1304 may skip these processes when the spaces do not include attribute information such as color information. Three-dimensional data encoding device 1300 may append, to the bitstream, information (flag) indicating whether to skip the processes of quantizer 1304.

[0509] Inverse quantizer 1305 generates an inverse quantized coefficient of the prediction residual by performing inverse quantization on the quantized coefficient generated by quantizer 1304 using the quantization control parameter, and outputs the generated inverse quantized coefficient to inverse transformer 1306.

[0510] Inverse transformer 1306 generates an inverse transformation-applied prediction residual by applying

inverse transformation on the inverse quantized coefficient generated by inverse quantizer **1305**. This inverse transformation-applied prediction residual does not need to completely coincide with the prediction residual outputted by transformer **1303**, since the inverse transformation-applied prediction residual is a prediction residual that is generated after the quantization.

[0511] Adder **1307** adds, to generate a reconstructed volume, (i) the inverse transformation-applied prediction residual generated by inverse transformer **1306** to (ii) a predicted volume that is generated through intra prediction or intra prediction, which will be described later, and is used to generate a pre-quantized prediction residual. This reconstructed volume is stored in reference volume memory **1308** or reference space memory **1310**.

[0512] Intra predictor **1309** generates a predicted volume of an encoding target volume using attribute information of a neighboring volume stored in reference volume memory **1308**. The attribute information includes color information or a reflectance of the voxels. Intra predictor **1309** generates a predicted value of color information or a reflectance of the encoding target volume.

[0513] FIG. 44 is a diagram for describing an operation of intra predictor **1309**. For example, intra predictor **1309** generates the predicted volume of the encoding target volume (volume idx=3) shown in FIG. 44, using a neighboring volume (volume idx=0). Volume idx here is identifier information that is appended to a volume in a space, and a different value is assigned to each volume. An order of assigning volume idx may be the same as an encoding order, and may also be different from the encoding order. For example, intra predictor **1309** uses an average value of color information of voxels included in volume idx=0, which is a neighboring volume, as the predicted value of the color information of the encoding target volume shown in FIG. 44. In this case, a prediction residual is generated by deducting the predicted value of the color information from the color information of each voxel included in the encoding target volume. The following processes are performed by transformer **1303** and subsequent processors with respect to this prediction residual. In this case, three-dimensional data encoding device **1300** appends, to the bitstream, neighboring volume information and prediction mode information. The neighboring volume information here is information indicating a neighboring volume used in the prediction, and indicates, for example, volume idx of the neighboring volume used in the prediction. The prediction mode information here indicates a mode used to generate the predicted volume. The mode is, for example, an average value mode in which the predicted value is generated using an average value of the voxels in the neighboring volume, or a median mode in which the predicted value is generated using the median of the voxels in the neighboring volume.

[0514] Intra predictor **1309** may generate the predicted volume using a plurality of neighboring volumes. For example, in the structure shown in FIG. 44, intra predictor **1309** generates predicted volume 0 using a volume with volume idx=0, and generates predicted volume 1 using a volume with volume idx=1. Intra predictor **1309** then generates an average of predicted volume 0 and predicted volume 1 as a final predicted volume. In this case, three-dimensional data encoding device **1300** may append, to the bitstream, a plurality of volumes idx of a plurality of volumes used to generate the predicted volume.

[0515] FIG. 45 is a diagram schematically showing the inter prediction process according to the present embodiment. Inter predictor **1311** encodes (inter predicts) a space (SPC) associated with certain time **T\_Cur** using an encoded space associated with different time **T\_LX**. In this case, inter predictor **1311** performs an encoding process by applying a rotation and translation process to the encoded space associated with different time **T\_LX**.

[0516] Three-dimensional data encoding device **1300** appends, to the bitstream, RT information relating to a rotation and translation process suited to the space associated with different time **T\_LX**. Different time **T\_LX** is, for example, time **T\_L0** before certain time **T\_Cur**. At this point, three-dimensional data encoding device **1300** may append, to the bitstream, RT information **RT\_L0** relating to a rotation and translation process suited to a space associated with time **T\_L0**.

[0517] Alternatively, different time **T\_LX** is, for example, time **T\_L1** after certain time **T\_Cur**. At this point, three-dimensional data encoding device **1300** may append, to the bitstream, RT information **RT\_L1** relating to a rotation and translation process suited to a space associated with time **T\_L1**.

[0518] Alternatively, inter predictor **1311** encodes (bidirectional prediction) with reference to the spaces associated with time **T\_L0** and time **T\_L1** that differ from each other. In this case, three-dimensional data encoding device **1300** may append, to the bitstream, both RT information **RT\_L0** and RT information **RT\_L1** relating to the rotation and translation process suited to the spaces thereof.

[0519] Note that **T\_L0** has been described as being before **T\_Cur** and **T\_L1** as being after **T\_Cur**, but are not necessarily limited thereto. For example, **T\_L0** and **T\_L1** may both be before **T\_Cur**. **T\_L0** and **T\_L1** may also both be after **T\_Cur**.

[0520] Three-dimensional data encoding device **1300** may append, to the bitstream, RT information relating to a rotation and translation process suited to spaces associated with different times, when encoding with reference to each of the spaces. For example, three-dimensional data encoding device **1300** manages a plurality of encoded spaces to be referred to, using two reference lists (list L0 and list L1). When a first reference space in list L0 is L0R0, a second reference space in list L0 is L0R1, a first reference space in list L1 is L1R0, and a second reference space in list L1 is L1R1, three-dimensional data encoding device **1300** appends, to the bitstream, RT information **RT\_L0R0** of L0R0, RT information **RT\_L0R1** of L0R1, RT information **RT\_L1R0** of L1R0, and RT information **RT\_L1R1** of L1R1. For example, three-dimensional data encoding device **1300** appends these pieces of RT information to a header and the like of the bitstream.

[0521] Three-dimensional data encoding device **1300** determines whether to apply rotation and translation per reference space, when encoding with reference to reference spaces associated with different times. In this case, three-dimensional data encoding device **1300** may append, to header information and the like of the bitstream, information (RT flag, etc.) indicating whether rotation and translation are applied per reference space. For example, three-dimensional data encoding device **1300** calculates the RT information and an Iterative Closest Point (ICP) error value, using an ICP algorithm per reference space to be referred to from the encoding target space. Three-dimensional data encoding

device **1300** determines that rotation and translation do not need to be performed and sets the RT flag to OFF, when the ICP error value is lower than or equal to a predetermined fixed value. In contrast, three-dimensional data encoding device **1300** sets the RT flag to ON and appends the RT information to the bitstream, when the ICP error value exceeds the above fixed value.

[0522] FIG. 46 is a diagram showing an example syntax to be appended to a header of the RT information and the RT flag. Note that a bit count assigned to each syntax may be decided based on a range of this syntax. For example, when eight reference spaces are included in reference list L0, 3 bits may be assigned to MaxRefSpc\_10. The bit count to be assigned may be variable in accordance with a value each syntax can be, and may also be fixed regardless of the value each syntax can be. When the bit count to be assigned is fixed, three-dimensional data encoding device **1300** may append this fixed bit count to other header information.

[0523] MaxRefSpc\_10 shown in FIG. 46 indicates a number of reference spaces included in reference list L0. RT\_flag\_10[i] is an RT flag of reference space i in reference list L0. When RT\_flag\_10[i] is 1, rotation and translation are applied to reference space i. When RT\_flag\_10[i] is 0, rotation and translation are not applied to reference space i.

[0524] R\_10[i] and T\_10[i] are RT information of reference space i in reference list L0. R\_10[i] is rotation information of reference space i in reference list L0. The rotation information indicates contents of the applied rotation process, and is, for example, a rotation matrix or a quaternion. T\_10[i] is translation information of reference space i in reference list L0. The translation information indicates contents of the applied translation process, and is, for example, a translation vector.

[0525] MaxRefSpc\_11 indicates a number of reference spaces included in reference list L1. RT\_flag\_11[i] is an RT flag of reference space i in reference list L1. When RT\_flag\_11[i] is 1, rotation and translation are applied to reference space i. When RT\_flag\_11[i] is 0, rotation and translation are not applied to reference space i.

[0526] R\_11[i] and T\_11[i] are RT information of reference space i in reference list L1. R\_11[i] is rotation information of reference space i in reference list L1. The rotation information indicates contents of the applied rotation process, and is, for example, a rotation matrix or a quaternion. T\_11[i] is translation information of reference space i in reference list L1. The translation information indicates contents of the applied translation process, and is, for example, a translation vector.

[0527] Inter predictor **1311** generates the predicted volume of the encoding target volume using information on an encoded reference space stored in reference space memory **1310**. As stated above, before generating the predicted volume of the encoding target volume, inter predictor **1311** calculates RT information at an encoding target space and a reference space using an ICP algorithm, in order to approach an overall positional relationship between the encoding target space and the reference space. Inter predictor **1311** then obtains reference space B by applying a rotation and translation process to the reference space using the calculated RT information. Subsequently, inter predictor **1311** generates the predicted volume of the encoding target volume in the encoding target space using information in reference space B. Three-dimensional data encoding device

**1300** appends, to header information and the like of the encoding target space, the RT information used to obtain reference space B.

[0528] In this manner, inter predictor **1311** is capable of improving precision of the predicted volume by generating the predicted volume using the information of the reference space, after approaching the overall positional relationship between the encoding target space and the reference space, by applying a rotation and translation process to the reference space. It is possible to reduce the code amount since it is possible to limit the prediction residual. Note that an example has been described in which ICP is performed using the encoding target space and the reference space, but is not necessarily limited thereto. For example, inter predictor **1311** may calculate the RT information by performing ICP using at least one of (i) an encoding target space in which a voxel or point cloud count is pruned, or (ii) a reference space in which a voxel or point cloud count is pruned, in order to reduce the processing amount.

[0529] When the ICP error value obtained as a result of the ICP is smaller than a predetermined first threshold, i.e., when for example the positional relationship between the encoding target space and the reference space is similar, inter predictor **1311** determines that a rotation and translation process is not necessary, and the rotation and translation process does not need to be performed. In this case, three-dimensional data encoding device **1300** may control the overhead by not appending the RT information to the bitstream.

[0530] When the ICP error value is greater than a predetermined second threshold, inter predictor **1311** determines that a shape change between the spaces is large, and intra prediction may be applied on all volumes of the encoding target space. Hereinafter, spaces to which intra prediction is applied will be referred to as intra spaces. The second threshold is greater than the above first threshold. The present embodiment is not limited to ICP, and any type of method may be used as long as the method calculates the RT information using two voxel sets or two point cloud sets.

[0531] When attribute information, e.g. shape or color information, is included in the three-dimensional data, inter predictor **1311** searches, for example, a volume whose attribute information, e.g. shape or color information, is the most similar to the encoding target volume in the reference space, as the predicted volume of the encoding target volume in the encoding target space. This reference space is, for example, a reference space on which the above rotation and translation process has been performed. Inter predictor **1311** generates the predicted volume using the volume (reference volume) obtained through the search. FIG. 47 is a diagram for describing a generating operation of the predicted volume. When encoding the encoding target volume (volume idx=0) shown in FIG. 47 using inter prediction, inter predictor **1311** searches a volume with a smallest prediction residual, which is the difference between the encoding target volume and the reference volume, while sequentially scanning the reference volume in the reference space. Inter predictor **1311** selects the volume with the smallest prediction residual as the predicted volume. The prediction residuals of the encoding target volume and the predicted volume are encoded through the processes performed by transformer **1303** and subsequent processors. The prediction residual here is a difference between the attribute information of the encoding target volume and the attribute

information of the predicted volume. Three-dimensional data encoding device **1300** appends, to the header and the like of the bitstream, volume idx of the reference volume in the reference space, as the predicted volume.

[0532] In the example shown in FIG. 47, the reference volume with volume idx=4 of reference space L0R0 is selected as the predicted volume of the encoding target volume. The prediction residuals of the encoding target volume and the reference volume, and reference volume idx=4 are then encoded and appended to the bitstream.

[0533] Note that an example has been described in which the predicted volume of the attribute information is generated, but the same process may be applied to the predicted volume of the position information.

[0534] Prediction controller **1312** controls whether to encode the encoding target volume using intra prediction or inter prediction. A mode including intra prediction and inter prediction is referred to here as a prediction mode. For example, prediction controller **1312** calculates the prediction residual when the encoding target volume is predicted using intra prediction and the prediction residual when the encoding target volume is predicted using inter prediction as evaluation values, and selects the prediction mode whose evaluation value is smaller. Note that prediction controller **1312** may calculate an actual code amount by applying orthogonal transformation, quantization, and entropy encoding to the prediction residual of the intra prediction and the prediction residual of the inter prediction, and select a prediction mode using the calculated code amount as the evaluation value. Overhead information (reference volume idx information, etc.) aside from the prediction residual may be added to the evaluation value. Prediction controller **1312** may continuously select intra prediction when it has been decided in advance to encode the encoding target space using intra space.

[0535] Entropy encoder **1313** generates an encoded signal (encoded bitstream) by variable-length encoding the quantized coefficient, which is an input from quantizer **1304**. To be specific, entropy encoder **1313**, for example, binarizes the quantized coefficient and arithmetically encodes the obtained binary signal.

[0536] A three-dimensional data decoding device that decodes the encoded signal generated by three-dimensional data encoding device **1300** will be described next. FIG. 48 is a block diagram of three-dimensional data decoding device **1400** according to the present embodiment. This three-dimensional data decoding device **1400** includes entropy decoder **1401**, inverse quantizer **1402**, inverse transformer **1403**, adder **1404**, reference volume memory **1405**, intra predictor **1406**, reference space memory **1407**, inter predictor **1408**, and prediction controller **1409**.

[0537] Entropy decoder **1401** variable-length decodes the encoded signal (encoded bitstream). For example, entropy decoder **1401** generates a binary signal by arithmetically decoding the encoded signal, and generates a quantized coefficient using the generated binary signal.

[0538] Inverse quantizer **1402** generates an inverse quantized coefficient by inverse quantizing the quantized coefficient inputted from entropy decoder **1401**, using a quantization parameter appended to the bitstream and the like.

[0539] Inverse transformer **1403** generates a prediction residual by inverse transforming the inverse quantized coefficient inputted from inverse quantizer **1402**. For example, inverse transformer **1403** generates the prediction residual

by inverse orthogonally transforming the inverse quantized coefficient, based on information appended to the bitstream.

[0540] Adder **1404** adds, to generate a reconstructed volume, (i) the prediction residual generated by inverse transformer **1403** to (ii) a predicted volume generated through intra prediction or inter prediction. This reconstructed volume is outputted as decoded three-dimensional data and is stored in reference volume memory **1405** or reference space memory **1407**.

[0541] Intra predictor **1406** generates a predicted volume through intra prediction using a reference volume in reference volume memory **1405** and information appended to the bitstream. To be specific, intra predictor **1406** obtains neighboring volume information (e.g. volume idx) appended to the bitstream and prediction mode information, and generates the predicted volume through a mode indicated by the prediction mode information, using a neighboring volume indicated in the neighboring volume information. Note that the specifics of these processes are the same as the above-mentioned processes performed by intra predictor **1309**, except for which information appended to the bitstream is used.

[0542] Inter predictor **1408** generates a predicted volume through inter prediction using a reference space in reference space memory **1407** and information appended to the bitstream. To be specific, inter predictor **1408** applies a rotation and translation process to the reference space using the RT information per reference space appended to the bitstream, and generates the predicted volume using the rotated and translated reference space. Note that when an RT flag is present in the bitstream per reference space, inter predictor **1408** applies a rotation and translation process to the reference space in accordance with the RT flag. Note that the specifics of these processes are the same as the above-mentioned processes performed by inter predictor **1311**, except for which information appended to the bitstream is used.

[0543] Prediction controller **1409** controls whether to decode a decoding target volume using intra prediction or inter prediction. For example, prediction controller **1409** selects intra prediction or inter prediction in accordance with information that is appended to the bitstream and indicates the prediction mode to be used. Note that prediction controller **1409** may continuously select intra prediction when it has been decided in advance to decode the decoding target space using intra space.

[0544] Hereinafter, variations of the present embodiment will be described. In the present embodiment, an example has been described in which rotation and translation is applied in units of spaces, but rotation and translation may also be applied in smaller units. For example, three-dimensional data encoding device **1300** may divide a space into subspaces, and apply rotation and translation in units of subspaces. In this case, three-dimensional data encoding device **1300** generates RT information per subspace, and appends the generated RT information to a header and the like of the bitstream. Three-dimensional data encoding device **1300** may apply rotation and translation in units of volumes, which is an encoding unit. In this case, three-dimensional data encoding device **1300** generates RT information in units of encoded volumes, and appends the generated RT information to a header and the like of the bitstream. The above may also be combined. In other words, three-dimensional data encoding device **1300** may apply

rotation and translation in large units and subsequently apply rotation and translation in small units. For example, three-dimensional data encoding device **1300** may apply rotation and translation in units of spaces, and may also apply different rotations and translations to each of a plurality of volumes included in the obtained spaces.

[0545] In the present embodiment, an example has been described in which rotation and translation is applied to the reference space, but is not necessarily limited thereto. For example, three-dimensional data encoding device **1300** may apply a scaling process and change a size of the three-dimensional data. Three-dimensional data encoding device **1300** may also apply one or two of the rotation, translation, and scaling. When applying the processes in multiple stages and different units as stated above, a type of the processes applied in each unit may differ. For example, rotation and translation may be applied in units of spaces, and translation may be applied in units of volumes.

[0546] Note that these variations are also applicable to three-dimensional data decoding device **1400**.

[0547] As stated above, three-dimensional data encoding device **1300** according to the present embodiment performs the following processes. FIG. 48 is a flowchart of the inter prediction process performed by three-dimensional data encoding device **1300**.

[0548] Three-dimensional data encoding device **1300** generates predicted position information (e.g. predicted volume) using position information on three-dimensional points included in three-dimensional reference data (e.g. reference space) associated with a time different from a time associated with current three-dimensional data (e.g. encoding target space) (S1301). To be specific, three-dimensional data encoding device **1300** generates the predicted position information by applying a rotation and translation process to the position information on the three-dimensional points included in the three-dimensional reference data.

[0549] Note that three-dimensional data encoding device **1300** may perform a rotation and translation process using a first unit (e.g. spaces), and may perform the generating of the predicted position information using a second unit (e.g. volumes) that is smaller than the first unit. For example, three-dimensional data encoding device **1300** searches a volume among a plurality of volumes included in the rotated and translated reference space, whose position information differs the least from the position information of the encoding target volume included in the encoding target space. Note that three-dimensional data encoding device **1300** may perform the rotation and translation process, and the generating of the predicted position information in the same unit.

[0550] Three-dimensional data encoding device **1300** may generate the predicted position information by applying (i) a first rotation and translation process to the position information on the three-dimensional points included in the three-dimensional reference data, and (ii) a second rotation and translation process to the position information on the three-dimensional points obtained through the first rotation and translation process, the first rotation and translation process using a first unit (e.g. spaces) and the second rotation and translation process using a second unit (e.g. volumes) that is smaller than the first unit.

[0551] For example, as illustrated in FIG. 41, the position information on the three-dimensional points and the predicted position information is represented using an octree structure. For example, the position information on the

three-dimensional points and the predicted position information is expressed in a scan order that prioritizes a breadth over a depth in the octree structure. For example, the position information on the three-dimensional points and the predicted position information is expressed in a scan order that prioritizes a depth over a breadth in the octree structure.

[0552] As illustrated in FIG. 46, three-dimensional data encoding device **1300** encodes an RT flag that indicates whether to apply the rotation and translation process to the position information on the three-dimensional points included in the three-dimensional reference data. In other words, three-dimensional data encoding device **1300** generates the encoded signal (encoded bitstream) including the RT flag. Three-dimensional data encoding device **1300** encodes RT information that indicates contents of the rotation and translation process. In other words, three-dimensional data encoding device **1300** generates the encoded signal (encoded bitstream) including the RT information. Note that three-dimensional data encoding device **1300** may encode the RT information when the RT flag indicates to apply the rotation and translation process, and does not need to encode the RT information when the RT flag indicates not to apply the rotation and translation process.

[0553] The three-dimensional data includes, for example, the position information on the three-dimensional points and the attribute information (color information, etc.) of each three-dimensional point. Three-dimensional data encoding device **1300** generates predicted attribute information using the attribute information of the three-dimensional points included in the three-dimensional reference data (S1302).

[0554] Three-dimensional data encoding device **1300** next encodes the position information on the three-dimensional points included in the current three-dimensional data, using the predicted position information. For example, as illustrated in FIG. 38, three-dimensional data encoding device **1300** calculates differential position information, the differential position information being a difference between the predicted position information and the position information on the three-dimensional points included in the current three-dimensional data (S1303).

[0555] Three-dimensional data encoding device **1300** encodes the attribute information of the three-dimensional points included in the current three-dimensional data, using the predicted attribute information. For example, three-dimensional data encoding device **1300** calculates differential attribute information, the differential attribute information being a difference between the predicted attribute information and the attribute information on the three-dimensional points included in the current three-dimensional data (S1304). Three-dimensional data encoding device **1300** next performs transformation and quantization on the calculated differential attribute information (S1305).

[0556] Lastly, three-dimensional data encoding device **1300** encodes (e.g. entropy encodes) the differential position information and the quantized differential attribute information (S1306). In other words, three-dimensional data encoding device **1300** generates the encoded signal (encoded bitstream) including the differential position information and the differential attribute information.

[0557] Note that when the attribute information is not included in the three-dimensional data, three-dimensional data encoding device **1300** does not need to perform steps S1302, S1304, and S1305. Three-dimensional data encoding device **1300** may also perform only one of the encoding of

the position information on the three-dimensional points and the encoding of the attribute information of the three-dimensional points.

[0558] An order of the processes shown in FIG. 49 is merely an example and is not limited thereto. For example, since the processes with respect to the position information (S1301 and S1303) and the processes with respect to the attribute information (S1302, S1304, and S1305) are separate from one another, they may be performed in an order of choice, and a portion thereof may also be performed in parallel.

[0559] With the above, three-dimensional data encoding device 1300 according to the present embodiment generates predicted position information using position information on three-dimensional points included in three-dimensional reference data associated with a time different from a time associated with current three-dimensional data; and encodes differential position information, which is a difference between the predicted position information and the position information on the three-dimensional points included in the current three-dimensional data. This makes it possible to improve encoding efficiency since it is possible to reduce the amount of data of the encoded signal.

[0560] Three-dimensional data encoding device 1300 according to the present embodiment generates predicted attribute information using attribute information on three-dimensional points included in three-dimensional reference data; and encodes differential attribute information, which is a difference between the predicted attribute information and the attribute information on the three-dimensional points included in the current three-dimensional data. This makes it possible to improve encoding efficiency since it is possible to reduce the amount of data of the encoded signal.

[0561] For example, three-dimensional data encoding device 1300 includes a processor and memory. The processor uses the memory to perform the above processes.

[0562] FIG. 48 is a flowchart of the inter prediction process performed by three-dimensional data decoding device 1400.

[0563] Three-dimensional data decoding device 1400 decodes (e.g. entropy decodes) the differential position information and the differential attribute information from the encoded signal (encoded bitstream) (S1401).

[0564] Three-dimensional data decoding device 1400 decodes, from the encoded signal, an RT flag that indicates whether to apply the rotation and translation process to the position information on the three-dimensional points included in the three-dimensional reference data. Three-dimensional data decoding device 1400 encodes RT information that indicates contents of the rotation and translation process. Note that three-dimensional data decoding device 1400 may decode the RT information when the RT flag indicates to apply the rotation and translation process, and does not need to decode the RT information when the RT flag indicates not to apply the rotation and translation process.

[0565] Three-dimensional data decoding device 1400 next performs inverse transformation and inverse quantization on the decoded differential attribute information (S1402).

[0566] Three-dimensional data decoding device 1400 next generates predicted position information (e.g. predicted volume) using the position information on the three-dimensional points included in the three-dimensional reference data (e.g. reference space) associated with a time different

from a time associated with the current three-dimensional data (e.g. decoding target space) (S1403). To be specific, three-dimensional data decoding device 1400 generates the predicted position information by applying a rotation and translation process to the position information on the three-dimensional points included in the three-dimensional reference data.

[0567] More specifically, when the RT flag indicates to apply the rotation and translation process, three-dimensional data decoding device 1400 applies the rotation and translation process on the position information on the three-dimensional points included in the three-dimensional reference data indicated in the RT information. In contrast, when the RT flag indicates not to apply the rotation and translation process, three-dimensional data decoding device 1400 does not apply the rotation and translation process on the position information on the three-dimensional points included in the three-dimensional reference data.

[0568] Note that three-dimensional data decoding device 1400 may perform the rotation and translation process using a first unit (e.g. spaces), and may perform the generating of the predicted position information using a second unit (e.g. volumes) that is smaller than the first unit. Note that three-dimensional data decoding device 1400 may perform the rotation and translation process, and the generating of the predicted position information in the same unit.

[0569] Three-dimensional data decoding device 1400 may generate the predicted position information by applying (i) a first rotation and translation process to the position information on the three-dimensional points included in the three-dimensional reference data, and (ii) a second rotation and translation process to the position information on the three-dimensional points obtained through the first rotation and translation process, the first rotation and translation process using a first unit (e.g. spaces) and the second rotation and translation process using a second unit (e.g. volumes) that is smaller than the first unit.

[0570] For example, as illustrated in FIG. 41, the position information on the three-dimensional points and the predicted position information is represented using an octree structure. For example, the position information on the three-dimensional points and the predicted position information is expressed in a scan order that prioritizes a breadth over a depth in the octree structure. For example, the position information on the three-dimensional points and the predicted position information is expressed in a scan order that prioritizes a depth over a breadth in the octree structure.

[0571] Three-dimensional data decoding device 1400 generates predicted attribute information using the attribute information of the three-dimensional points included in the three-dimensional reference data (S1404).

[0572] Three-dimensional data decoding device 1400 next restores the position information on the three-dimensional points included in the current three-dimensional data, by decoding encoded position information included in an encoded signal, using the predicted position information. The encoded position information here is the differential position information. Three-dimensional data decoding device 1400 restores the position information on the three-dimensional points included in the current three-dimensional data, by adding the differential position information to the predicted position information (S1405).

[0573] Three-dimensional data decoding device 1400 restores the attribute information of the three-dimensional

points included in the current three-dimensional data, by decoding encoded attribute information included in an encoded signal, using the predicted attribute information. The encoded attribute information here is the differential position information. Three-dimensional data decoding device **1400** restores the attribute information on the three-dimensional points included in the current three-dimensional data, by adding the differential attribute information to the predicted attribute information (**S1406**).

**[0574]** Note that when the attribute information is not included in the three-dimensional data, three-dimensional data decoding device **1400** does not need to perform steps **S1402**, **S1404**, and **S1406**. Three-dimensional data decoding device **1400** may also perform only one of the decoding of the position information on the three-dimensional points and the decoding of the attribute information of the three-dimensional points.

**[0575]** An order of the processes shown in FIG. 50 is merely an example and is not limited thereto. For example, since the processes with respect to the position information (**S1403** and **S1405**) and the processes with respect to the attribute information (**S1402**, **S1404**, and **S1406**) are separate from one another, they may be performed in an order of choice, and a portion thereof may also be performed in parallel.

#### Embodiment 8

**[0576]** Information of a three-dimensional point cloud includes geometry information (geometry) and attribute information (attribute). Geometry information includes coordinates (x-coordinate, y-coordinate, z-coordinate) with respect to a certain point. When geometry information is encoded, a method of representing the position of each of three-dimensional points in octree representation and encoding the octree information to reduce a code amount is used instead of directly encoding the coordinates of the three-dimensional point.

**[0577]** On the other hand, attribute information includes information indicating, for example, color information (RGB, YUV, etc.) of each three-dimensional point, a reflectance, and a normal vector. For example, a three-dimensional data encoding device is capable of encoding attribute information using an encoding method different from a method used to encode geometry information.

**[0578]** In the present embodiment, a method of encoding attribute information is explained. It is to be noted that, in the present embodiment, the method is explained based on an example case using integer values as values of attribute information. For example, when each of RGB or YUV color components is of an 8-bit accuracy, the color component is an integer value in a range from 0 to 255. When a reflectance value is of 10-bit accuracy, the reflectance value is an integer in a range from 0 to 1023. It is to be noted that, when the bit accuracy of attribute information is a decimal accuracy, the three-dimensional data encoding device may multiply the value by a scale value to round it to an integer value so that the value of the attribute information becomes an integer value. It is to be noted that the three-dimensional data encoding device may add the scale value to, for example, a header of a bitstream.

**[0579]** As a method of encoding attribute information of a three-dimensional point, it is conceivable to calculate a predicted value of the attribute information of the three-dimensional point and encode a difference (prediction

residual) between the original value of the attribute information and the predicted value. For example, when the value of attribute information at three-dimensional point p is  $A_p$  and a predicted value is  $P_p$ , the three-dimensional data encoding device encodes differential absolute value  $Dif_{pp} = |A_p - P_p|$ . In this case, when highly-accurate predicted value  $P_p$  can be generated, differential absolute value  $Dif_{pp}$  is small. Thus, for example, it is possible to reduce the code amount by entropy encoding differential absolute value  $Dif_{pp}$  using a coding table that reduces an occurrence bit count more when differential absolute value  $Dif_{pp}$  is smaller.

**[0580]** As a method of generating a prediction value of attribute information, it is conceivable to use attribute information of a reference three-dimensional point that is another three-dimensional point which neighbors a current three-dimensional point to be encoded. Here, a reference three-dimensional point is a three-dimensional point in a range of a predetermined distance from the current three-dimensional point. For example, when there are current three-dimensional point  $p = (x_1, y_1, z_1)$  and three-dimensional point  $q = (x_2, y_2, z_2)$ , the three-dimensional data encoding device calculates Euclidean distance  $d(p, q)$  between three-dimensional point p and three-dimensional point q represented by (Equation A1).

[Math. 1]

$$d(p, q) = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2 + (x_3 - y_3)^2} \quad (\text{Equation A1})$$

**[0581]** The three-dimensional data encoding device determines that the position of three-dimensional point q is closer to the position of current three-dimensional point p when Euclidean distance  $d(p, q)$  is smaller than predetermined threshold value  $TH_d$ , and determines to use the value of the attribute information of three-dimensional point q to generate a predicted value of the attribute information of current three-dimensional point p. It is to be noted that the method of calculating the distance may be another method, and a Mahalanobis distance or the like may be used. In addition, the three-dimensional data encoding device may determine not to use, in prediction processing, any three-dimensional point outside the predetermined range of distance from the current three-dimensional point. For example, when three-dimensional point r is present, and distance  $d(p, r)$  between current three-dimensional point p and three-dimensional point r is larger than or equal to threshold value  $TH_d$ , the three-dimensional data encoding device may determine not to use three-dimensional point r for prediction. It is to be noted that the three-dimensional data encoding device may add the information indicating threshold value  $TH_d$  to, for example, a header of a bitstream.

**[0582]** FIG. 51 is a diagram illustrating an example of three-dimensional points. In this example, distance  $d(p, q)$  between current three-dimensional point p and three-dimensional point q is smaller than threshold value  $TH_d$ . Thus, the three-dimensional data encoding device determines that three-dimensional point q is a reference three-dimensional point of current three-dimensional point p, and determines to use the value of attribute information  $A_q$  of three-dimensional point q to generate predicted value  $P_p$  of attribute information  $A_p$  of current three-dimensional point p.

**[0583]** In contrast, distance  $d(p, r)$  between current three-dimensional point p and three-dimensional point r is larger

than or equal to threshold value THd. Thus, the three-dimensional data encoding device determines that three-dimensional point r is not any reference three-dimensional point of current three-dimensional point p, and determines not to use the value of attribute information Ar of three-dimensional point r to generate predicted value Pp of attribute information Ap of current three-dimensional point p.

[0584] In addition, when encoding the attribute information of the current three-dimensional point using a predicted value, the three-dimensional data encoding device uses a three-dimensional point whose attribute information has already been encoded and decoded, as a reference three-dimensional point. Likewise, when decoding the attribute information of a current three-dimensional point to be decoded, the three-dimensional data decoding device uses a three-dimensional point whose attribute information has already been decoded, as a reference three-dimensional point. In this way, it is possible to generate the same predicted value at the time of encoding and decoding. Thus, a bitstream of the three-dimensional point generated by the encoding can be decoded correctly at the decoding side.

[0585] Furthermore, when encoding attribute information of each of three-dimensional points, it is conceivable to classify the three-dimensional point into one of a plurality of layers using geometry information of the three-dimensional point and then encode the attribute information. Here, each of the layers classified is referred to as a Level of Detail (LoD). A method of generating LoDs is explained with reference to FIG. 52.

[0586] First, the three-dimensional data encoding device selects initial point a0 and assigns initial point a0 to LoD0. Next, the three-dimensional data encoding device extracts point a1 distant from point a0 more than threshold value Thres\_LoD[0] of LoD0 and assigns point a1 to LoD0. Next, the three-dimensional data encoding device extracts point a2 distant from point a1 more than threshold value Thres\_LoD[0] of LoD0 and assigns point a2 to LoD0. In this way, the three-dimensional data encoding device configures LoD0 in such a manner that the distance between the points in LoD0 is larger than threshold value Thres\_LoD[0].

[0587] Next, the three-dimensional data encoding device selects point b0 which has not yet been assigned to any LoD and assigns point b0 to LoD1. Next, the three-dimensional data encoding device extracts point b1 which is distant from point b0 more than threshold value Thres\_LoD[1] of LoD1 and which has not yet been assigned to any LoD, and assigns point b1 to LoD1. Next, the three-dimensional data encoding device extracts point b2 which is distant from point b1 more than threshold value Thres\_LoD[1] of LoD1 and which has not yet been assigned to any LoD, and assigns point b2 to LoD1. In this way, the three-dimensional data encoding device configures LoD1 in such a manner that the distance between the points in LoD1 is larger than threshold value Thres\_LoD[1].

[0588] Next, the three-dimensional data encoding device selects point c0 which has not yet been assigned to any LoD and assigns point c0 to LoD2. Next, the three-dimensional data encoding device extracts point c1 which is distant from point c0 more than threshold value Thres\_LoD[2] of LoD2 and which has not yet been assigned to any LoD, and assigns point c1 to LoD2. Next, the three-dimensional data encoding device extracts point c2 which is distant from point c1 more than threshold value Thres\_LoD[2] of LoD2 and which has

not yet been assigned to any LoD, and assigns point c2 to LoD2. In this way, the three-dimensional data encoding device configures LoD2 in such a manner that the distance between the points in LoD2 is larger than threshold value Thres\_LoD[2]. For example, as illustrated in FIG. 53, threshold values Thres\_LoD[0], Thres\_LoD[1], and Thres\_LoD[2] of respective LoDs are set.

[0589] In addition, the three-dimensional data encoding device may add the information indicating the threshold value of each LoD to, for example, a header of a bitstream. For example, in the case of the example illustrated in FIG. 53, the three-dimensional data encoding device may add threshold values Thres\_LoD[0], Thres\_LoD[1], and Thres\_LoD[2] of respective LoDs to a header.

[0590] Alternatively, the three-dimensional data encoding device may assign all three-dimensional points which have not yet been assigned to any LoD in the lowermost-layer LoD. In this case, the three-dimensional data encoding device is capable of reducing the code amount of the header by not assigning the threshold value of the lowermost-layer LoD to the header. For example, in the case of the example illustrated in FIG. 53, the three-dimensional data encoding device assigns threshold values Thres\_LoD[0] and Thres\_LoD[1] to the header, and does not assign Thres\_LoD[2] to the header. In this case, the three-dimensional data encoding device may estimate value  $\alpha$  of Thres\_LoD[2]. In addition, the three-dimensional data encoding device may add the number of LoDs to a header. In this way, the three-dimensional data encoding device is capable of determining the lowermost-layer LoD using the number of LoDs.

[0591] In addition, setting threshold values for the respective layers LoDs in such a manner that a larger threshold value is set to a higher layer makes a higher layer (layer closer to LoD0) to have a sparse point cloud (sparse) in which three-dimensional points are more distant and makes a lower layer to have a dense point cloud (dense) in which three-dimensional points are closer. It is to be noted that, in an example illustrated in FIG. 53, LoD0 is the uppermost layer.

[0592] In addition, the method of selecting an initial three-dimensional point at the time of setting each LoD may depend on an encoding order at the time of geometry information encoding. For example, the three-dimensional data encoding device configures LoD0 by selecting the three-dimensional point encoded first at the time of the geometry information encoding as initial point a0 of LoD0, and selecting point a1 and point a2 from initial point a0 as the origin. The three-dimensional data encoding device then may select the three-dimensional point whose geometry information has been encoded at the earliest time among three-dimensional points which do not belong to LoD0, as initial point b0 of LoD1. In other words, the three-dimensional data encoding device may select the three-dimensional point whose geometry information has been encoded at the earliest time among three-dimensional points which do not belong to layers (LoD0 to LoDn-1) above LoDn, as initial point n0 of LoDn. In this way, the three-dimensional data encoding device is capable of configuring the same LoD as in encoding by using, in decoding, the initial point selecting method similar to the one used in the encoding, which enables appropriate decoding of a bitstream. More specifically, the three-dimensional data encoding device selects the three-dimensional point whose geometry information has been decoded at the earliest time among three-

dimensional points which do not belong to layers above LoD<sub>n</sub>, as initial point n0 of LoD<sub>n</sub>.

[0593] Hereinafter, a description is given of a method of generating the predicted value of the attribute information of each three-dimensional point using information of LoDs. For example, when encoding three-dimensional points starting with the three-dimensional points included in LoD0, the three-dimensional data encoding device generates current three-dimensional points which are included in LoD1 using encoded and decoded (hereinafter also simply referred to as “encoded”) attribute information included in LoD0 and LoD1. In this way, the three-dimensional data encoding device generates a predicted value of attribute information of each three-dimensional point included in LoDn using encoded attribute information included in LoDn' (n'≤n). In other words, the three-dimensional data encoding device does not use attribute information of each of three-dimensional points included in any layer below LoDn to calculate a predicted value of attribute information of each of the three-dimensional points included in LoDn.

[0594] For example, the three-dimensional data encoding device calculates an average of attribute information of N or less three-dimensional points among encoded three-dimensional points surrounding a current three-dimensional point to be encoded, to generate a predicted value of attribute information of the current three-dimensional point. In addition, the three-dimensional data encoding device may add value N to, for example, a header of a bitstream. It is to be noted that the three-dimensional data encoding device may change value N for each three-dimensional point, and may add value N for each three-dimensional point. This enables selection of appropriate N for each three-dimensional point, which makes it possible to increase the accuracy of the predicted value. Accordingly, it is possible to reduce the prediction residual. Alternatively, the three-dimensional data encoding device may add value N to a header of a bitstream, and may fix the value indicating N in the bitstream. This eliminates the need to encode or decode value N for each three-dimensional point, which makes it possible to reduce the processing amount. In addition, the three-dimensional data encoding device may encode the values of N separately for each LoD. In this way, it is possible to increase the coding efficiency by selecting appropriate N for each LoD.

[0595] Alternatively, the three-dimensional data encoding device may calculate a predicted value of attribute information of three-dimensional point based on weighted average values of attribute information of encoded N neighbor three-dimensional points. For example, the three-dimensional data encoding device calculates weights using distance information between a current three-dimensional point and each of N neighbor three-dimensional points.

[0596] When encoding value N for each LoD, for example, the three-dimensional data encoding device sets larger value N to a higher layer LoD, and sets smaller value N to a lower layer LoD. The distance between three-dimensional points belonging to a higher layer LoD is large, there is a possibility that it is possible to increase the prediction accuracy by setting large value N, selecting a plurality of neighbor three-dimensional points, and averaging the values. Furthermore, the distance between three-dimensional points belonging to a lower layer LoD is small, it is possible to perform efficient prediction while reducing the processing amount of averaging by setting smaller value N.

[0597] FIG. 54 is a diagram illustrating an example of attribute information to be used for predicted values. As described above, the predicted value of point P included in LoD<sub>N</sub> is generated using encoded neighbor point P' included in LoD<sub>N'</sub> (N'≤N). Here, neighbor point P' is selected based on the distance from point P. For example, the predicted value of attribute information of point b2 illustrated in FIG. 54 is generated using attribute information of each of points a0, a1, b0, and b1.

[0598] Neighbor points to be selected vary depending on the values of N described above. For example, in the case of N=5, a0, a1, a2, b0, and b1 are selected as neighbor points. In the case of N=4, a0, a1, a2, and b1 are selected based on distance information.

[0599] The predicted value is calculated by distance-dependent weighted averaging. For example, in the example illustrated in FIG. 54, predicted value a2p of point a2 is calculated by weighted averaging of attribute information of each of point a0 and a1, as represented by (Equation A2) and (Equation A3). It is to be noted that Ai is an attribute information value of ai.

[Math. 2]

$$a2p = \sum_{i=0}^1 w_i \times A_i \quad (\text{Equation A2})$$

$$w_i = \frac{1}{\sum_{j=0}^1 \frac{1}{d(a2, aj)}} \quad (\text{Equation A3})$$

[0600] In addition, predicted value b2p of point b2 is calculated by weighted averaging of attribute information of each of point a0, a1, a2, b0, and b1, as represented by (Equation A4) and (Equation A6). It is to be noted that Bi is an attribute information value of bi.

[Math. 3]

$$b2p = \sum_{i=0}^2 wa_i \times A_i + \sum_{i=0}^1 wb_i \times B_i \quad (\text{Equation A4})$$

$$wa_i = \frac{1}{\sum_{j=0}^2 \frac{1}{d(b2, aj)} + \sum_{j=0}^1 \frac{1}{d(b2, bj)}} \quad (\text{Equation A5})$$

$$wb_i = \frac{1}{\sum_{j=0}^2 \frac{1}{d(b2, aj)} + \sum_{j=0}^1 \frac{1}{d(b2, bj)}} \quad (\text{Equation A6})$$

[0601] In addition, the three-dimensional data encoding device may calculate a difference value (prediction residual) generated from the value of attribute information of a three-dimensional point and neighbor points, and may quantize the calculated prediction residual. For example, the three-dimensional data encoding device performs quantization by dividing the prediction residual by a quantization scale (also referred to as a quantization step). In this case, an error (quantization error) which may be generated by quantization reduces as the quantization scale is smaller. In the other case where the quantization scale is larger, the resulting quantization error is larger.

**[0602]** It is to be noted that the three-dimensional data encoding device may change the quantization scale to be used for each LoD. For example, the three-dimensional data encoding device reduces the quantization scale more for a higher layer, and increases the quantization scale more for a lower layer. The value of attribute information of a three-dimensional point belonging to a higher layer may be used as a predicted value of attribute information of a three-dimensional point belonging to a lower layer. Thus, it is possible to increase the coding efficiency by reducing the quantization scale for the higher layer to reduce the quantization error that can be generated in the higher layer and to increase the prediction accuracy of the predicted value. It is to be noted that the three-dimensional data encoding device may add the quantization scale to be used for each LoD to, for example, a header. In this way, the three-dimensional data encoding device can decode the quantization scale correctly, thereby appropriately decoding the bitstream.

**[0603]** In addition, the three-dimensional data encoding device may convert a signed integer value (signed quantized value) which is a quantized prediction residual into an unsigned integer value (unsigned quantized value). This eliminates the need to consider occurrence of a negative integer when entropy encoding the prediction residual. It is to be noted that the three-dimensional data encoding device does not always need to convert a signed integer value into an unsigned integer value, and, for example, that the three-dimensional data encoding device may entropy encode a sign bit separately.

**[0604]** The prediction residual is calculated by subtracting a prediction value from the original value. For example, as represented by (Equation A7), prediction residual  $a2r$  of point  $a2$  is calculated by subtracting predicted value  $a2p$  of point  $a2$  from value  $A2$  of attribute information of point  $a2$ . As represented by (Equation A8), prediction residual  $b2r$  of point  $b2$  is calculated by subtracting predicted value  $b2p$  of point  $b2$  from value  $B2$  of attribute information of point  $b2$ .

$$a2r = A2 - a2p \quad (\text{Equation A7})$$

$$b2r = B2 - b2p \quad (\text{Equation A8})$$

**[0605]** In addition, the prediction residual is quantized by being divided by a Quantization Step (QS). For example, quantized value  $a2q$  of point  $a2$  is calculated according to (Equation A9). Quantized value  $b2q$  of point  $b2$  is calculated according to (Equation A10). Here,  $QS\_LoD0$  is a QS for LoD0, and  $QS\_LoD1$  is a QS for LoD1. In other words, a QS may be changed according to an LoD.

$$a2q = a2r/QS\_LoD0 \quad (\text{Equation A9})$$

$$b2q = b2r/QS\_LoD1 \quad (\text{Equation A10})$$

**[0606]** In addition, the three-dimensional data encoding device converts signed integer values which are quantized values as indicated below into unsigned integer values as indicated below. When signed integer value  $a2q$  is smaller than 0, the three-dimensional data encoding device sets unsigned integer value  $a2u$  to  $-1-(2xa2q)$ . When signed

integer value  $a2q$  is 0 or more, the three-dimensional data encoding device sets unsigned integer value  $a2u$  to  $2xa2q$ .

**[0607]** Likewise, when signed integer value  $b2q$  is smaller than 0, the three-dimensional data encoding device sets unsigned integer value  $b2u$  to  $-1-(2xb2q)$ . When signed integer value  $b2q$  is 0 or more, the three-dimensional data encoding device sets unsigned integer value  $b2u$  to  $2xb2q$ .

**[0608]** In addition, the three-dimensional data encoding device may encode the quantized prediction residual (unsigned integer value) by entropy encoding. For example, the three-dimensional data encoding device may binarize the unsigned integer value and then apply binary arithmetic encoding to the binary value.

**[0609]** It is to be noted that, in this case, the three-dimensional data encoding device may switch binarization methods according to the value of a prediction residual. For example, when prediction residual  $pu$  is smaller than threshold value  $R\_TH$ , the three-dimensional data encoding device binarizes prediction residual  $pu$  using a fixed bit count required for representing threshold value  $R\_TH$ . In addition, when prediction residual  $pu$  is larger than or equal to threshold value  $R\_TH$ , the three-dimensional data encoding device binarizes the binary data of threshold value  $R\_TH$  and the value of  $(pu-R\_TH)$ , using exponential-Golomb coding, or the like.

**[0610]** For example, when threshold value  $R\_TH$  is 63 and prediction residual  $pu$  is smaller than 63, the three-dimensional data encoding device binarizes prediction residual  $pu$  using 6 bits. When prediction residual  $pu$  is larger than or equal to 63, the three-dimensional data encoding device performs arithmetic encoding by binarizing the binary data (111111) of threshold value  $R\_TH$  and  $(pu-63)$  using exponential-Golomb coding.

**[0611]** In a more specific example, when prediction residual  $pu$  is 32, the three-dimensional data encoding device generates 6-bit binary data (100000), and arithmetic encodes the bit sequence. In addition, when prediction residual  $pu$  is 66, the three-dimensional data encoding device generates binary data (111111) of threshold value  $R\_TH$  and a bit sequence (00100) representing value 3 (66-63) using exponential-Golomb coding, and arithmetic encodes the bit sequence (111111+00100).

**[0612]** In this way, the three-dimensional data encoding device can perform encoding while preventing a binary bit count from increasing abruptly in the case where a prediction residual becomes large by switching binarization methods according to the magnitude of the prediction residual. It is to be noted that the three-dimensional data encoding device may add threshold value  $R\_TH$  to, for example, a header of a bitstream.

**[0613]** For example, in the case where encoding is performed at a high bit rate, that is, when a quantization scale is small, a small quantization error and a high prediction accuracy are obtained. As a result, a prediction residual may not be large. Thus, in this case, the three-dimensional data encoding device sets large threshold value  $R\_TH$ . This reduces the possibility that the binary data of threshold value  $R\_TH$  is encoded, which increases the coding efficiency. In the opposite case where encoding is performed at a low bit rate, that is, when a quantization scale is large, a large quantization error and a low prediction accuracy are obtained. As a result, a prediction residual may be large. Thus, in this case, the three-dimensional data encoding

device sets small threshold value  $R_{TH}$ . In this way, it is possible to prevent abrupt increase in bit length of binary data.

[0614] In addition, the three-dimensional data encoding device may switch threshold value  $R_{TH}$  for each LoD, and may add threshold value  $R_{TH}$  for each LoD to, for example, a header. In other words, the three-dimensional data encoding device may switch binarization methods for each LoD. For example, since distances between three-dimensional points are large in a higher layer, a prediction accuracy is low, which may increase a prediction residual. Thus, the three-dimensional data encoding device prevents abrupt increase in bit length of binary data by setting small threshold value  $R_{TH}$  to the higher layer. In addition, since distances between three-dimensional points are small in a lower layer, a prediction accuracy is high, which may reduce a prediction residual. Thus, the three-dimensional data encoding device increases the coding efficiency by setting large threshold value  $R_{TH}$  to the lower layer.

[0615] FIG. 55 is a diagram indicating examples of exponential-Golomb codes. The diagram indicates the relationships between pre-binariization values (non-binary values) and post-binariization bits (codes). It is to be noted that 0 and 1 indicated in FIG. 55 may be inverted.

[0616] The three-dimensional data encoding device applies arithmetic encoding to the binary data of prediction residuals. In this way, the coding efficiency can be increased. It is to be noted that, in the application of the arithmetic encoding, there is a possibility that occurrence probability tendencies of 0 and 1 in each bit vary, in binary data, between an n-bit code which is a part binarized by n bits and a remaining code which is a part binarized using exponential-Golomb coding. Thus, the three-dimensional data encoding device may switch methods of applying arithmetic encoding between the n-bit code and the remaining code.

[0617] For example, the three-dimensional data encoding device performs arithmetic encoding on the n-bit code using one or more coding tables (probability tables) different for each bit. At this time, the three-dimensional data encoding device may change the number of coding tables to be used for each bit. For example, the three-dimensional data encoding device performs arithmetic encoding using one coding table for first bit  $b_0$  in an n-bit code. The three-dimensional data encoding device uses two coding tables for the next bit  $b_1$ . The three-dimensional data encoding device switches coding tables to be used for arithmetic encoding of bit  $b_1$  according to the value (0 or 1) of  $b_0$ . Likewise, the three-dimensional data encoding device uses four coding tables for the next bit  $b_2$ . The three-dimensional data encoding device switches coding tables to be used for arithmetic encoding of bit  $b_2$  according to the values (in a range from 0 to 3) of  $b_0$  and  $b_1$ .

[0618] In this way, the three-dimensional data encoding device uses  $2n-1$  coding tables when arithmetic encoding each bit  $b_{n-1}$  in n-bit code. The three-dimensional data encoding device switches coding tables to be used according to the values (occurrence patterns) of bits before  $b_{n-1}$ . In this way, the three-dimensional data encoding device can use coding tables appropriate for each bit, and thus can increase the coding efficiency.

[0619] It is to be noted that the three-dimensional data encoding device may reduce the number of coding tables to be used for each bit. For example, the three-dimensional data encoding device may switch  $2m$  coding tables accord-

ing to the values (occurrence patterns) of m bits ( $m < n-1$ ) before  $b_{n-1}$  when arithmetic encoding each bit  $b_{n-1}$ . In this way, it is possible to increase the coding efficiency while reducing the number of coding tables to be used for each bit. It is to be noted that the three-dimensional data encoding device may update the occurrence probabilities of 0 and 1 in each coding table according to the values of binary data occurred actually. In addition, the three-dimensional data encoding device may fix the occurrence probabilities of 0 and 1 in coding tables for some bit(s). In this way, it is possible to reduce the number of updates of occurrence probabilities, and thus to reduce the processing amount.

[0620] For example, when an n-bit code is  $b_0, b_1, b_2, \dots, b_{n-1}$ , the coding table for  $b_0$  is one table (CTb0). Coding tables for  $b_1$  are two tables (CTb10 and CTb11). Coding tables to be used are switched according to the value (0 or 1) of  $b_0$ . Coding tables for  $b_2$  are four tables (CTb20, CTb21, CTb22, and CTb23). Coding tables to be used are switched according to the values (in the range from 0 to 3) of  $b_0$  and  $b_1$ . Coding tables for  $b_{n-1}$  are  $2n-1$  tables (CTbn0, CTbn1, ..., CTbn( $2n-1-1$ )). Coding tables to be used are switched according to the values (in a range from 0 to  $2n-1-1$ ) of  $b_0, b_1, \dots, b_{n-2}$ .

[0621] It is to be noted that the three-dimensional data encoding device may apply, to an n-bit code, arithmetic encoding ( $m=2n$ ) by m-ary that sets the value in the range from 0 to  $2n-1$  without binarization. When the three-dimensional data encoding device arithmetic encodes an n-bit code by an m-ary, the three-dimensional data decoding device may reconstruct the n-bit code by arithmetic decoding the m-ary.

[0622] FIG. 56 is a diagram for illustrating processing in the case where remaining codes are exponential-Golomb codes. As indicated in FIG. 56, each remaining code which is a part binarized using exponential-Golomb coding includes a prefix and a suffix. For example, the three-dimensional data encoding device switches coding tables between the prefix and the suffix. In other words, the three-dimensional data encoding device arithmetic encodes each of bits included in the prefix using coding tables for the prefix, and arithmetic encodes each of bits included in the suffix using coding tables for the suffix.

[0623] It is to be noted that the three-dimensional data encoding device may update the occurrence probabilities of 0 and 1 in each coding table according to the values of binary data occurred actually. In addition, the three-dimensional data encoding device may fix the occurrence probabilities of 0 and 1 in one of coding tables. In this way, it is possible to reduce the number of updates of occurrence probabilities, and thus to reduce the processing amount. For example, the three-dimensional data encoding device may update the occurrence probabilities for the prefix, and may fix the occurrence probabilities for the suffix.

[0624] In addition, the three-dimensional data encoding device decodes a quantized prediction residual by inverse quantization and reconstruction, and uses a decoded value which is the decoded prediction residual for prediction of a current three-dimensional point to be encoded and the following three-dimensional point(s). More specifically, the three-dimensional data encoding device calculates an inverse quantized value by multiplying the quantized prediction residual (quantized value) with a quantization scale, and adds the inverse quantized value and a prediction value to obtain the decoded value (reconstructed value).

**[0625]** For example, quantized value a2iq of point a2 is calculated using quantized value a2q of point a2 according to (Equation A11). Inverse quantized value b2iq of point b2q is calculated using quantized value b2q of point b2 according to (Equation A12). Here, QS\_LoD0 is a QS for LoD0, and QS\_LoD1 is a QS for LoD1. In other words, a QS may be changed according to an LoD.

$$a2iq = a2q \times QS\_LoD0 \quad (\text{Equation A11})$$

$$b2iq = b2q \times QS\_LoD1 \quad (\text{Equation A12})$$

**[0626]** For example, as represented by (Equation A13), decoded value a2rec of point a2 is calculated by adding inverse quantization value a2iq of point a2 to predicted value a2p of point a2. As represented by (Equation A14), decoded value b2rec of point b2 is calculated by adding inverse quantized value b2iq of point b2 to predicted value b2p of point b2.

$$a2rec = a2iq + a2p \quad (\text{Equation A13})$$

$$b2rec = b2iq + b2p \quad (\text{Equation A14})$$

**[0627]** Hereinafter, a syntax example of a bitstream according to the present embodiment is described. FIG. 57 is a diagram indicating the syntax example of an attribute header (attribute\_header) according to the present embodiment. The attribute header is header information of attribute information. As indicated in FIG. 57, the attribute header includes the number of layers information (NumLoD), the number of three-dimensional points information (NumOfPoint[i]), a layer threshold value (Thres\_LoD[i]), the number of neighbor points information (NumNeighborPoint[i]), a prediction threshold value (THd[i]), a quantization scale (QS[i]), and a binarization threshold value (R\_TH[i]).

**[0628]** The number of layers information (NumLoD) indicates the number of LoDs to be used.

**[0629]** The number of three-dimensional points information (NumOfPoint[i]) indicates the number of three-dimensional points belonging to layer i. It is to be noted that the three-dimensional data encoding device may add, to another header, the number of three-dimensional points information indicating the total number of three-dimensional points. In this case, the three-dimensional data encoding device does not need to add, to a header, NumOfPoint [NumLoD-1] indicating the number of three-dimensional points belonging to the lowermost layer. In this case, the three-dimensional data decoding device is capable of calculating NumOfPoint [NumLoD-1] according to (Equation A15). In this case, it is possible to reduce the code amount of the header.

[Math. 4]

$$\text{NumOfPoint}[\text{NumLoD}-1] = \quad (\text{Equation A15})$$

$$\text{AllNumOfPoint} - \sum_{j=0}^{\text{NumLoD}-2} \text{NumOfPoint}[j]$$

**[0630]** The layer threshold value (Thres\_LoD[i]) is a threshold value to be used to set layer i. The three-dimensional data encoding device and the three-dimensional data decoding device configure LoDi in such a manner that the distance between points in LoDi becomes larger than threshold value Thres\_LoD[i]. The three-dimensional data encoding device does not need to add the value of Thres\_LoD [NumLoD-1] (lowermost layer) to a header. In this case, the three-dimensional data decoding device may estimate 0 as the value of Thres\_LoD[NumLoD-1]. In this case, it is possible to reduce the code amount of the header.

**[0631]** The number of neighbor points information (NumNeighborPoint[i]) indicates the upper limit value of the number of neighbor points to be used to generate a predicted value of a three-dimensional point belonging to layer i. The three-dimensional data encoding device may calculate a predicted value using the number of neighbor points M when the number of neighbor points M is smaller than NumNeighborPoint[i] ( $M < \text{NumNeighborPoint}[i]$ ). Furthermore, when there is no need to differentiate the values of NumNeighborPoint[i] for respective LoDs, the three-dimensional data encoding device may add a piece of the number of neighbor points information (NumNeighborPoint) to be used in all LoDs to a header.

**[0632]** The prediction threshold value (THd[i]) indicates the upper limit value of the distance between a current three-dimensional point to be encoded or decoded in layer i and each of neighbor three-dimensional points to be used to predict the current three-dimensional point. The three-dimensional data encoding device and the three-dimensional data decoding device do not use, for prediction, any three-dimensional point distant from the current three-dimensional point over THd[i]. It is to be noted that, when there is no need to differentiate the values of THd[i] for respective LoDs, the three-dimensional data encoding device may add a single prediction threshold value (THd) to be used in all LoDs to a header.

**[0633]** The quantization scale (QS[i]) indicates a quantization scale to be used for quantization and inverse quantization in layer i.

**[0634]** The binarization threshold value (R\_TH[i]) is a threshold value for switching binarization methods of prediction residuals of three-dimensional points belonging to layer i. For example, the three-dimensional data encoding device binarizes prediction residual pu using a fixed bit count when a prediction residual is smaller than threshold value R\_TH, and binarizes the binary data of threshold value R\_TH and the value of (pu-R\_TH) using exponential-Golomb coding when a prediction residual is larger than or equal to threshold value R\_TH. It is to be noted that, when there is no need to switch the values of R\_TH[i] between LoDs, the three-dimensional data encoding device may add a single binarization threshold value (R\_TH) to be used in all LoDs to a header.

**[0635]** It is to be noted that R\_TH[i] may be the maximum value which can be represented by n bits. For example, R\_TH is 63 in the case of 6 bits, and R\_TH is 255 in the case of 8 bits. Alternatively, the three-dimensional data encoding device may encode a bit count instead of encoding the maximum value which can be represented by n bits as a binarization threshold value. For example, the three-dimensional data encoding device may add value 6 in the case of R\_TH[i]=63 to a header, and may add value 8 in the case of R\_TH[i]=255 to a header. Alternatively, the three-dimen-

sional data encoding device may define the minimum value (minimum bit count) representing R\_TH[i], and add a relative bit count from the minimum value to a header. For example, the three-dimensional data encoding device may add value 0 to a header when R\_TH[i]=63 is satisfied and the minimum bit count is 6, and may add value 2 to a header when R\_TH[i]=255 is satisfied and the minimum bit count is 6.

[0636] Alternatively, the three-dimensional data encoding device may entropy encode at least one of NumLoD, Thres\_LoD[i], NumNeighborPoint[i], THd[i], QS[i], and R\_TH[i], and add the entropy encoded one to a header. For example, the three-dimensional data encoding device may binarize each value and perform arithmetic encoding on the binary value. In addition, the three-dimensional data encoding device may encode each value using a fixed length in order to reduce the processing amount.

[0637] Alternatively, the three-dimensional data encoding device does not always need to add at least one of NumLoD, Thres\_LoD[i], NumNeighborPoint[i], THd[i], QS[i], and R\_TH[i] to a header. For example, at least one of these values may be defined by a profile or a level in a standard, or the like. In this way, it is possible to reduce the bit amount of the header.

[0638] FIG. 58 is a diagram indicating the syntax example of attribute data (attribute\_data) according to the present embodiment. The attribute data includes encoded data of the attribute information of a plurality of three-dimensional points. As indicated in FIG. 58, the attribute data includes an n-bit code and a remaining code.

[0639] The n-bit code is encoded data of a prediction residual of a value of attribute information or a part of the encoded data. The bit length of the n-bit code depends on value R\_TH[i]. For example, the bit length of the n-bit code is 6 bits when the value indicated by R\_TH[i] is 63, the bit length of the n-bit code is 8 bits when the value indicated by R\_TH[i] is 255.

[0640] The remaining code is encoded data encoded using exponential-Golomb coding among encoded data of the prediction residual of the value of the attribute information. The remaining code is encoded or decoded when the value of the n-bit code is equal to R\_TH[i]. The three-dimensional data decoding device decodes the prediction residual by adding the value of the n-bit code and the value of the remaining code. It is to be noted that the remaining code does not always need to be encoded or decoded when the value of the n-bit code is not equal to R\_TH[i].

[0641] Hereinafter, a description is given of a flow of processing in the three-dimensional data encoding device. FIG. 59 is a flowchart of a three-dimensional data encoding process performed by the three-dimensional data encoding device.

[0642] First, the three-dimensional data encoding device encodes geometry information (geometry) (S3001). For example, the three-dimensional data encoding is performed using octree representation.

[0643] When the positions of three-dimensional points changed by quantization, etc., after the encoding of the geometry information, the three-dimensional data encoding device re-assigns attribute information of the original three-dimensional points to the post-change three-dimensional points (S3002). For example, the three-dimensional data encoding device interpolates values of attribute information according to the amounts of change in position to re-assign

the attribute information. For example, the three-dimensional data encoding device detects pre-change N three-dimensional points closer to the post-change three-dimensional positions, and performs weighted averaging of the values of attribute information of the N three-dimensional points. For example, the three-dimensional data encoding device determines weights based on distances from the post-change three-dimensional positions to the respective N three-dimensional positions in weighted averaging. The three-dimensional data encoding device then determines the values obtained through the weighted averaging to be the values of the attribute information of the post-change three-dimensional points. When two or more of the three-dimensional points are changed to the same three-dimensional position through quantization, etc., the three-dimensional data encoding device may assign the average value of the attribute information of the pre-change two or more three-dimensional points as the values of the attribute information of the post-change three-dimensional points.

[0644] Next, the three-dimensional data encoding device encodes the attribute information (attribute) re-assigned (S3003). For example, when encoding a plurality of kinds of attribute information, the three-dimensional data encoding device may encode the plurality of kinds of attribute information in order. For example, when encoding colors and reflectances as attribute information, the three-dimensional data encoding device may generate a bitstream added with the color encoding results and the reflectance encoding results after the color encoding results. It is to be noted that the order of the plurality of encoding results of attribute information to be added to a bitstream is not limited to the order, and may be any order.

[0645] Alternatively, the three-dimensional data encoding device may add, to a header for example, information indicating the start location of encoded data of each attribute information in a bitstream. In this way, the three-dimensional data decoding device is capable of selectively decoding attribute information required to be decoded, and thus is capable of skipping the decoding process of the attribute information not required to be decoded. Accordingly, it is possible to reduce the amount of processing by the three-dimensional data decoding device. Alternatively, the three-dimensional data encoding device may encode a plurality of kinds of attribute information in parallel, and may integrate the encoding results into a single bitstream. In this way, the three-dimensional data encoding device is capable of encoding the plurality of kinds of attribute information at high speed.

[0646] FIG. 60 is a flowchart of an attribute information encoding process (S3003). First, the three-dimensional data encoding device sets LoDs (S3011). In other words, the three-dimensional data encoding device assigns each of three-dimensional points to any one of the plurality of LoDs.

[0647] Next, the three-dimensional data encoding device starts a loop for each LoD (S3012). In other words, the three-dimensional data encoding device iteratively performs the processes of Steps from S3013 to S3021 for each LoD.

[0648] Next, the three-dimensional data encoding device starts a loop for each three-dimensional point (S3013). In other words, the three-dimensional data encoding device iteratively performs the processes of Steps from S3014 to S3020 for each three-dimensional point.

[0649] First, the three-dimensional data encoding device searches a plurality of neighbor points which are three-

dimensional points present in the neighborhood of a current three-dimensional point to be processed and are to be used to calculate a predicted value of the current three-dimensional point (S3014). Next, the three-dimensional data encoding device calculates the weighted average of the values of attribute information of the plurality of neighbor points, and sets the resulting value to predicted value P (S3015). Next, the three-dimensional data encoding device calculates a prediction residual which is the difference between the attribute information of the current three-dimensional point and the predicted value (S3016). Next, the three-dimensional data encoding device quantizes the prediction residual to calculate a quantized value (S3017). Next, the three-dimensional data encoding device arithmetic encodes the quantized value (S3018).

[0650] Next, the three-dimensional data encoding device inverse quantizes the quantized value to calculate an inverse quantized value (S3019). Next, the three-dimensional data encoding device adds a prediction value to the inverse quantized value to generate a decoded value (S3020). Next, the three-dimensional data encoding device ends the loop for each three-dimensional point (S3021). Next, the three-dimensional data encoding device ends the loop for each LoD (S3022).

[0651] Hereinafter, a description is given of a three-dimensional data decoding process in the three-dimensional data decoding device which decodes a bitstream generated by the three-dimensional data encoding device.

[0652] The three-dimensional data decoding device generates decoded binary data by arithmetic decoding the binary data of the attribute information in the bitstream generated by the three-dimensional data encoding device, according to the method similar to the one performed by the three-dimensional data encoding device. It is to be noted that when methods of applying arithmetic encoding are switched between the part (n-bit code) binarized using n bits and the part (remaining code) binarized using exponential-Golomb coding in the three-dimensional data encoding device, the three-dimensional data decoding device performs decoding in conformity with the arithmetic encoding, when applying arithmetic decoding.

[0653] For example, the three-dimensional data decoding device performs arithmetic decoding using coding tables (decoding tables) different for each bit in the arithmetic decoding of the n-bit code. At this time, the three-dimensional data decoding device may change the number of coding tables to be used for each bit. For example, the three-dimensional data decoding device performs arithmetic decoding using one coding table for first bit b0 in the n-bit code. The three-dimensional data decoding device uses two coding tables for the next bit b1. The three-dimensional data decoding device switches coding tables to be used for arithmetic decoding of bit b1 according to the value (0 or 1) of b0. Likewise, the three-dimensional data decoding device uses four coding tables for the next bit b2. The three-dimensional data decoding device switches coding tables to be used for arithmetic decoding of bit b2 according to the values (in the range from 0 to 3) of b0 and b1.

[0654] In this way, the three-dimensional data decoding device uses 2n-1 coding tables when arithmetic decoding each bit bn-1 in the n-bit code. The three-dimensional data decoding device switches coding tables to be used according to the values (occurrence patterns) of bits before bn-1. In this way, the three-dimensional data decoding device is

capable of appropriately decoding a bitstream encoded at an increased coding efficiency using the coding tables appropriate for each bit.

[0655] It is to be noted that the three-dimensional data decoding device may reduce the number of coding tables to be used for each bit. For example, the three-dimensional data decoding device may switch 2m coding tables according to the values (occurrence patterns) of m bits ( $m < n-1$ ) before bn-1 when arithmetic decoding each bit bn-1. In this way, the three-dimensional data decoding device is capable of appropriately decoding the bitstream encoded at the increased coding efficiency while reducing the number of coding tables to be used for each bit. It is to be noted that the three-dimensional data decoding device may update the occurrence probabilities of 0 and 1 in each coding table according to the values of binary data occurred actually. In addition, the three-dimensional data decoding device may fix the occurrence probabilities of 0 and 1 in coding tables for some bit(s). In this way, it is possible to reduce the number of updates of occurrence probabilities, and thus to reduce the processing amount.

[0656] For example, when an n-bit code is b0, b1, b2, . . . , bn-1, the coding table for b0 is one (CTb0). Coding tables for b1 are two tables (CTb10 and CTb11). Coding tables to be used are switched according to the value (0 or 1) of b0. Coding tables for b2 are four tables (CTb20, CTb21, CTb22, and CTb23). Coding tables to be used according to the values (in the range from 0 to 3) of b0 and b1. Coding tables for bn-1 are 2n-1 tables (CTbn0, CTbn1, . . . , CTbn (2n-1)). Coding tables to be used are switched according to the values (in the range from 0 to 2n-1-1) of b0, b1, . . . , bn-2.

[0657] FIG. 61 is a diagram for illustrating processing in the case where remaining codes are exponential-Golomb codes. As indicated in FIG. 61, the part (remaining part) binarized and encoded by the three-dimensional data encoding device using exponential-Golomb coding includes a prefix and a suffix. For example, the three-dimensional data decoding device switches coding tables between the prefix and the suffix. In other words, the three-dimensional data decoding device arithmetic decodes each of bits included in the prefix using coding tables for the prefix, and arithmetic decodes each of bits included in the suffix using coding tables for the suffix.

[0658] It is to be noted that the three-dimensional data decoding device may update the occurrence probabilities of 0 and 1 in each coding table according to the values of binary data occurred at the time of decoding. In addition, the three-dimensional data decoding device may fix the occurrence probabilities of 0 and 1 in one of coding tables. In this way, it is possible to reduce the number of updates of occurrence probabilities, and thus to reduce the processing amount. For example, the three-dimensional data decoding device may update the occurrence probabilities for the prefix, and may fix the occurrence probabilities for the suffix.

[0659] Furthermore, the three-dimensional data decoding device decodes the quantized prediction residual (unsigned integer value) by debinarizing the binary data of the prediction residual arithmetic decoded according to a method in conformity with the encoding method used by the three-dimensional data encoding device. The three-dimensional data decoding device first arithmetic decodes the binary data of an n-bit code to calculate a value of the n-bit code. Next,

the three-dimensional data decoding device compares the value of the n-bit code with threshold value R\_TH.

[0660] In the case where the value of the n-bit code and threshold value R\_TH match, the three-dimensional data decoding device determines that a bit encoded using exponential-Golomb coding is present next, and arithmetic decodes the remaining code which is the binary data encoded using exponential-Golomb coding. The three-dimensional data decoding device then calculates, from the decoded remaining code, a value of the remaining code using a reverse lookup table indicating the relationship between the remaining code and the value. FIG. 62 is a diagram indicating an example of a reverse lookup table indicating relationships between remaining codes and the values thereof. Next, the three-dimensional data decoding device adds the obtained value of the remaining code to R\_TH, thereby obtaining a debinarized quantized prediction residual.

[0661] In the opposite case where the value of the n-bit code and threshold value R\_TH do not match (the value of the n-bit code is smaller than value R\_TH), the three-dimensional data decoding device determines the value of the n-bit code to be the debinarized quantized prediction residual as it is. In this way, the three-dimensional data decoding device is capable of appropriately decoding the bitstream generated while switching the binarization methods according to the values of the prediction residuals by the three-dimensional data encoding device.

[0662] It is to be noted that, when threshold value R\_TH is added to, for example, a header of a bitstream, the three-dimensional data decoding device may decode threshold value R\_TH from the header, and may switch decoding methods using decoded threshold value R\_TH. When threshold value R\_TH is added to, for example, a header for each LoD, the three-dimensional data decoding device switch decoding methods using threshold value R\_TH decoded for each LoD.

[0663] For example, when threshold value R\_TH is 63 and the value of the decoded n-bit code is 63, the three-dimensional data decoding device decodes the remaining code using exponential-Golomb coding, thereby obtaining the value of the remaining code. For example, in the example indicated in FIG. 62, the remaining code is 00100, and 3 is obtained as the value of the remaining code. Next, the three-dimensional data decoding device adds 63 that is threshold value R\_TH and 3 that is the value of the remaining code, thereby obtaining 66 that is the value of the prediction residual.

[0664] In addition, when the value of the decoded n-bit code is 32, the three-dimensional data decoding device sets 32 that is the value of the n-bit code to the value of the prediction residual.

[0665] In addition, the three-dimensional data decoding device converts the decoded quantized prediction residual, for example, from an unsigned integer value to a signed integer value, through processing inverse to the processing in the three-dimensional data encoding device. In this way, when entropy decoding the prediction residual, the three-dimensional data decoding device is capable of appropriately decoding the bitstream generated without considering occurrence of a negative integer. It is to be noted that the three-dimensional data decoding device does not always need to convert an unsigned integer value to a signed integer value, and that, for example, the three-dimensional data

decoding device may decode a sign bit when decoding a bitstream generated by separately entropy encoding the sign bit.

[0666] The three-dimensional data decoding device performs decoding by inverse quantizing and reconstructing the quantized prediction residual after being converted to the signed integer value, to obtain a decoded value. The three-dimensional data decoding device uses the generated decoded value for prediction of a current three-dimensional point to be decoded and the following three-dimensional point(s). More specifically, the three-dimensional data decoding device multiplies the quantized prediction residual by a decoded quantization scale to calculate an inverse quantized value and adds the inverse quantized value and the predicted value to obtain the decoded value.

[0667] The decoded unsigned integer value (unsigned quantized value) is converted into a signed integer value through the processing indicated below. When the least significant bit (LSB) of decoded unsigned integer value a2u is 1, the three-dimensional data decoding device sets signed integer value a2q to  $-((a2u+1)>>1)$ . When the LSB of unsigned integer value a2u is not 1, the three-dimensional data decoding device sets signed integer value a2q to  $((a2u>>1)$ .

[0668] Likewise, when an LSB of decoded unsigned integer value b2u is 1, the three-dimensional data decoding device sets signed integer value b2q to  $-((b2u+1)>>1)$ . When the LSB of decoded unsigned integer value n2u is not 1, the three-dimensional data decoding device sets signed integer value b2q to  $((b2u>>1)$ .

[0669] Details of the inverse quantization and reconstruction processing by the three-dimensional data decoding device are similar to the inverse quantization and reconstruction processing in the three-dimensional data encoding device.

[0670] Hereinafter, a description is given of a flow of processing in the three-dimensional data decoding device. FIG. 63 is a flowchart of a three-dimensional data decoding process performed by the three-dimensional data decoding device. First, the three-dimensional data decoding device decodes geometry information (geometry) from a bitstream (S3031). For example, the three-dimensional data decoding device performs decoding using octree representation.

[0671] Next, the three-dimensional data decoding device decodes attribute information (attribute) from the bitstream (S3032). For example, when decoding a plurality of kinds of attribute information, the three-dimensional data decoding device may decode the plurality of kinds of attribute information in order. For example, when decoding colors and reflectances as attribute information, the three-dimensional data decoding device decodes the color encoding results and the reflectance encoding results in order of assignment in the bitstream. For example, when the reflectance encoding results are added after the color encoding results in a bitstream, the three-dimensional data decoding device decodes the color encoding results, and then decodes the reflectance encoding results. It is to be noted that the three-dimensional data decoding device may decode, in any order, the encoding results of the attribute information added to the bitstream.

[0672] Alternatively, the three-dimensional data encoding device may add, to a header for example, information indicating the start location of encoded data of each attribute information in a bitstream. In this way, the three-dimen-

sional data decoding device is capable of selectively decoding attribute information required to be decoded, and thus is capable of skipping the decoding process of the attribute information not required to be decoded. Accordingly, it is possible to reduce the amount of processing by the three-dimensional data decoding device. In addition, the three-dimensional data decoding device may decode a plurality of kinds of attribute information in parallel, and may integrate the decoding results into a single three-dimensional point cloud. In this way, the three-dimensional data decoding device is capable of decoding the plurality of kinds of attribute information at high speed.

[0673] FIG. 64 is a flowchart of an attribute information decoding process (S3032). First, the three-dimensional data decoding device sets LoDs (S3041). In other words, the three-dimensional data decoding device assigns each of three-dimensional points having the decoded geometry information to any one of the plurality of LoDs. For example, this assignment method is the same as the assignment method used in the three-dimensional data encoding device.

[0674] Next, the three-dimensional data decoding device starts a loop for each LoD (S3042). In other words, the three-dimensional data decoding device iteratively performs the processes of Steps from S3043 to S3049 for each LoD.

[0675] Next, the three-dimensional data decoding device starts a loop for each three-dimensional point (S3043). In other words, the three-dimensional data decoding device iteratively performs the processes of Steps from S3044 to S3048 for each three-dimensional point.

[0676] First, the three-dimensional data decoding device searches a plurality of neighbor points which are three-dimensional points present in the neighborhood of a current three-dimensional point to be processed and are to be used to calculate a predicted value of the current three-dimensional point to be processed (S3044). Next, the three-dimensional data decoding device calculates the weighted average of the values of attribute information of the plurality of neighbor points, and sets the resulting value to predicted value P (S3045). It is to be noted that these processes are similar to the processes in the three-dimensional data encoding device.

[0677] Next, the three-dimensional data decoding device arithmetic decodes the quantized value from the bitstream (S3046). The three-dimensional data decoding device inverse quantizes the decoded quantized value to calculate an inverse quantized value (S3047). Next, the three-dimensional data decoding device adds a predicted value to the inverse quantized value to generate a decoded value (S3048). Next, the three-dimensional data decoding device ends the loop for each three-dimensional point (S3049). Next, the three-dimensional data encoding device ends the loop for each LoD (S3050).

[0678] The following describes configurations of the three-dimensional data encoding device and three-dimensional data decoding device according to the present embodiment. FIG. 65 is a block diagram illustrating a configuration of three-dimensional data encoding device 3000 according to the present embodiment. Three-dimensional data encoding device 3000 includes geometry information encoder 3001, attribute information re-assigner 3002, and attribute information encoder 3003.

[0679] Attribute information encoder 3003 encodes geometry information (geometry) of a plurality of three-dimen-

sional points included in an input point cloud. Attribute information re-assigner 3002 re-assigns the values of attribute information of the plurality of three-dimensional points included in the input point cloud, using the encoding and decoding results of the geometry information. Attribute information encoder 3003 encodes the re-assigned attribute information (attribute). Furthermore, three-dimensional data encoding device 3000 generates a bitstream including the encoded geometry information and the encoded attribute information.

[0680] FIG. 66 is a block diagram illustrating a configuration of three-dimensional data decoding device 3010 according to the present embodiment. Three-dimensional data decoding device 3010 includes geometry information decoder 3011 and attribute information decoder 3012.

[0681] Geometry information decoder 3011 decodes the geometry information (geometry) of a plurality of three-dimensional points from a bitstream. Attribute information decoder 3012 decodes the attribute information (attribute) of the plurality of three-dimensional points from the bitstream. Furthermore, three-dimensional data decoding device 3010 integrates the decoded geometry information and the decoded attribute information to generate an output point cloud.

[0682] As described above, the three-dimensional data encoding device according to the present embodiment performs the process illustrated in FIG. 67. The three-dimensional data encoding device encodes a three-dimensional point having attribute information. First, the three-dimensional data encoding device calculates a predicted value of the attribute information of the three-dimensional point (S3061). Next, the three-dimensional data encoding device calculates a prediction residual which is the difference between the attribute information of the three-dimensional point and the predicted value (S3062). Next, the three-dimensional data encoding device binarizes the prediction residual to generate binary data (S3063). Next, the three-dimensional data encoding device arithmetic encodes the binary data (S3064).

[0683] In this way, the three-dimensional data encoding device is capable of reducing the code amount of the to-be-coded data of the attribute information by calculating the prediction residual of the attribute information, and binarizing and arithmetic encoding the prediction residual.

[0684] For example, in arithmetic encoding (S3064), the three-dimensional data encoding device uses coding tables different for each of bits of binary data. By doing so, the three-dimensional data encoding device can increase the coding efficiency.

[0685] For example, in arithmetic encoding (S3064), the number of coding tables to be used is larger for a lower-order bit of the binary data.

[0686] For example, in arithmetic encoding (S3064), the three-dimensional data encoding device selects coding tables to be used to arithmetic encode a current bit included in binary data, according to the value of a higher-order bit with respect to the current bit. By doing so, since the three-dimensional data encoding device can select coding tables to be used according to the value of the higher-order bit, the three-dimensional data encoding device can increase the coding efficiency.

[0687] For example, in binarization (S3063), the three-dimensional data encoding device binarizes a prediction residual using a fixed bit count to generate binary data when

the prediction residual is smaller than a threshold value (R\_TH); and generates binary data including a first code (n-bit code) and a second code (remaining code) when the prediction residual is larger than or equal to the threshold value (R\_TH). The first code is of a fixed bit count indicating the threshold value (R\_TH), and the second code (remaining code) is obtained by binarizing, using exponential-Golomb coding, the value obtained by subtracting the threshold value (R\_TH) from the prediction residual. In arithmetic encoding (S3064), the three-dimensional data encoding device uses arithmetic encoding methods different between the first code and the second code.

[0688] With this, for example, since it is possible to arithmetic encode the first code and the second code using arithmetic encoding methods respectively suitable for the first code and the second code, it is possible to increase coding efficiency.

[0689] For example, the three-dimensional data encoding device quantizes the prediction residual, and, in binarization (S3063), binarizes the quantized prediction residual. The threshold value (R\_TH) is changed according to a quantization scale in quantization. With this, since the three-dimensional data encoding device can use the threshold value suitably according to the quantization scale, it is possible to increase the coding efficiency.

[0690] For example, the second code includes a prefix and a suffix. In arithmetic encoding (S3064), the three-dimensional data encoding device uses different coding tables between the prefix and the suffix. In this way, the three-dimensional data encoding device can increase the coding efficiency.

[0691] For example, the three-dimensional data encoding device includes a processor and memory, and the processor performs the above process using the memory.

[0692] The three-dimensional data decoding device according to the present embodiment performs the process illustrated in FIG. 68. The three-dimensional data decoding device decodes a three-dimensional point having attribute information. First, the three-dimensional data decoding device calculates a predicted value of the attribute information of a three-dimensional point (S3071). Next, the three-dimensional data decoding device arithmetic decodes encoded data included in a bitstream to generate binary data (S3072). Next, the three-dimensional data decoding device debinarizes the binary data to generate a prediction residual (S3073). Next, the three-dimensional data decoding device calculates a decoded value of the attribute information of the three-dimensional point by adding the predicted value and the prediction residual (S3074).

[0693] In this way, the three-dimensional data decoding device is capable of appropriately decoding the bitstream of the attribute information generated by calculating the prediction residual of the attribute information and binarizing and arithmetic decoding the prediction residual.

[0694] For example, in arithmetic decoding (S3072), the three-dimensional data decoding device uses coding tables different for each of bits of binary data. With this, the three-dimensional data decoding device is capable of appropriately decoding the bitstream encoded at an increased coding efficiency.

[0695] For example, in arithmetic decoding (S3072), the number of coding tables to be used is larger for a lower bit of the binary data.

[0696] For example, in arithmetic decoding (S3072), the three-dimensional data decoding device selects coding tables to be used to arithmetic decode a current bit included in binary data, according to the value of a higher-order bit with respect to the current bit. With this, the three-dimensional data decoding device is capable of appropriately decoding the bitstream encoded at an increased coding efficiency.

[0697] For example, in debinarization (S3073), the three-dimensional data decoding device debinarizes the first code (n-bit code) of a fixed bit count included in the binary data to generate a first value. The three-dimensional data decoding device: determines the first value to be the prediction residual when the first value is smaller than the threshold value (R\_TH); and, when the first value is larger than or equal to the threshold value (R\_YH), generates a second value by debinarizing the second code (remaining code) which is an exponential-Golomb code included in the binary data and adds the first value and the second value, thereby generating a prediction residual. In the arithmetic decoding (S3072), the three-dimensional data decoding device uses arithmetic decoding methods different between the first code and the second code.

[0698] With this, the three-dimensional data decoding device is capable of appropriately decoding the bitstream encoded at an increased coding efficiency.

[0699] For example, the three-dimensional data decoding device inverse quantizes the prediction residual, and, in addition (S3074), adds the predicted value and the inverse quantized prediction residual. The threshold value (R\_TH) is changed according to a quantization scale in inverse quantization. With this, the three-dimensional data decoding device is capable of appropriately decoding the bitstream encoded at an increased coding efficiency.

[0700] For example, the second code includes a prefix and a suffix. In arithmetic decoding (S3072), the three-dimensional data decoding device uses different coding tables between the prefix and the suffix. With this, the three-dimensional data decoding device is capable of appropriately decoding the bitstream encoded at an increased coding efficiency.

[0701] For example, the three-dimensional data decoding device includes a processor and memory, and the processor performs the above-described process using the memory.

#### Embodiment 9

[0702] Predicted values may be generated by a method different from that in Embodiment 8. Hereinafter, a three-dimensional point to be encoded is referred to as a first three-dimensional point, and one or more three-dimensional points in the vicinity of the first three-dimensional point is referred to as one or more second three-dimensional points in some cases.

[0703] For example, in generating of a predicted value of an attribute information item (attribute information) of a three-dimensional point, an attribute value as it is of a closest three-dimensional point among encoded and decoded three-dimensional points in the vicinity of a three-dimensional point to be encoded may be generated as a predicted value. In the generating of the predicted value, prediction mode information (PredMode) may be appended for each three-dimensional point, and one predicted value may be selected from a plurality of predicted values to allow generation of a predicted value. Specifically, for example,

is conceivable that, for total number M of prediction modes, an average value is assigned to prediction mode 0, an attribute value of three-dimensional point A is assigned to prediction mode 1, . . . , and an attribute value of three-dimensional point Z is assigned to prediction mode M-1, and the prediction mode used for prediction is appended to a bitstream for each three-dimensional point. As such, a first prediction mode value indicating a first prediction mode for calculating, as a predicted value, an average of attribute information items of the surrounding three-dimensional points may be smaller than a second prediction mode value indicating a second prediction mode for calculating, as a predicted value, an attribute information item as it is of a surrounding three-dimensional point. Here, the “average value” as the predicted value calculated in prediction mode 0 is an average value of the attribute values of the three-dimensional points in the vicinity of the three-dimensional point to be encoded.

[0704] FIG. 69 is a diagram showing a first example of a table representing predicted values calculated in the prediction modes according to Embodiment 9. FIG. 70 is a diagram showing examples of attribute information items used as the predicted values according to Embodiment 9. FIG. 71 is a diagram showing a second example of a table representing predicted values calculated in the prediction modes according to Embodiment 9.

[0705] Number M of prediction modes may be appended to a bitstream. Number M of prediction modes may be defined by a profile or a level of standards rather than appended to the bitstream. Number M of prediction modes may be also calculated from number N of three-dimensional points used for prediction. For example, number M of prediction modes may be calculated by  $M=N+1$ .

[0706] The table in FIG. 69 is an example of a case with number N of three-dimensional points used for prediction being 4 and number M of prediction modes being 5. A predicted value of an attribute information item of point b2 can be generated by using attribute information items of points a0, a1, a2, b1. In selecting one prediction mode from a plurality of prediction modes, a prediction mode for generating, as a predicted value, an attribute value of each of points a0, a1, a2, b1 may be selected in accordance with distance information from point b2 to each of points a0, a1, a2, b1. The prediction mode is appended for each three-dimensional point to be encoded. The predicted value is calculated in accordance with a value corresponding to the appended prediction mode.

[0707] The table in FIG. 71 is, as in FIG. 69, an example of a case with number N of three-dimensional points used for prediction being 4 and number M of prediction modes being 5. A predicted value of an attribute information item of point a2 can be generated by using attribute information items of points a0, a1. In selecting one prediction mode from a plurality of prediction modes, a prediction mode for generating, as a predicted value, an attribute value of each of points a0 and a1 may be selected in accordance with distance information from point a2 to each of points a0, a1. The prediction mode is appended for each three-dimensional point to be encoded. The predicted value is calculated in accordance with a value corresponding to the appended prediction mode.

[0708] When the number of neighboring points, that is, number N of surrounding three-dimensional points is smaller than four such as at point a2 above, a prediction

mode to which a predicted value is not assigned may be written as “not available” in the table.

[0709] Assignment of values of the prediction modes may be determined in accordance with the distance from the three-dimensional point to be encoded. For example, prediction mode values indicating a plurality of prediction modes decrease with decreasing distance from the three-dimensional point to be encoded to the surrounding three-dimensional points having the attribute information items used as the predicted values. The example in FIG. 69 shows that points b1, a2, a1, a0 are sequentially located closer to point b2 as the three-dimensional point to be encoded. For example, in the calculating of the predicted value, the attribute information item of point b1 is calculated as the predicted value in a prediction mode indicated by a prediction mode value of “1” among two or more prediction modes, and the attribute information item of point a2 is calculated as the predicted value in a prediction mode indicated by a prediction mode value of “2”. As such, the prediction mode value indicating the prediction mode for calculating, as the predicted value, the attribute information item of point b1 is smaller than the prediction mode value indicating the prediction mode for calculating, as the predicted value, the attribute information item of point a2 farther from point b2 than point b1.

[0710] Thus, a small prediction mode value can be assigned to a point that is more likely to be predicted and selected due to a short distance, thereby reducing a bit number for encoding the prediction mode value. Also, a small prediction mode value may be preferentially assigned to a three-dimensional point belonging to the same LoD as the three-dimensional point to be encoded.

[0711] FIG. 72 is a diagram showing a third example of a table representing predicted values calculated in the prediction modes according to Embodiment 9. Specifically, the third example is an example of a case where an attribute information item used as a predicted value is a value of color information (YUV) of a surrounding three-dimensional point. As such, the attribute information item used as the predicted value may be color information indicating a color of the three-dimensional point.

[0712] As shown in FIG. 72, a predicted value calculated in a prediction mode indicated by a prediction mode value of “0” is an average of Y, U, and V components defining a YUV color space. Specifically, the predicted value includes a weighted average Yave of Y component values Yb1, Ya2, Ya1, Ya0 corresponding to points b1, a2, a1, a0, respectively, a weighted average Uave of U component values Ub1, Ua2, Ua1, Ua0 corresponding to points b1, a2, a1, a0, respectively, and a weighted average Vave of V component values Vb1, Va2, Va1, Va0 corresponding to points b1, a2, a1, a0, respectively. Predicted values calculated in prediction modes indicated by prediction mode values of “1” to “4” include color information of the surrounding three-dimensional points b1, a2, a1, a0. The color information is indicated by combinations of the Y, U, and V component values.

[0713] In FIG. 72, the color information is indicated by a value defined by the YUV color space, but not limited to the YUV color space. The color information may be indicated by a value defined by an RGB color space or a value defined by any other color space.

[0714] As such, in the calculating of the predicted value, two or more averages or two or more attribute information

items may be calculated as the predicted values of the prediction modes. The two or more averages or the two or more attribute information items may indicate two or more component values each defining a color space.

[0715] For example, when a prediction mode indicated by a prediction mode value of “2” in the table in FIG. 72 is selected, a Y component, a U component, and a V component as attribute values of the three-dimensional point to be encoded may be encoded as predicted values Ya2, Ua2, Va2. In this case, the prediction mode value of “2” is appended to the bitstream.

[0716] FIG. 73 is a diagram showing a fourth example of a table representing predicted values calculated in the prediction modes according to Embodiment 9. Specifically, the fourth example is an example of a case where an attribute information item used as a predicted value is a value of reflectance information of a surrounding three-dimensional point. The reflectance information is, for example, information indicating reflectance R.

[0717] As shown in FIG. 73, a predicted value calculated in a prediction mode indicated by a prediction mode value of “0” is weighted average Rave of reflectances Rb1, Ra2, Ra1, Ra0 corresponding to points b1, a2, a1, a0, respectively. Predicted values calculated in prediction modes indicated by prediction mode values of “1” to “4” are reflectances Rb1, Ra2, Ra1, Ra0 of surrounding three-dimensional points b1, a2, a1, a0, respectively.

[0718] For example, when a prediction mode indicated by a prediction mode value of “3” in the table in FIG. 73 is selected, a reflectance as an attribute value of a three-dimensional point to be encoded may be encoded as predicted value Ra1. In this case, the prediction mode value of “3” is appended to the bitstream.

[0719] As shown in FIGS. 89 and 90, the attribute information item may include a first attribute information item and a second attribute information item different from the first attribute information item. The first attribute information item is, for example, color information. The second attribute information item is, for example, reflectance information. In the calculating of the predicted value, a first predicted value may be calculated by using the first attribute information item, and a second predicted value may be calculated by using the second attribute information item.

#### Embodiment 10

[0720] As another example of encoding the attribute information of a three-dimensional point by using the information on the LoDs, a method will be described that encodes a plurality of three-dimensional points in order from the three-dimensional points included in the higher layers of the LoDs. For example, when calculating the predicted value of the attribute value (attribute information) of a three-dimensional point included in the LoDn, the three-dimensional data encoding device may switch the attribute value of a three-dimensional point included in which LoD may be referred to, by using a flag or the like. For example, the three-dimensional data encoding device generates EnableReferringSameLoD (the same layer reference permission flag), which is the information indicating whether or not to permit referring to the other three-dimensional points in the same LoD as a current three-dimensional point to be encoded. For example, when EnableReferringSameLoD is

the value 1, reference in the same LoD is permitted, and when EnableReferringSameLoD is the value 0, reference in the same LoD is prohibited.

[0721] For example, the three-dimensional data encoding device generates the predicted value of the attribute information of a current three-dimensional point by selecting three-dimensional points around the current three-dimensional point based on EnableReferringSameLoD, and calculating the average of the attribute values of predefined N or less three-dimensional points among the selected surrounding three-dimensional points. Additionally, the three-dimensional data encoding device adds the value of N to the header of a bitstream or the like. Note that the three-dimensional data encoding device may add the value of N for each three-dimensional point for which the predicted value is generated. Accordingly, since an appropriate N can be selected for each three-dimensional point for which the predicted value is generated, the accuracy of the predicted value can be improved to reduce the predicted residual.

[0722] Alternatively, the three-dimensional data encoding device may add the value of N to the header of a bitstream, and may fix the value of N within the bitstream. Accordingly, it becomes unnecessary to encode or decode the value of N for each three-dimensional point, and the processing amount can be reduced.

[0723] Alternatively, the three-dimensional data encoding device may separately encode the information indicating the value of N for each LoD. Accordingly, the coding efficiency can be improved by selecting an appropriate value of N for each LoD. Note that the three-dimensional data encoding device may calculate the predicted value of the attribute information of a three-dimensional point from the weighted average value of the attribute information of N surrounding three-dimensional points. For example, the three-dimensional data encoding device calculates the weight by using respective distance information of the current three-dimensional point and N three-dimensional points.

[0724] As described above, EnableReferringSameLoD is the information indicating whether or not to permit referring to the three-dimensional points in the same LoD. For example, the value 1 indicates referable, and the value 0 indicates not referable. Note that, in the case of the value 1, among the three-dimensional points in the same LoD, the three-dimensional points that are already encoded or decoded may be referable.

[0725] FIG. 74 is a diagram showing an example of the reference relationship in the case where EnableReferringSameLoD=0. The predicted value of the point P included in the LoDn is generated by using a reconstruction value P' included in the LoDn' ( $N' < N$ ) that is higher than the LoDn. Here, the reconstruction value P' is the encoded and decoded attribute value (attribute information). For example, the reconstruction value P' of an adjacent point based on the distance is used.

[0726] Additionally, in the example shown in FIG. 74, for example, the predicted value of b2 is generated by using any of the attribute values of a0, a1, and a2. Even when b0 and b1 are already encoded and decoded, reference to b0 and b1 is prohibited.

[0727] Accordingly, the three-dimensional data encoding device and the three-dimensional decoding device can generate the predicted value of b2, without waiting for the encoding or decoding processing of b0 and b1 to be completed. That is, since the three-dimensional point data encod-

ing device and the three-dimensional decoding device can calculate in parallel a plurality of predicted values for the attribute values of a plurality of three-dimensional points in the same LoD, the processing time can be reduced.

[0728] FIG. 75 is a diagram showing an example of the reference relationship in the case where EnableReferencingSameLoD=1. The predicted value of the point P included in the LoDN is generated by using the reconstruction value P' included in the LODN' (N' $\square$ N) that is the same layer as or a layer higher than the LoDN. Here, the reconstruction value P' is the encoded and decoded attribute value (attribute information). For example, the reconstruction value P' of an adjacent point based on the distance is used.

[0729] Additionally, in the example shown in FIG. 75, for example, the predicted value of b2 is generated by using any of the attribute values of a0, a1, a2, b0, and b1. That is, b0 and b1 are referable when b0 and b1 are already encoded and decoded.

[0730] Accordingly, the three-dimensional data encoding device can generate the predicted value of b2 by using the attribute information of a lot of neighboring three-dimensional points. Therefore, the prediction accuracy is improved, and the coding efficiency is improved.

[0731] Hereinafter, a technique will be described that limits the number of times of searching when selecting N three-dimensional points that are used for the predicted value generation of the attribute information of a three-dimensional point. Accordingly, the processing amount can be reduced.

[0732] For example, SearchNumPoint (search point number information) is defined. SearchNumPoint indicates the number of times of searching at the time of selecting N three-dimensional points used for prediction from the three-dimensional point cloud in the LoD. For example, the three-dimensional data encoding device may select the same number of three-dimensional points as the number indicated by SearchNumPoint from a total of T three-dimensional points included in the LoD, and may select N three-dimensional points used for prediction from the selected three-dimensional points. Accordingly, since it becomes unnecessary for the three-dimensional data encoding device to search for all of the T three-dimensional points included in the LoD, the processing amount can be reduced.

[0733] Note that the three-dimensional data encoding device may switch the selection method of the value of SearchNumPoint according to the geometry of the LoD to be referred to. An example will be shown below.

[0734] For example, when a reference LoD, which is a LoD to be referred to, is a layer higher than the LoD to which a current three-dimensional point belongs, the three-dimensional data encoding device searches for a three-dimensional point A with the closest distance to the current three-dimensional point among the three-dimensional points included in the reference LoD. Next, the three-dimensional data encoding device selects the number of three-dimensional points indicated by SearchNumPoint that are adjacent to the front and rear of the three-dimensional point A. Accordingly, since the three-dimensional data encoding device can efficiently search for three-dimensional points of the higher layers with a close distance to the current three-dimensional point, the prediction efficiency can be improved.

[0735] For example, when the reference LoD is the same layer as the LoD to which the current three-dimensional point belongs, the three-dimensional data encoding device selects the number of three-dimensional points indicated by SearchNumPoint that have been encoded and decoded earlier than the current three-dimensional point. For example, the three-dimensional data encoding device selects the number of three-dimensional points indicated by SearchNumPoint that have been encoded and decoded immediately before the current three-dimensional point.

[0736] Accordingly, the three-dimensional data encoding device can select the number of three-dimensional points indicated by SearchNumPoint with a low processing amount. Note that the three-dimensional data encoding device may select a three-dimensional point B with a close distance to the current three-dimensional point from the three-dimensional points that have been encoded and decoded earlier than the current three-dimensional point, and may select the number of three-dimensional points indicated by SearchNumPoint that are adjacent to the front and rear of the three-dimensional point B. Accordingly, since the three-dimensional data encoding device can efficiently search for the three-dimensional points of the same layer with a close distance to the current three-dimensional point, the prediction efficiency can be improved.

[0737] Additionally, when selecting N three-dimensional points utilized for prediction from the number of three-dimensional points indicated by SearchNumPoint, the three-dimensional data encoding device may select, for example, the top N three-dimensional points with a close distance to the current three-dimensional point. Accordingly, since the prediction accuracy can be improved, the coding efficiency can be improved.

[0738] Note that SearchNumPoint may be prepared for each LoD, and the number of times of searching may be changed for each LoD. FIG. 76 is a diagram showing an example of setting the number of times of searching for each LoD. For example, as shown in FIG. 76, SearchNumPoint [LoD0]=3 for the LoD0 and SearchNumPoint [LoD1]=2 for the LoD1 are defined. In this manner, the processing amount and the coding efficiency can be balanced by switching the number of times of searching for each LoD.

[0739] In the example shown in FIG. 76, as the three-dimensional points used for prediction of b2, a0, a1, and a2 are selected from the LoD0, and b0 and b1 are selected from the LoD1. N three-dimensional points are selected from the selected a0, a1, a2, b0, and b1, and the predicted value is generated by using the N selected three-dimensional points.

[0740] Additionally, the predicted value of the point P included in the LoDN is generated by using the reconstruction value P' included in the LODN' (N' $\square$ N) that is the same layer as or a layer higher than the LoDN. Here, the reconstruction value P' is the encoded and decoded attribute value (attribute information). For example, the reconstruction value P' of an adjacent point based on the distance is used.

[0741] Additionally, SearchNumPoint may indicate the total number of the numbers of times of searching of all the LoDs. For example, when SearchNumPoint=5, and when searching has been performed three times in the LoD0, searching can be performed for the remaining twice in the LoD1. Accordingly, since the worst number of times for the number of times of searching can be guaranteed, the processing time can be stabilized.

**[0742]** The three-dimensional data encoding device may add SearchNumPoint to a header or the like. Accordingly, the three-dimensional decoding device can generate the same predicted value as the three-dimensional data encoding device by decoding SearchNumPoint from the header, and can appropriately decode a bitstream. Additionally, SearchNumPoint need not necessarily be added to the header, and for example, the value of SearchNumPoint may be specified by the profile, layer, or the like of a standard or the like. Accordingly, the amount of bits of a header can be reduced.

**[0743]** When calculating the predicted value of the attribute value of a three-dimensional point included in the LoDn, the following EnableReferenceLoD may be defined. Accordingly, the three-dimensional data encoding device and the three-dimensional decoding device can determine the attribute value of a three-dimensional point included in which LoD may be referred to, by referring to EnableReferenceLoD (reference permitted layer information)

**[0744]** EnableReferenceLoD is the information indicating whether or not it is permitted for a current three-dimensional point to refer to the three-dimensional points of the layer higher than or equal to the LoD (n-EnableReferenceLoD), when the current three-dimensional point belongs to the LoDn. For example, when EnableReferenceLoD=0, reference to the three-dimensional points included in the LoDn and in the layers higher than the LoDn is permitted. When EnableReferenceLoD=1, reference to the three-dimensional points included in the layers higher than the LoDn-1 is permitted. Additionally, when EnableReferenceLoD=2, reference to the three-dimensional points included in the layers higher than the LoDn-2 is permitted. In this manner, since the layers of the LoD that can be referred to can be set according to the set value of EnableReferenceLoD, it becomes possible to balance the coding efficiency and the processing time by controlling the layers that can be processed in parallel. Note that three-dimensional points that are included in each layer and that have already been encoded or decoded may be referable.

**[0745]** FIG. 77 is a diagram showing the reference relationship in the case where EnableReferenceLoD=0. As shown in FIG. 77, for example, the predicted value of c2 is generated by using any of the attribute values of a0, a1, a2, b0, b1, b2, c0, and c1. Each three-dimensional point may be referable when each three-dimensional point has already been encoded or decoded. Accordingly, since the predicted value of c2 is generated by using the attribute information of more adjacent three-dimensional points, the prediction accuracy is improved, and the coding efficiency can be improved.

**[0746]** FIG. 78 is a diagram showing the reference relationship in the case where EnableReferenceLoD=1. As shown in FIG. 78, for example, the predicted value of c2 is generated by using any of the attribute values of a0, a1, a2, b0, b1, and b2. Reference to c0 and c1 is prohibited even when c0 and c1 have been already encoded or decoded. Accordingly, the three-dimensional data encoding device and the three-dimensional decoding device can generate the predicted value of c2, without waiting for the encoding or decoding processing of c0 and c1 to be completed. That is, since the three-dimensional data encoding device and the three-dimensional decoding device can calculate in parallel the predicted values for the attribute values of three-dimensional points in the same LoD, the processing time can be reduced.

**[0747]** FIG. 79 is a diagram showing the reference relationship in the case where EnableReferenceLoD=2. As shown in FIG. 79, for example, the predicted value of c2 is generated by using any of the attribute values of a0, a1, and a2. Even when c0, c1, b0, b1, and b2 are already encoded or decoded, reference to c0, c1, b0, b1, and b2 is prohibited. Accordingly, the three-dimensional data encoding device and the three-dimensional decoding device can generate the predicted value of c2, without waiting for the encoding or decoding processing of c0, c1, b0, b1, and b2 to be completed. That is, since the three-dimensional data encoding device and the three-dimensional decoding device can calculate in parallel the predicted values for the attribute values of the three-dimensional points of the LoD1 and LoD2, the processing time can be reduced.

**[0748]** FIG. 80 is a diagram showing a syntax example of an attribute information header (attribute\_header) according to the present embodiment. The attribute information header is the header information of the attribute information. As shown in FIG. 80, the attribute information header includes a same layer reference permission flag (EnableReferringSameLoD), layer number information (NumLoD), search point number information (SearchNumPoint [i]), and surrounding point number information (NumNeighborPoint [i]).

**[0749]** EnableReferringSameLoD is the information indicating whether or not to permit referring to the three-dimensional points in the same LoD as a current three-dimensional point. For example, the value 1 indicates referable, and the value 0 indicates not referable (reference is prohibited). Note that, in the case of the value 1, among the three-dimensional points in the same LoD, the three-dimensional points that are already encoded or decoded may be referable. NumLoD shows the number of layers of the LoDs to be used.

**[0750]** SearchNumPoint [i] indicates the number of times of searching at the time of selecting N three-dimensional points used for prediction from the three-dimensional point cloud in the i-th LoD. For example, the three-dimensional data encoding device may select the same number of three-dimensional points as the number indicated by SearchNumPoint from a total of T three-dimensional points included in the LoD, and may select N three-dimensional points used for prediction from the selected three-dimensional points. Accordingly, since it becomes unnecessary for the three-dimensional data encoding device to search for all of the T three-dimensional points included in the LoD, the processing amount can be reduced.

**[0751]** NumNeighborPoint [i] indicates the upper limit N of the number of surrounding points used for generation of the predicted value of a three-dimensional point belonging to the layer i. When the number M of surrounding three-dimensional points is less than NumNeighborPoint[i] ( $M < \text{NumNeighborPoint}[i]$ ), the three-dimensional data encoding device may calculate the predicted value by using M surrounding three-dimensional points. Additionally, when it is unnecessary to separate the value of NumNeighborPoint [i] for each LoD, the three-dimensional data encoding device may add one NumNeighborPoint used by all of the LoDs to a header.

**[0752]** The three-dimensional data encoding device may entropy encode EnableReferringSameLoD and SearchNumPoint, and may add them to a header. For example, the three-dimensional data encoding device arithmetically

encodes each value after binarizing each value. Additionally, the three-dimensional data encoding device may perform encoding with a fixed length in order to suppress the processing amount.

[0753] Additionally, EnableReferringSameLoD and SearchNumPoint need not necessarily be added to a header, and for example, these values may be specified by the profile, layer or the like of a standard or the like. Accordingly, the amount of bits of a header can be reduced.

[0754] Additionally, the three-dimensional data encoding device may add EnableReferringSameLoD and SearchNumPoint to the header of WLD, SPC, or volume, in order to switch per WLD, SPC, or volume. In addition, the three-dimensional data encoding device may add the information indicating whether or not to permit referring to the same layer according to the layer to a bitstream, and may switch whether or not to permit referring to the same layer according to the layer.

[0755] Restrictions may be provided for the set value of EnableReferringSameLoD depending on the encoding scheme of the attribute value. For example, when an encoding scheme L is used in which all the predicted residuals of the attribute values of the three-dimensional points included in the lower layers of the LoD are once calculated, and the predicted residuals are fed back to the higher layers, the three-dimensional points included in the same layer cannot be referred to for generation of the predicted value, since the encoding or decoding processing is not completed. When using the encoding scheme L as such, the value of EnableReferringSameLoD may be restricted to be 0. Additionally, in the case where the encoding scheme L as such is used, when the value of EnableReferringSameLoD is 1, the three-dimensional decoding device may determine that it is a conformance error of a standard.

[0756] Additionally, the three-dimensional data encoding device may add the information indicating whether or not encoding has been performed with the encoding scheme L to a bitstream, may add the value of EnableReferringSameLoD to the bitstream when encoding has not been performed with the encoding scheme L, and need not add EnableReferringSameLoD to the bitstream when encoding has been performed with the encoding scheme L. Accordingly, the three-dimensional decoding device can determine whether or not EnableReferringSameLoD is added to the bitstream by decoding the information indicating whether or not encoding has been performed with the encoding scheme L from the header, and can correctly decode the bitstream. Note that the three-dimensional decoding device may decode EnableReferringSameLoD of the header when encoding has not been performed with the encoding scheme L, and may estimate the value of EnableReferringSameLoD to be 0 when encoding has been performed with the encoding scheme L.

[0757] Note that the three-dimensional data encoding device need not add EnableReferringSameLoD to a header. In this case, when a bitstream to be processed is the bitstream whose encoding has been performed with the encoding scheme L, the three-dimensional decoding device may estimate the value of EnableReferringSameLoD to be 0, and otherwise, the three-dimensional decoding device may estimate the value of EnableReferringSameLoD to be 1 and perform decoding processing.

[0758] FIG. 81 is a diagram showing another syntax example of the attribute information header (attribute\_

header) according to the present embodiment. Compared with the attribute information header shown in FIG. 80, the attribute information header shown in FIG. 81 includes reference permission layer information (EnableReferenceLoD), instead of the same layer reference permission flag (EnableReferringSameLoD). Note that the meaning of the other information is the same as that in FIG. 80.

[0759] EnableReferenceLoD is the information indicating whether or not to permit referring to the three-dimensional points of the layers higher than or equal to the LoD (n-EnableReferenceLoD), when a current three-dimensional point belongs to the LoDn. For example, when EnableReferenceLoD=0, reference to the three-dimensional points included in the LoDn and in the layers higher than the LoDn is permitted. When EnableReferenceLoD=1, reference to the three-dimensional points included in the layers higher than or equal to LoDn-1 is permitted. Additionally, when EnableReferenceLoD=2, reference to the three-dimensional points included in the layers higher than or equal to LoDn-2 is permitted. In this manner, since the layers of the LoD that can be referred to can be set according to the set value of EnableReferenceLoD, it becomes possible to balance the coding efficiency and the processing time by controlling the layers that can be processed in parallel. Note that three-dimensional points that are included in each layer and that have already been encoded or decoded may be referable.

[0760] The three-dimensional data encoding device may entropy encode EnableReferenceLoD and SearchNumPoint, and may add them to a header. For example, the three-dimensional data encoding device arithmetically encodes each value after binarizing each value. Additionally, the three-dimensional data encoding device may perform encoding with a fixed length in order to suppress the processing amount.

[0761] Additionally, EnableReferenceLoD and SearchNumPoint need not necessarily be added to a header, and for example, these values may be specified by the profile, layer, or the like of a standard or the like. Accordingly, the amount of bits of a header can be reduced.

[0762] Additionally, the three-dimensional data encoding device may add EnableReferenceLoD and SearchNumPoint to the header of WLD, SPC, or volume, in order to switch per WLD, SPC, or volume.

[0763] Restrictions may be provided for the set value of EnableReferenceLoD depending on the encoding scheme of the attribute value. For example, when using the above-described encoding scheme L, the value of EnableReferenceLoD may be restricted to be 1 or more. Additionally, in the case where the encoding scheme L is used, when the value of EnableReferenceLoD is 0, the three-dimensional data decoding device may determine that it is a conformance error of a standard.

[0764] FIG. 82 is a flowchart of the three-dimensional data encoding processing according to the present embodiment. First, the three-dimensional data encoding device encodes geometry information (geometry) (S6901). For example, the three-dimensional data encoding device performs encoding by using an octree representation.

[0765] Next, the three-dimensional data encoding device converts the attribute information (S6902). For example, after the encoding of the geometry information, when the position of a three-dimensional point is changed due to quantization or the like, the three-dimensional data encoding device reassigned the attribute information of the original

three-dimensional point to the three-dimensional point after the change. Note that the three-dimensional data encoding device may interpolate the value of the attribute information according to the amount of change of the position to perform the reassignment. For example, the three-dimensional data encoding device detects N three-dimensional points before the change near the three-dimensional position after the change, performs the weighted averaging of the value of the attribute information of the N three-dimensional points based on the distance from the three-dimensional position after the change to each of the N three-dimensional points, and sets the obtained value to the value of the attribute information of the three-dimensional point after the change. Additionally, when two or more three-dimensional points are changed to the same three-dimensional position due to quantization or the like, the three-dimensional data encoding device may assign the average value of the attribute information in the two or more three-dimensional points before the change as the value of the attribute information after the change.

[0766] Next, the three-dimensional data encoding device encodes the attribute information (S6903). For example, when encoding a plurality of pieces of attribute information, the three-dimensional data encoding device may encode the plurality of pieces of attribute information in order. For example, when encoding the color and the reflectance as the attribute information, the three-dimensional data encoding device generates a bitstream to which the encoding result of the reflectance is added after the encoding result of the color. Note that a plurality of encoding results of the attribute information added to a bitstream may be in any order.

[0767] Additionally, the three-dimensional data encoding device may add the information indicating the start location of the encoded data of each attribute information in a bitstream to a header or the like. Accordingly, since the three-dimensional data decoding device can selectively decode the attribute information that needs to be decoded, the decoding processing of the attribute information that does not need to be decoded can be omitted. Therefore, the processing amount for the three-dimensional data decoding device can be reduced. Additionally, the three-dimensional data encoding device may encode a plurality of pieces of attribute information in parallel, and may integrate the encoding results into one bitstream. Accordingly, the three-dimensional data encoding device can encode a plurality of pieces of attribute information at high speed.

[0768] FIG. 83 is a flowchart of the attribute information encoding processing (S6903). First, the three-dimensional data encoding device sets LoDs (S6911). That is, the three-dimensional data encoding device assigns each three-dimensional point to any of the plurality of LoDs.

[0769] Next, the three-dimensional data encoding device starts a loop per LoD (S6912). That is, the three-dimensional data encoding device repeatedly performs the processing of steps S6913 to S6921 for each LoD.

[0770] Next, the three-dimensional data encoding device starts a loop per three-dimensional point (S6913). That is, the three-dimensional data encoding device repeatedly performs the processing of steps S6914 to S6920 for each three-dimensional point.

[0771] First, the three-dimensional data encoding device searches for a plurality of surrounding points, which are three-dimensional points that exist in the surroundings of a current three-dimensional point, and that are used for cal-

culation of the predicted value of the current three-dimensional point (S6914). Next, the three-dimensional data encoding device calculates the weighted average of the value of the attribute information of the plurality of surrounding points, and sets the obtained value to the predicted value P (S6915). Next, the three-dimensional data encoding device calculates the predicted residual, which is the difference between the attribute information of the current three-dimensional point and the predicted value (S6916). Next, the three-dimensional data encoding device calculates the quantized value by quantizing the predicted residual (S6917). Next, the three-dimensional data encoding device arithmetically encode the quantized value (S6918).

[0772] Additionally, the three-dimensional data encoding device calculates the inverse quantized value by inverse quantizing the quantized value (S6919). Next, the three-dimensional data encoding device generates the decoded value by adding the predicted value to the inverse quantized value (S6920). Next, the three-dimensional data encoding device ends the loop per three-dimensional point (S6921). Additionally, the three-dimensional data encoding device ends the loop per LoD (S6922).

[0773] FIG. 84 is a flowchart of the three-dimensional data decoding processing according to the present embodiment. First, the three-dimensional decoding device decodes the geometry information (geometry) from a bitstream (S6931). For example, the three-dimensional data decoding device performs decoding by using an octree representation.

[0774] Next, the three-dimensional decoding device decodes the attribute information from the bitstream (S6932). For example, when decoding a plurality of pieces of attribute information, the three-dimensional data decoding device may decode the plurality of pieces of attribute information in order. For example, when decoding the color and the reflectance as the attribute information, the three-dimensional data decoding device decodes the encoding result of the color and the encoding result of the reflectance according to the order in which they are added to the bitstream. For example, when the encoding result of the reflectance is added after the encoding result of the color in a bitstream, the three-dimensional data decoding device decodes the encoding result of the color, and thereafter decodes the encoding result of the reflectance. Note that the three-dimensional data decoding device may decode the encoding results of the attribute information added to a bitstream in any order.

[0775] Additionally, the three-dimensional data decoding device may obtain the information indicating the start location of the encoded data of each attribute information in a bitstream by decoding a header or the like. Accordingly, since the three-dimensional data decoding device can selectively decode the attribute information that needs to be decoded, the decoding processing of the attribute information that does not need to be decoded can be omitted. Therefore, the processing amount for the three-dimensional data decoding device can be reduced. Additionally, the three-dimensional data decoding device may decode a plurality of pieces of attribute information in parallel, and may integrate the decoding results into one three-dimensional point cloud. Accordingly, the three-dimensional data decoding device can decode a plurality of pieces of attribute information at high speed.

[0776] FIG. 85 is a flowchart of the attribute information decoding processing (S6932). First, the three-dimensional

decoding device sets LoDs (S6941). That is, the three-dimensional data decoding device assigns each of a plurality of three-dimensional points having the decoded geometry information to any of the plurality of LoDs. For example, this assigning method is the same method as the assigning method used by the three-dimensional data encoding device.

[0777] Next, the three-dimensional decoding device starts a loop per LOD (S6942). That is, the three-dimensional data decoding device repeatedly performs the processing of steps S6943 to S6949 for each LoD.

[0778] Next, the three-dimensional decoding device starts a loop per three-dimensional point (S6943). That is, the three-dimensional data decoding device repeatedly performs the processing of steps S6944 to S6948 for each three-dimensional point.

[0779] First, the three-dimensional data decoding device searches for a plurality of surrounding points, which are three-dimensional points that exist in the surroundings of a current three-dimensional point, and that are used for calculation of the predicted value of the current three-dimensional point (S6944). Next, the three-dimensional data decoding device calculates the weighted average of the value of the attribute information of the plurality of surrounding points, and sets the obtained value to the predicted value P (S6945). Note that these processings are the same as the processings in the three-dimensional data encoding device.

[0780] Next, the three-dimensional data decoding device arithmetically decodes the quantized value from a bitstream (S6946). Additionally, the three-dimensional data decoding device calculates the inverse quantized value by performing inverse quantization of the decoded quantized value (S6947). Next, the three-dimensional data decoding device generates the decoded value by adding the predicted value to the inverse quantized value (S6948). Next, the three-dimensional data decoding device ends the loop per three-dimensional point (S6949). Additionally, the three-dimensional data decoding device ends the loop per LoD (S6950).

[0781] FIG. 86 is a flowchart of the surrounding point searching processing (S6914). First, the three-dimensional data encoding device selects three-dimensional points that are as many as SearchNumPoint [higher LoD] and are included in a higher LoD layer than the layer to which a current three-dimensional point belongs, and calculates N three-dimensional points for predicted value generation from the selected three-dimensional points (S6961). Next, the three-dimensional data encoding device determines whether EnableReferringSameLoD is 1 (S6962). When EnableReferringSameLoD is 1 (Yes in S6962), the three-dimensional data encoding device selects three-dimensional points that are as many as SearchNumPoint [the same LoD] and are included in the same LoD layer as the layer to which the current three-dimensional point belongs, and updates N three-dimensional points for predicted value generation (S6963). For example, the three-dimensional data encoding device calculates N three-dimensional points from three-dimensional points that are as many as SearchNumPoint [higher LoD] and are selected in step S6961, and three-dimensional points that are as many as SearchNumPoint [the same LoD] and are selected in step S6963.

[0782] On the other hand, when EnableReferringSameLoD is 0 (No in S6962), N three-dimensional points selected in step S6961 are used as they are.

[0783] FIG. 87 is a flowchart showing another example of the surrounding point searching processing (S6914). First, the three-dimensional data encoding device determines whether EnableReferringSameLoD is 1 (S6971). When EnableReferringSameLoD is 1 (Yes in S6971), the three-dimensional data encoding device selects three-dimensional points that are as many as SearchNumPoint [the same LoD] and are included in the same LoD layer as the layer to which a current three-dimensional point belongs, and calculates N three-dimensional points for predicted value generation from the selected three-dimensional points (S6972). Next, the three-dimensional data encoding device selects three-dimensional points that are as many as SearchNumPoint [higher LoD] and are included in a higher LoD layer than the layer to which the current three-dimensional point belongs, and updates N three-dimensional points for predicted value generation (S6973). For example, the three-dimensional data encoding device calculates N three-dimensional points from three-dimensional points that are as many as SearchNumPoint [the same LoD] and are selected in step S6972, and three-dimensional points that are as many as SearchNumPoint [higher LoD] and are selected in step S6973.

[0784] On the other hand, when EnableReferringSameLoD is 0 (No in S6971), the three-dimensional data encoding device selects three-dimensional points that are as many as SearchNumPoint [higher LoD] and are included in a higher LoD layer than the layer to which the current three-dimensional point belongs, and calculates N three-dimensional points for predicted value generation from the selected three-dimensional points (S6973).

[0785] FIG. 88 is a flowchart showing another example of the surrounding point searching processing (S6914). First, the three-dimensional data encoding device selects three-dimensional points that are as many as pieces of and are included in the layer higher than or equal to the LoD (n-EnableReferenceLoD), and calculates N three-dimensional points for predicted value generation from the selected three-dimensional points (S6981).

[0786] Note that the surrounding point searching processing (S6944) in the three-dimensional decoding device is the same as the surrounding point searching processing (S6914) in the three-dimensional data encoding device.

[0787] As stated above, the three-dimensional data encoding device according to the present embodiment performs the process shown by FIG. 89. The three-dimensional data encoding device classifies three-dimensional points included in point cloud data into layers (e.g., LoDs), based on geometry information of the three-dimensional points (S6991). Next, the three-dimensional data encoding device generates first information (e.g., EnableReferringSameLoD) indicating whether to permit referring to, for a current three-dimensional point included in the three-dimensional points, attribute information of another three-dimensional point belonging to a same layer as the current three-dimensional point (S6992). Then, the three-dimensional data encoding device encodes attribute information of the current three-dimensional point to generate a bitstream, by or without referring to the attribute information of the other three-dimensional point according to the first information (S6993). The bitstream includes the first information.

[0788] For example, when the first information indicates to permit referring to the attribute information of the other three-dimensional point belonging to the same layer as the

current three-dimensional point, the three-dimensional data encoding device encodes the attribute information of the current three-dimensional point by referring to a three-dimensional point belonging to the same layer as the current three-dimensional point; and when the first information indicates not to permit (prohibit) referring to the attribute information of the other three-dimensional point belonging to the same layer as the current three-dimensional point, the three-dimensional data encoding device encodes the attribute information of the current three-dimensional point without referring to the three-dimensional point belonging to the same layer as the current three-dimensional point. Moreover, referring to a three-dimensional point means, for example, using a three-dimensional point in generating a predicted value. In this case, a difference value (prediction residual) between the attribute information of the current three-dimensional point and the predicted value is calculated, and the calculated difference value is encoded (e.g., quantized and entropy encoded).

[0789] According to this, since the three-dimensional data encoding device can switch whether or not to refer to the other three-dimensional point of the same layer, the three-dimensional data encoding device can perform encoding appropriately.

[0790] For example, when the first information indicates to permit referring to the attribute information of the other three-dimensional point, the three-dimensional data encoding device encodes the attribute information of the current three-dimensional point by referring to attribute information of an encoded three-dimensional point included in three-dimensional points belonging to the same layer as the current three-dimensional point.

[0791] For example, in the encoding, the three-dimensional data encoding device encodes the attribute information of the current three-dimensional point by referring to attribute information of a three-dimensional point belonging to a layer higher than a layer to which the current three-dimensional point belongs, regardless of the first information.

[0792] For example, the three-dimensional data encoding device includes a processor and memory, and the processor performs the above process using the memory.

[0793] The three-dimensional data decoding device according to the present embodiment performs the process shown by FIG. 90. The three-dimensional data decoding device classifies three-dimensional points included in point cloud data into layers (e.g., LoDs), based on geometry information of the three-dimensional points (S6995). Next, the three-dimensional data decoding device obtains first information (e.g., EnableReferringSameLoD) from a bitstream, the first information indicating whether to permit referring to, for a current three-dimensional point included in the three-dimensional points, attribute information of another three-dimensional point belonging to a same layer as the current three-dimensional point (S6996). Then, the three-dimensional data decoding device decodes attribute information of the current three-dimensional point from the bitstream, by or without referring to the attribute information of the other three-dimensional point according to the first information (S6997).

[0794] For example, when the first information indicates to permit referring to the attribute information of the other three-dimensional point belonging to the same layer as the current three-dimensional point, the three-dimensional data

decoding device decodes the attribute information of the current three-dimensional point by referring to a three-dimensional point belonging to the same layer as the current three-dimensional point; and when the first information indicates not to permit (prohibit) referring to the attribute information of the other three-dimensional point belonging to the same layer as the current three-dimensional point, the three-dimensional data decoding device decodes the attribute information of the current three-dimensional point without referring to the three-dimensional point belonging to the same layer as the current three-dimensional point. Moreover, referring to a three-dimensional point means, for example, using a three-dimensional point in generating a predicted value. In this case, the three-dimensional data decoding device decodes (e.g., entropy decodes and inverse quantizes), from the bitstream, a difference value (prediction residual) between the attribute information of the current three-dimensional point and the predicted value, and restores the attribute information by adding the predicted value to the obtained difference value.

[0795] According to this, the three-dimensional data decoding device can switch whether or not to refer to the other three-dimensional point of the same layer, based on the first information. Therefore, the three-dimensional data decoding device can decode a bitstream generated by performing encoding appropriately.

[0796] For example, when the first information indicates to permit referring to the attribute information of the other three-dimensional point, the three-dimensional data decoding device decodes the attribute information of the current three-dimensional point by referring to attribute information of a decoded three-dimensional point included in three-dimensional points belonging to the same layer as the current three-dimensional point.

[0797] For example, in the decoding, the three-dimensional data decoding device decodes the attribute information of the current three-dimensional point by referring to attribute information of a three-dimensional point belonging to a layer higher than a layer to which the current three-dimensional point belongs, regardless of the first information.

[0798] For example, the three-dimensional data decoding device includes a processor and memory, and the processor performs the above process using the memory.

#### Embodiment 11

[0799] FIG. 91 is a diagram for illustrating the re-ordering process according to this embodiment. Specifically, part (a) of FIG. 91 is a diagram showing an example of a plurality of voxels (specifically, eight voxels) and Morton codes assigned to the plurality of voxels. Part (b) of FIG. 91 is a diagram showing another example of a plurality of voxels (specifically, eight voxels) and Morton codes assigned to the plurality of voxels. Part (c) of FIG. 91 is a diagram showing an example of an ordering of a point cloud obtained by modifying the ordering of the point cloud shown in part (b) of FIG. 91.

[0800] In each of parts (a) and (b) of FIG. 91, the left part shows the plurality of voxels, and the right part shows the ordering of the point cloud. Note that the ordering of the point cloud is indicated by Morton codes.

[0801] As shown in parts (a) and (b) of FIG. 91, for example, the point cloud is arranged in a Z order or Morton order before the transformation process is performed. Here,

in part (b) of FIG. 91, for example, in order to effectively perform the transformation process, the three-dimensional data encoding device performs the re-ordering process to further re-order the point cloud arranged in a Morton order based on the geometry information on the three-dimensional points as shown in part (c) of FIG. 91, for example.

[0802] Part (a) of FIG. 91 shows an example of a point cloud arranged in a Morton order. Specifically, the example shown in part (a) of FIG. 91 is an example in which each voxel includes one three-dimensional point. In this case, for example, the Morton order of the point cloud is 0, 1, 2, 3, 4, 5, 6, 7, and the point cloud is arranged in this order.

[0803] On the other hand, part (b) of FIG. 91 shows a Morton order in the case where all the voxels are not occupied by a three-dimensional point. Specifically, voxel 1 and voxel 2 are not occupied by any three-dimensional point. In this case, for example, the Morton order of the point cloud is 0, 3, 4, 5, 6, 7, and the point cloud is arranged in this order.

[0804] The attribute information concerning the position of a three-dimensional point is obtained from the surface of a three-dimensional object, for example. Therefore, attribute information on three-dimensional points (closest three-dimensional points) whose surfaces are the closest to each other are highly correlated to each other. That is, attribute information on three-dimensional points that are close to each other are likely to have values close to each other. Therefore, the three-dimensional data encoding device performs the re-ordering process of re-ordering the point cloud so that such three-dimensional points at close positions are brought closer to each other, before performing the transformation process. For example, the three-dimensional data encoding device re-orders the point cloud from the order of 0, 3, 4, 5, 6, 7 shown in part (b) of FIG. 91 to the order of 0, 4, 3, 5, 6, 7 shown in part (c) of FIG. 91. That is, the three-dimensional data encoding device swaps the positions of the pieces of data (geometry information, attribute information or the like) on the three-dimensional point assigned with a Morton code of 3 and the three-dimensional point assigned with a Morton code of 4 with each other.

[0805] Note that the “re-ordering process” in this example may refer to a process of generating re-ordering information that indicates the order of a new point cloud generated by performing the re-ordering process on a point cloud arranged in a Morton order using distance information, geometry information or the like on three-dimensional points, for example.

[0806] As another example of predicting and encoding the attribute information of a three-dimensional point, a method of efficiently selecting N three-dimensional points used for prediction will be described.

[0807] For example, first, the three-dimensional data encoding device selects candidates of N second three-dimensional points that are used for calculating the predicted value of the attribute information of the first three-dimensional point to be encoded included in LoDn, and that are in the periphery of the three-dimensional point to be encoded. In this case, it is conceivable that the three-dimensional data encoding device selects the N second three-dimensional points in the order of evaluation values (the descending order of evaluation values, or the ascending order of evaluation values), by calculating an evaluation value, such as the distance between each of all the referable second three-dimensional points and the first three-dimensional point to

be encoded. Note that the candidates of N three-dimensional points that are used for calculating the predicted value of the attribute information may also be called the three-dimensional point candidates for predicted value generation.

[0808] Additionally, instead of calculating the distance between the first three-dimensional point and each of all the second three-dimensional points, the three-dimensional data encoding device may divide all the second three-dimensional points into a plurality of sets, and calculate the evaluation value per set for each of the divided sets. That is, in this case, the three-dimensional data encoding device calculates one evaluation value for one set for each set. Then, it is conceivable that, when the evaluation value calculated for each set satisfies a certain condition, the three-dimensional data encoding device calculates the distance between each of all the plurality of second three-dimensional points included in a set that satisfies the certain condition, and the first three-dimensional point. Accordingly, since the three-dimensional data encoding device can omit the calculation of the distance between each of a plurality of second three-dimensional points included in sets whose evaluation values do not satisfy the certain condition, and the first three-dimensional point, it becomes unnecessary to calculate the distances to all the referable three-dimensional points for each three-dimensional point to be encoded, and the processing amount can be reduced.

[0809] Hereinafter, using FIG. 91, a description will be given of an example of selecting candidates of N three-dimensional points for predicted value generation from a plurality of referable second three-dimensional points in the same LoD layer. FIG. 91 is a diagram for describing a method of selecting N three-dimensional points.

[0810] First, the three-dimensional data encoding device generates a LoD with a method such as Embodiment 8 (for example, the description using FIG. 51 to FIG. 53). In FIG. 91, three-dimensional points b0 to b47 in LoDn layer of a plurality of layers generated in a LoD are illustrated. Note that the three-dimensional data encoding device may generate a LoD after rearranging the input three-dimensional points in an ascending order by using, for example, the Morton codes. Accordingly, since three-dimensional points with relatively close distances can be collectively encoded, and the prediction accuracy of attribute information can be improved, the coding efficiency can be improved.

[0811] Then, the three-dimensional data encoding device divides the plurality of three-dimensional points b0 to b47 in a LoDn layer into a plurality of sets (also called groups) G0 to G5, so that each set has M (M=8 in the present embodiment) three-dimensional points.

[0812] Next, as illustrated in FIG. 92, the three-dimensional data encoding device may calculate (max\_x, max\_y, max\_z) and (min\_x, min\_y, min\_z) of each group from the three-dimensional points included in each group G, and define spaces (bounding boxes) including the plurality of three-dimensional points of respective groups G0 to G5. FIG. 92 is a diagram illustrating an example of a bounding box of group Gk (k is an integer equal to or more than 0).

[0813] Note that max\_x indicates the maximum value of the x-coordinates of a plurality of three-dimensional points included in group Gk. max\_y indicates the maximum value of the y coordinates of the plurality of three-dimensional points included in group Gk. max\_z indicates the maximum value of the z coordinates of the plurality of three-dimensional points included in group Gk. min\_x indicates the

minimum value of the x-coordinates of the plurality of three-dimensional points included in group Gk. min\_y indicates the minimum value of the y coordinates of the plurality of three-dimensional points included in group Gk. min\_z indicates the minimum value of the z coordinates of the plurality of three-dimensional points included in group Gk.

**[0814]** In this case, the three-dimensional data encoding device may calculate a distance dist between a certain three-dimensional point A (point\_x, point\_y, point\_z) and the bounding box for group Gk as follows. point\_x is the x-coordinate of the three-dimensional point A, point\_y is the y coordinate of the three-dimensional point A, and point\_z is the z coordinate of the three-dimensional point A.

$$\begin{aligned} dx &= \max(\max(\min_x - point_x, 0), point_x - \max_x) \\ dy &= \max(\max(\min_y - point_y, 0), point_y - \max_y) \\ dz &= \max(\max(\min_z - point_z, 0), point_z - \max_z) \\ distGk &= dx * dx + dy * dy + dz * dz \quad (* \text{ represents multiplication}) \end{aligned}$$

**[0815]** When the three-dimensional point A is included in the bounding box of group Gk, the value of the distance distGk obtained by using the above-described Equation N1 will be 0. Additionally, the more distant the three-dimensional point A is from the bounding box of group Gk on a three-dimensional space, the greater the value of distGk.

**[0816]** The three-dimensional data encoding device may include, in a bitstream, the number M of the three-dimensional points included in each group. For example, the information indicating the number M may be added to the header of a bitstream or the like. Accordingly, the three-dimensional data decoding device can find that decoding processing is to be performed by grouping every M points of a plurality of three-dimensional points to be decoded, by obtaining a bitstream or decoding the header included in the bitstream, and can correctly decode the bitstream. Additionally, the number M may be specified by the profile of the standard or the like.

**[0817]** When selecting the candidates of N three-dimensional points used for prediction of a first three-dimensional point to be encoded, the three-dimensional data encoding device first calculates the distance in the three-dimensional space between each of a plurality of referable second three-dimensional points among a plurality of second three-dimensional points in the periphery of the first three-dimensional point that exist in the same group as the first three-dimensional point to be encoded, and the first three-dimensional point. The three-dimensional data encoding device may include second three-dimensional points with close calculated distance in the candidates of N three-dimensional points used for prediction. Here, the referable three-dimensional points may be, for example, three-dimensional points that are encoded or decoded before the first three-dimensional point to be encoded. Additionally, the calculated distance between two points may be Euclidean distance or the like.

**[0818]** FIG. 94 is a diagram for describing the processing of selecting the candidates of N three-dimensional points in a case where the first three-dimensional point and a plurality of second three-dimensional points belong to the same group.

**[0819]** In FIG. 94, when selecting N three-dimensional points used for calculating the predicted value of the attribute information of three-dimensional point b26 to be encoded, the three-dimensional data encoding device first calculates the distance in the three-dimensional space to three-dimensional point b26 for each of referable three-dimensional points b24 and b25 in group G3 in which three-dimensional point b26 is included. In this case, when N is two or more, the three-dimensional data encoding device sets both three-dimensional points b24 and b25 as the three-dimensional point candidates for predicted value generation. When N=1, the three-dimensional data encoding device sets the three-dimensional point with a closer distance to three-dimensional points b26 to be encoded among three-dimensional points b24 and b25 as the three-dimensional point candidate for predicted value generation. For example, when the distance between three-dimensional point b26 and three-dimensional point b25 is dist0, and when the distance between three-dimensional point b26 and three-dimensional point b24 is dist1, and dist0<dist1, it is conceivable that the three-dimensional data encoding device sets three-dimensional point b25 as a three-dimensional point candidate [0], and sets three-dimensional point b24 as a three-dimensional point candidate [1]. That is, the three-dimensional data encoding device stores, in a memory, the information indicating that the three-dimensional point candidate [0] is three-dimensional point b25, and the information indicating that the three-dimensional point candidate [1] is three-dimensional point b24. Note that it may be indicated that the three-dimensional point candidate [0] is a candidate with a higher preferential order than the three-dimensional point candidate [1]. That is, the three-dimensional data encoding device may set three-dimensional point b25, which is closer to three-dimensional point b26 to be encoded among three-dimensional points b24 and b25, as the candidate with a higher preferential order.

**[0820]** Next, the three-dimensional data encoding device calculates the distance between the plurality of second three-dimensional points in the same group as the first three-dimensional point and the first three-dimensional point, and after setting a three-dimensional point candidate according to the calculated distances, calculates the distance between the groups different from the first three-dimensional point and the first three-dimensional point. Using FIG. 95, a description will be given of the processing of calculating the distances to a plurality of second three-dimensional points belonging to a different group. FIG. 95 is a diagram for describing the processing of selecting the candidates of N three-dimensional points in a case where the first three-dimensional point and the plurality of second three-dimensional points belong to different groups.

**[0821]** The three-dimensional data encoding device calculates a distance distG2 between first three-dimensional point b26 and the bounding box of group G2 by using Equation N1 ((1) in FIG. 95). For example, when distG2 is smaller than dist1 of the three-dimensional point candidate [1], the distance between each of second three-dimensional points b16, b17, . . . , b23 included in group G2 and first three-dimensional point b26 may be calculated ((2) in FIG. 95), and the three-dimensional point candidates for predicted value generation may be set in the order of closest to first three-dimensional point b26 (that is, the smallest calculated distance) as the preferential order. For example, when a distance dist2 between second three-dimensional

point b17 and first three-dimensional point b26 is smaller than dist0 and dist1, the three-dimensional data encoding device sets second three-dimensional point b17 to the three-dimensional point candidate [0], since second three-dimensional point b17 is prioritized over second three-dimensional point b25 that is already stored in the three-dimensional point candidate [0]. As a result, the three-dimensional data encoding device may set second three-dimensional point b25 that has been set to the three-dimensional point candidate [0] to the three-dimensional point candidate [1], and may remove (delete) second three-dimensional point b24 from the three-dimensional point candidates.

[0822] In this manner, the three-dimensional data encoding device may assign, to the three-dimensional point candidate [0], a three-dimensional point with a small distance to first three-dimensional point b26, and may subsequently set three-dimensional point candidates in the ascending order of distance. Here, when  $\text{distG2}=0$ , that is, when three-dimensional point b26 exists in the bounding box of group G2, the three-dimensional data encoding device may calculate the distance between each of second three-dimensional points b16, b17, . . . , b23 included in group G2 and first three-dimensional point b26, and may set the three-dimensional point candidates for predicted value generation, in the order of closest to first three-dimensional point b26 (that is, the smallest calculated distance) as the preferential order.

[0823] Note that the three-dimensional point with a small distance to first three-dimensional point b26 may be one of one or more three-dimensional points with a distance to first three-dimensional point b26 smaller than a predetermined distance, or may be a three-dimensional point with the smallest distance to first three-dimensional point b26. Hereinafter, the other three-dimensional point whose distance to one three-dimensional points is smaller than a predetermined distance, or the other three-dimensional point with the smallest distance to the one three-dimensional point is called the three-dimensional point with a small distance to the one three-dimensional point. Note that the same can be said even when the three-dimensional points are read as groups.

[0824] After the processing of group G2, the three-dimensional data encoding device performs processing similar to the above-described processing for group G2 on next group G1 ((3) in FIG. 95).

[0825] Note that when  $\text{distG2}$  is equal to or more than dist1, the three-dimensional data encoding device may determine that the distance between first three-dimensional point b26 and the plurality of second three-dimensional points in group G2 is far, and may skip the calculation of the distance between each of the plurality of second three-dimensional points in group G2 and first three-dimensional point b26 to perform processing similar to the above-described processing for group G2 on next group G1. Accordingly, the distance calculation processing can be reduced, and the processing time can be reduced.

[0826] Note that the three-dimensional data encoding device may define the maximum number  $\text{search\_range}$  of a plurality of referable second three-dimensional points, and may select the candidate of a three-dimensional point from a plurality of second three-dimensional points within the range of  $\text{search\_range}$ . Additionally, the three-dimensional data encoding device may include  $\text{search\_range}$  in a bitstream. For example,  $\text{search\_range}$  may be added to the header of a bitstream or the like. Accordingly, by adjusting

$\text{search\_range}$ , it is possible to control the processing amount related to the selection of the three-dimensional point candidate for predicted value generation of the three-dimensional point to be encoded.

[0827] In this manner, the three-dimensional data encoding device classifies a plurality of referable second three-dimensional points into a plurality of groups G0 to G5, and calculates the distances to a plurality of second three-dimensional points in group G3 to which the first three-dimensional point to be encoded belongs. Then, based on the calculated distances, the three-dimensional data encoding device sets the three-dimensional point candidates for predicted value generation, in the order of closest to first three-dimensional point b26 (that is, the smallest calculated distance) as the preferential order. Next, the three-dimensional data encoding device calculates  $\text{distGk}$  between the first three-dimensional point to be encoded and each group Gk by using the information of the bounding box of each group Gk different from group G3 to which the first three-dimensional point belongs, and when the calculated  $\text{distGk}$  is smaller than  $\text{dist}(N-1)$  of the three-dimensional point candidate [N-1] that is set at the time, calculates the distance between each of a plurality of second three-dimensional points included in that group Gk and the first three-dimensional point. Then, based on the calculated distances, the three-dimensional data encoding device sets the three-dimensional point candidates for predicted value generation, in the order of closest to first three-dimensional point b26 (that is, the smallest calculated distance) as the preferential order. When  $\text{distGk}$  is larger than  $\text{dist}(N-1)$ , the three-dimensional data encoding device may calculate  $\text{distG}(k-1)$  between the next group G (k-1) and the first three-dimensional point, without calculating the distance between the plurality of second three-dimensional points in group Gk and the first three-dimensional point, and may perform processing similar to the processing for group Gk. Accordingly, it is possible to reduce the processing amount of selecting the three-dimensional point candidates for predicted value generation of the attribute information that the first three-dimensional point to be encoded has.

[0828] Next, using FIG. 96, a description will be given of an example of selecting N three-dimensional point candidates for predicted value generation from the referable three-dimensional points in the LoD (n-1) layer, which is higher than the LoDn layer to which the first three-dimensional point to be encoded belongs. FIG. 96 is a diagram for describing the processing of selecting three-dimensional point candidates from a plurality of second three-dimensional points belonging to a different layer.

[0829] When selecting N three-dimensional point candidates for predicted value generation of the first three-dimensional point to be encoded belonging to the LoDn layer from a plurality of second three-dimensional points belonging to the LoD (n-1) layer, which is higher than the LoDn layer, the three-dimensional data encoding device first selects the initial group Gk of the LoD (n-1) layer that may include three-dimensional points with a close distance to first three-dimensional point c0 to be encoded. For example, the three-dimensional data encoding device may select, from the LoD (n-1) layer, three-dimensional points with Morton codes whose values are close to the Morton code of the first three-dimensional point to be encoded, and may select group Gk to which the selected three-dimensional points belong as the initial group.

**[0830]** In this manner, with the selection or searching using the Morton code, the initial group can be selected with a low processing amount from a plurality of groups into which a plurality of second three-dimensional points belonging to a higher LoD (n-1) layer are classified. As indicated in (1) in FIG. 96, the three-dimensional data encoding device selects second three-dimensional point b26 with the Morton code close to the Morton code that first three-dimensional point c0 to be encoded has, and selects group G3 to which second three-dimensional point b26 belongs as the initial group.

**[0831]** Note that the method of selecting the initial group from a plurality of groups in the LoD (n-1) layer is not limited to this. For example, the three-dimensional data encoding device may select or search, from the plurality of second three-dimensional points belonging to LoD (n-1), a three-dimensional point whose distance in the three-dimensional space, such as Euclidean distance, is close to first three-dimensional point c0 to be encoded, and may select the group to which the selected three-dimensional point belongs as the initial group. Accordingly, it is possible to more correctly find the initial group that has a possibility of including a three-dimensional point with a close distance to the first three-dimensional point to be encoded, and the coding efficiency can be improved.

**[0832]** As indicated by (2) in FIG. 96, after selecting initial group G3 belonging to the higher LoD (n-1) layer, the three-dimensional data encoding device may calculate the distance in the three-dimensional space between a plurality of referable second three-dimensional points among a plurality of second three-dimensional points b24, b25, b26, . . . , b31 that exist in initial group G3, and three-dimensional point c0 to be encoded, and may set the three-dimensional point candidates for predicted value generation, in the order of closest distance to first three-dimensional point c0 (that is, the smallest calculated distance) as the preferential order. For example, when a distance dist0 between first three-dimensional point c0 and second three-dimensional point b25 is the smallest among second three-dimensional points b24, b25, b26, . . . , b31, and when a distance dist1 between first three-dimensional point c0 and second three-dimensional point b24 is the next smallest, it is conceivable that the three-dimensional data encoding device sets second three-dimensional point b25 to the three-dimensional point candidate [0] for predicted value generation of first three-dimensional point c0, and sets second three-dimensional point b24 to the three-dimensional point candidate [1].

**[0833]** Here, the plurality of referable second three-dimensional points may be, for example, three-dimensional points that are encoded or decoded before the first three-dimensional point to be encoded. Additionally, the plurality of referable second three-dimensional points may be a plurality of second three-dimensional points belonging to L groups that are arranged each of before and after the initial group selected with the above-described method among a plurality of groups belonging to the LoD (n-1) layer. In this manner, by switching a plurality of referable second three-dimensional points according to the first three-dimensional point to be encoded, the coding efficiency and the processing amount can be balanced. Additionally, the calculated distance between two points may use Euclidean distance or the like.

**[0834]** Note that the selection method of the initial group is not limited to the above. For example, the three-dimensional data encoding device may calculate distGk between

first three-dimensional point c0 to be encoded and each group Gk by using the information of the bounding box of each group Gk to which a plurality of referable second three-dimensional points belong, and may set a group with which the calculated distGk becomes the smallest to the initial group. Accordingly, it is possible to set a group that has a possibility of including a second three-dimensional point with a close distance to first three-dimensional point c0 to be encoded to the initial group, and the coding efficiency can be improved.

**[0835]** Additionally, when a plurality of groups whose values of distG become the same are found, the three-dimensional data encoding device compares the Morton code of first three-dimensional point c0 to be encoded with the Morton codes assigned to one or more second three-dimensional points in the plurality of groups whose distG become the same. Then, the three-dimensional data encoding device may set a group to which the second three-dimensional point with a Morton code close to the Morton code of first three-dimensional point c0 (that is, a Morton code with a small difference from the Morton code of first three-dimensional point c0) belongs as the initial group.

**[0836]** The second three-dimensional point with a Morton code close to the Morton code of first three-dimensional point c0 may be one of one or more second three-dimensional points with a Morton code whose difference from the Morton code of first three-dimensional point c0 is smaller than a predetermined value, or may be a second three-dimensional point with a Morton code with the smallest difference.

**[0837]** Accordingly, when distGs of a plurality of groups become the same, the three-dimensional data encoding device can set, to the initial group, a group including a three-dimensional point with a close distance to the first three-dimensional point to be encoded among the plurality of groups whose distGs become the same, and the coding efficiency can be improved.

**[0838]** Note that, instead of comparing the Morton codes, the three-dimensional data encoding device may calculate the distance in the three-dimensional space between the first three-dimensional point to be encoded and a plurality of second three-dimensional points, and may set a group including a three-dimensional point with a small distance to the initial group. Accordingly, it is possible to appropriately select the initial group including a second three-dimensional point with a close distance to the first three-dimensional point to be encoded, and the coding efficiency can be improved. Additionally, when the value of distG is the same among a plurality of groups, a group with a bounding box whose size is small may be set to the initial group. Accordingly, it is possible to appropriately select the initial group including a second three-dimensional point with a close distance to the first three-dimensional point to be encoded, and the coding efficiency can be improved.

**[0839]** Using FIG. 97, a description will be given of an example of the three-dimensional data encoding device selecting or updating three-dimensional point candidates from the groups before and after the initial group, after selecting the three-dimensional point candidates from the initial group. FIG. 97 is a diagram for describing the processing of selecting or updating three-dimensional point candidates from the groups before and after the initial group.

**[0840]** For example, as indicated by (1) in FIG. 97, the three-dimensional data encoding device calculates the dis-

tance distG2 between first three-dimensional point c0 and the bounding box of group G2 by using Equation N1, by using the three-dimensional-point coordinates of first three-dimensional point c0, and the information of the bounding box of group G2.

**[0841]** Next, as illustrated by (2) in FIG. 97, when distG2 is smaller than dist1 of the three-dimensional point candidate [1], the three-dimensional data encoding device may calculate the distance between each of the plurality of second three-dimensional points b16, b17, ..., b23 included in group G2 and first three-dimensional point c0, and may set the three-dimensional point candidates for predicted value generation, in the order of closest distance to first three-dimensional point c0 (that is, the smallest calculated distance) as the preferential order. Additionally, for example, when the distance dist2 to second three-dimensional point b17 is smaller than dist0 and dist1, the three-dimensional data encoding device sets second three-dimensional point b17 to the three-dimensional point candidate [0]. As a result, the three-dimensional data encoding device may set second three-dimensional point b25, which has been set to the three-dimensional point candidate [0], to the three-dimensional point candidate [1], and may remove (delete) second three-dimensional point b24 from the three-dimensional point candidates.

**[0842]** In this manner, the three-dimensional data encoding device may assign, to the three-dimensional point candidate [0], a three-dimensional point with a small distance to first three-dimensional point c0, and may subsequently set three-dimensional point candidates in the ascending order of distance. Here, when distG2=0, that is, when three-dimensional point c0 exists in the bounding box of group G2, the three-dimensional data encoding device may calculate the distance between each of second three-dimensional points b16, b17, ..., b23 included in group G2 and first three-dimensional point c0, and may set the three-dimensional point candidates for predicted value generation, in the order of closest to first three-dimensional point c0 (that is, the smallest calculated distance) as the preferential order.

**[0843]** Additionally, when distG2 is equal to or more than dist1, the three-dimensional data encoding device may determine that the distance between first three-dimensional point c0 and the plurality of second three-dimensional points in group G2 is distant, may skip the calculation of the distance between each of the plurality of second three-dimensional points in group G2 and first three-dimensional point c0, and may perform processing similar to the above-described processing for group G2 on next group G1 or group G4. Accordingly, the distance calculation processing can be reduced.

**[0844]** Note that the three-dimensional data encoding device may define the maximum number search\_range of a plurality of referable second three-dimensional points, and may select the candidate of a three-dimensional point from a plurality of second three-dimensional points within the range of search\_range. Additionally, the three-dimensional data encoding device may include search\_range in a bit-stream. For example, search\_range may be added to the header of a bitstream or the like. Accordingly, by adjusting search\_range, it is possible to control the processing amount related to the selection of the three-dimensional point candidate for predicted value generation of the three-dimensional point to be encoded.

**[0845]** The three-dimensional data encoding device classifies a plurality of referable second three-dimensional points in the LoD (n-1) layer into a plurality of groups as described above, and selects the initial group that has a possibility of including a three-dimensional point with a close distance to the three-dimensional point to be encoded. Then, the three-dimensional data encoding device calculates the distance between each of a plurality of second three-dimensional points in the initial group and the first three-dimensional point, and based on the calculated distances, sets the three-dimensional point candidates for predicted value generation, in the order of closest to first three-dimensional point c0 (that is, the smallest calculated distance) as the preferential order. Next, the three-dimensional data encoding device calculates distGk between the first three-dimensional point to be encoded and each group Gk by using the information of the bounding boxes of a plurality of groups before and after the initial group, and when the calculated distGk is smaller than dist (N-1) of the three-dimensional point candidate [N-1] that is set at the time, calculates the distance between each of a plurality of second three-dimensional points included in that group Gk and the first three-dimensional point. Then, based on the calculated distances, the three-dimensional data encoding device sets the three-dimensional point candidates for predicted value generation, in the order of closest to first three-dimensional point c0 (that is, the smallest calculated distance) as the preferential order. When distGk is larger than dist (N-1), the three-dimensional data encoding device may calculate distG (k-1) between the next group G (k-1) and the first three-dimensional point, without calculating the distances to the plurality of second three-dimensional points in that group Gk, and may perform processing similar to the processing for group Gk. Accordingly, the processing amount of selecting the three-dimensional point candidate to be encoded can be reduced.

**[0846]** Note that, in the present embodiment, although the example has been illustrated in which the three-dimensional data encoding device calculates the distance between each of the plurality of second three-dimensional points in the initial group and the first three-dimensional point, after selecting the initial group of the first three-dimensional point to be encoded, it is not necessarily limited to this. For example, the three-dimensional data encoding device calculates distG by using the first three-dimensional point to be encoded and the information of the bounding box of the initial group, and determines whether or not distG is larger than a predetermined threshold value TH. When distG is larger than the predetermined threshold value TH as a result of the determination, the three-dimensional data encoding device may skip the calculation of the distance between each of the plurality of second three-dimensional points in the initial group and the first three-dimensional point. Accordingly, the distance calculation processing can be reduced, and the processing time can be reduced.

**[0847]** Additionally, the three-dimensional data encoding device may select the initial group from another group. For example, the three-dimensional data encoding device may calculate distG to each group by using the information of the bounding boxes before and after the first initial group, and using the first three-dimensional point, and may reset a group with a small distG to the initial group. Accordingly, even when there is a possibility that the first three-dimensional point to be encoded is not included in the first initial

group, it is possible to improve the code amount while suppressing the processing amount, by selecting the initial group from the groups before and after the first initial group. [0848] Additionally, the order in which the three-dimensional data encoding device searches for three-dimensional point candidates may be any order. For example, the three-dimensional data encoding device may sequentially search the groups before and after the initial group. In FIG. 97, the three-dimensional data encoding device may search from previous group G2 or following group G4, which includes a three-dimensional point whose Morton order is close to the initial group, such as in the order of G3->G2->G4->G1->G5, or in the order of G3->G4->G2->G5->G1, on the basis of initial group G3. Accordingly, a three-dimensional point candidate with a close distance to the three-dimensional point to be encoded can be found faster, and the speed can be increased by terminating the search midway and the like. Additionally, the three-dimensional data encoding device may perform searching by giving preference to either one of the directions on the basis of initial group G3, such as in the order of G3->G2->G1->G4->G5, or in the order of G3->G4->G5->G2->G1. Accordingly, the access efficiency to the memory storing the information of referable three-dimensional points can be improved.

[0849] Note that, when dividing a plurality of second three-dimensional points belonging to the higher LoD (n-1) layer into a plurality of groups, the three-dimensional data encoding device may divide the plurality of second three-dimensional points into a plurality of groups so as to include one three-dimensional point. Additionally, when a plurality of groups include one three-dimensional point, that is, when division is performed with M=1, the processing in the case where a plurality of groups having the same distG value are found may be performed. In this case, a plurality of third three-dimensional points with an equal distance to the first three-dimensional point to be encoded will be in a plurality of second three-dimensional points.

[0850] In such a case, in the selection of the three-dimensional point candidates for predicted value generation, the three-dimensional data encoding device may select three-dimensional point candidates from a plurality of third three-dimensional points in the preferential order based on the first Morton code of the first three-dimensional point. For example, the three-dimensional data encoding device may select three-dimensional point candidates by using, as the preferential order, the order that is specified by the Morton codes of a plurality of third three-dimensional points, and is the order of the third three-dimensional points having the Morton codes close to the first Morton code.

[0851] As described above, the three-dimensional data encoding device selects, as the initial group, the fourth three-dimensional point having the second Morton code close to the first Morton code of the first three-dimensional point among a plurality of third three-dimensional points. Then, the three-dimensional data encoding device may search from previous group G2 or following group G4, which includes a three-dimensional point whose Morton order is close to the initial group, such as in the order of G3->G2->G4->G1->G5, or in the order of G3->G4->G2->G5->G1, on the basis of initial group G3. That is, the three-dimensional data encoding device may select three-dimensional point candidates by using, as the preferential order, the order of the third three-dimensional points close to the second Morton code, in a case where the three-dimen-

sional point candidates are selected one at a time alternately from a first group including a plurality of third three-dimensional points having Morton codes lower than the second Morton code of the fourth three-dimensional point as initial group G3, and a second group including a plurality of third three-dimensional points having Morton codes higher than the second Morton code.

[0852] In the case of the order of G3->G2->G4->G1->G5, or the order of G3->G4->G2->G5->G1, the third three-dimensional point belonging to the first group is one three-dimensional point included in each of groups G1 and G2, and the third three-dimensional point belonging to the second group is one three-dimensional point included in each of groups G4 and G5. Note that the first three-dimensional point and a plurality of third three-dimensional points in this case belong to mutually different layers.

[0853] Additionally, the three-dimensional data encoding device may select a group including three-dimensional points that are close in the Morton order to the initial group in one of before and after group G3, and may thereafter select a group including three-dimensional points that are close in the Morton order to the initial group in the other, on the basis of initial group G3, such as in the order of G3->G2->G1->G4->G5, or in the order of G3->G4->G5->G2->G1. That is, the three-dimensional data encoding device may select three-dimensional point candidates by using, as the preferential order, the order that is specified by the Morton codes of a plurality of third three-dimensional points belonging to one of the first group including a plurality of third three-dimensional points having Morton codes lower than the first Morton code, and the second group including a plurality of third three-dimensional points having Morton codes higher than the first Morton code, and that is the order of the third three-dimensional points having the Morton codes close to the first Morton code.

[0854] In the case of the order of G3->G2->G1->G4->G5, or the order of G3->G4->G5->G2->G1, the third three-dimensional point belonging to the first group is one three-dimensional point included in each of groups G1 and G2, and the third three-dimensional point belonging to the second group is one three-dimensional point included in each of groups G4 and G5. Note that the first three-dimensional point and a plurality of third three-dimensional points in this case belong to the same layer.

[0855] In the present embodiment, although the example has been illustrated in which the three-dimensional data encoding device calculates the distance distGk between each group Gk and the first three-dimensional point within the range of search\_range, calculates the distance between each of a plurality of three-dimensional points in group Gk and the first three-dimensional point when the calculated distGk is smaller than dist (N-1) of the three-dimensional point candidate [N-1], and sets three-dimensional point candidate for predicted value generation, in the order of closest to the first three-dimensional point (that is, the smallest calculated distance) as the preferential order, but it is not necessarily limited to this. For example, when a certain condition is satisfied, the three-dimensional data encoding device may stop searching or addition of three-dimensional point candidates.

[0856] For example, when dist (N-1) of the three-dimensional point candidate [N-1] becomes smaller than a threshold value  $\alpha$ , the three-dimensional data encoding device may determine that N three-dimensional point candidates

with relatively close distance to the first three-dimensional point to be encoded have been found, and may stop further searching or addition. Accordingly, the processing amount can be reduced. Note that the threshold value  $\alpha$  may be settable for each LoD layer. Accordingly, the processing amount and the coding efficiency can be balanced by setting an appropriate threshold value for each LoD layer. Additionally, the threshold value  $\alpha$  may be included in a bitstream, or may be added to the header of a bitstream or the like. Further, the threshold value  $\alpha$  may be specified by the standard or the like.

[0857] For example, when  $distG$  becomes smaller than  $dist(N-1)$ , the three-dimensional data encoding device may count the number of times of calculating the distance between each of a plurality of second three-dimensional points in each group and the first three-dimensional point, and may stop searching or addition of three-dimensional point candidates at the time when the counted number of times exceeds a threshold value  $\beta$ . Accordingly, the processing amount can be reduced. Note that the threshold value  $\beta$  may be settable for each LoD layer. Accordingly, the processing amount and the coding efficiency can be balanced by setting an appropriate threshold value for each LoD layer. Additionally, the threshold value  $\beta$  may be included in a bitstream, or may be added to the header of a bitstream or the like. Further, the threshold value  $\beta$  may be specified by the standard or the like.

[0858] Additionally, for example, when  $distG$  becomes equal to or more than  $dist(N-1)$ , the three-dimensional data encoding device may count the number of times of skipping the calculation of the distance between each of a plurality of second three-dimensional points in each group and the first three-dimensional point, and may change the value of  $search\_range$  according to the number of times of skipping. Specifically, the three-dimensional data encoding device may increase the value of  $search\_range$  as the number of times of skipping increases. Additionally, the three-dimensional data encoding device may decrease the value of  $search\_range$  as the number of times of skipping decreases. In this manner, the three-dimensional data encoding device balance the processing amount and the coding efficiency by changing the value of  $search\_range$  according to the number of times of skipping.

[0859] Additionally, for example, the three-dimensional data encoding device may add or update three-dimensional point candidates while referring to each group by skipping  $s$  points ( $s$  is 1 or more), in order to suppress the number of times of searching even when  $search\_range$  is increased. Accordingly, the processing amount can be reduced.

[0860] Note that, in the present embodiment, although the three-dimensional data encoding device calculates  $distG_k$  based on the first three-dimensional point to be encoded and the information of the bounding box of each group, compares  $distG_k$  with  $dist(N-1)$  of the three-dimensional point candidate  $[N-1]$  at the time, and determines whether or not to obtain the distance to each of a plurality of second three-dimensional points in group  $G_k$ , the determination may be made by using  $dist0$  of the three-dimensional point candidate  $[0]$ , instead of using  $dist(N-1)$ . Accordingly, when a three-dimensional point whose distance is even closer than the minimum distance included in the three-dimensional point candidates is included in group  $G$ , the processing amount can be reduced by calculating the distance to the three-dimensional point in the group.

[0861] Note that, when searching for three-dimensional point candidates from each group, the three-dimensional data encoding device may change the preference of searching, according to the size of the bounding box of each group. For example, as illustrated in FIG. 98, the initial group may be set or searching may be performed by giving preference to a group with a small bounding box. That is, processing may be performed by giving preference to group G1 illustrated in (a) over group G2 illustrated in (b) in FIG. 98.

[0862] Distances  $distG1$  and  $distG2$  between group G1 and group G2 and the first three-dimensional point to be encoded, respectively, are both 0, since the first three-dimensional point is included in the bounding boxes of both groups G1 and G2. However, G1 with a small bounding box has a higher possibility of including a three-dimensional point with a close distance to the first three-dimensional point to be encoded. Therefore, the initial group may be set, or searching may be performed by giving preference to a group with a small bounding box.

[0863] Hereinafter, the processing flow in the three-dimensional data encoding device will be described. FIG. 99 is a flowchart of three-dimensional data encoding processing by the three-dimensional data encoding device.

[0864] First, the three-dimensional data encoding device encodes geometry information (geometry) (S7601). For example, the three-dimensional data encoding device performs encoding by using an octree representation.

[0865] When the geometry of a three-dimensional point is changed due to quantization or the like, after encoding of the geometry information, the three-dimensional data encoding device re-assigns the attribute information of the original three-dimensional point to the three-dimensional point after the change (S7602). For example, the three-dimensional data encoding device performs re-assigning by interpolating the value of the attribute information according to the amount of change of the geometry. For example, the three-dimensional data encoding device detects  $N$  three-dimensional points before the change that are close to the three-dimensional position after the change, and performs weighted average of the value of the attribute information of the  $N$  three-dimensional points. For example, in the weighted average, the three-dimensional data encoding device determines the weight based on the distance from the three-dimensional position after the change to each of the  $N$  three-dimensional points. Then, the three-dimensional data encoding device determines the value obtained by the weighted average to be the value of the attribute information of the three-dimensional point after the change. Additionally, when two or more three-dimensional points are changed to the same three-dimensional position due to quantization or the like, the three-dimensional data encoding device may assign the average value of the attribute information of the two or more three-dimensional points before the change as the value of the attribute information of the three-dimensional point after the change.

[0866] Next, the three-dimensional data encoding device encodes the attribute information (Attribute) after the re-assigning (S7603). For example, when encoding a plurality of types of attribute information, the three-dimensional data encoding device may sequentially encode the plurality of types of attribute information. For example, when encoding color and reflectance as the attribute information, the three-dimensional data encoding device may generate a bitstream to which the encoded result of reflectance is added after the

encoded result of color. Note that the order of a plurality of encoded results of the attribute information added to a bitstream is not limited to this order, and may be any order. [0867] Additionally, the three-dimensional data encoding device may add, to the header or the like, the information indicating the encoded data start location of each attribute information in a bitstream. Accordingly, since the three-dimensional data decoding device can selectively decode the attribute information that needs to be decoded, the decoding processing of the attribute information that does not need to be decoded can be omitted. Therefore, the processing amount by the three-dimensional data decoding device can be reduced. Additionally, the three-dimensional data encoding device may encode a plurality of types of attribute information in parallel, and integrate the encoded results into one bitstream. Accordingly, the three-dimensional data encoding device can encode a plurality of types of attribute information at high speed.

[0868] FIG. 100 is a flowchart of the attribute information encoding processing (S7603). First, the three-dimensional data encoding device sets LoDs (S7611). That is, the three-dimensional data encoding device assigns each three-dimensional point to any of the plurality of LoDs.

[0869] Next, the three-dimensional data encoding device starts a loop per LoD (S7612). That is, the three-dimensional data encoding device repeatedly performs the processing of steps S7613 to S7621 for each LoD.

[0870] Next, the three-dimensional data encoding device starts a loop per three-dimensional point (S7613). That is, the three-dimensional data encoding device repeatedly performs the processing of steps S7614 to S7620 for each three-dimensional point.

[0871] First, the three-dimensional data encoding device searches for a plurality of surrounding points, which are three-dimensional points that are used for calculation of the predicted value of a current three-dimensional point to be processed, and that exist in the surrounding of the current three-dimensional point (S7614). Specifically, the three-dimensional data encoding device searches for a plurality of surrounding points with the method described by using FIG. 91 to FIG. 98, and determines the three-dimensional point candidates for predicted value generation. The details of the search processing of a plurality of surrounding points will be described later by using FIG. 103.

[0872] Next, the three-dimensional data encoding device calculates a predicted value P of the current three-dimensional point (S7615).

[0873] Next, the three-dimensional data encoding device calculates the prediction residual that is the difference between the attribute information and the predicted value of the current three-dimensional point (S7616).

[0874] Next, the three-dimensional data encoding device calculates a quantized value by quantizing the prediction residual (S7617).

[0875] Next, the three-dimensional data encoding device arithmetically encodes the quantized value (S7618).

[0876] Additionally, the three-dimensional data encoding device calculates an inverse quantized value by inverse quantizing the quantized value (S7619).

[0877] Next, the three-dimensional data encoding device generates a decoded value by adding the predicted value to the inverse quantized value (S7620).

[0878] Next, the three-dimensional data encoding device ends the loop per three-dimensional point (S7621).

[0879] Additionally, the three-dimensional data encoding device ends the loop per LoD (S7622).

[0880] Hereinafter, the processing flow in the three-dimensional data decoding device will be described. FIG. 101 is a flowchart of three-dimensional data decoding processing by the three-dimensional data decoding device. First, the three-dimensional data decoding device decodes geometry information (geometry) from a bitstream (S7631). For example, the three-dimensional data decoding device performs decoding by using an octree representation.

[0881] Next, the three-dimensional data decoding device decodes attribute information (Attribute) from the bitstream (S7632). For example, when decoding a plurality of types of attribute information, the three-dimensional data decoding device may sequentially decode the plurality of types of attribute information. For example, when decoding color and reflectance as the attribute information, the three-dimensional data decoding device decodes the encoded result of color and the encoded result of reflectance, according to the order of addition to the bitstream. For example, in a bitstream, when the encoded result of reflectance is added after the encoded result of color, the three-dimensional data decoding device decodes the encoded result of color, and thereafter decodes the encoded result of reflectance. Note that the three-dimensional data decoding device may decode the encoded results of the attribute information added to a bitstream in any order.

[0882] Additionally, the three-dimensional data decoding device may obtain the information indicating the encoded data start location of each attribute information in a bitstream by decoding the header or the like. Accordingly, since the three-dimensional data decoding device can selectively decode the attribute information that needs to be decoded, the decoding processing of the attribute information that does not need to be decoded can be omitted. Therefore, the processing amount by the three-dimensional data decoding device can be reduced. Additionally, the three-dimensional data decoding device may decode a plurality of types of attribute information in parallel, and integrate the decoded results into one three-dimensional point cloud. Accordingly, the three-dimensional data decoding device can decode a plurality of types of attribute information at high speed.

[0883] FIG. 102 is a flowchart of the attribute information decoding processing (S7632). First, the three-dimensional data decoding device sets LoDs (S7641). That is, the three-dimensional data decoding device assigns each of a plurality of three-dimensional points having the decoded geometry information to any of the plurality of LoDs. For example, this assigning method is the same method as the assigning method used by the three-dimensional data encoding device.

[0884] Next, the three-dimensional data decoding device starts a loop per LOD (S7642). That is, the three-dimensional data decoding device repeatedly performs the processing of steps S7643 to S7649 for each LoD.

[0885] Next, the three-dimensional data decoding device starts a loop per three-dimensional point (S7643). That is, the three-dimensional data decoding device repeatedly performs the processing of steps S7644 to S7648 for each three-dimensional point.

[0886] First, the three-dimensional data decoding device searches for a plurality of surrounding points, which are three-dimensional points that are used for calculation of the predicted value of a current three-dimensional point to be processed, and that exist in the surrounding of the current

three-dimensional point (S7644). Note that this processing is the same as the processing in the three-dimensional data encoding device.

[0887] Next, the three-dimensional data decoding device calculates the predicted value P of the current three-dimensional point (S7645).

[0888] Next, the three-dimensional data decoding device arithmetically decodes a quantized value from a bitstream (S7646).

[0889] Additionally, the three-dimensional data decoding device calculates an inverse quantized value by inverse quantizing the decoded quantized value (S7647).

[0890] Next, the three-dimensional data decoding device generates a decoded value by adding the predicted value to the inverse quantized value (S7648).

[0891] Next, the three-dimensional data decoding device ends the loop per three-dimensional point (S7649).

[0892] Additionally, the three-dimensional data decoding device ends the loop per LoD (S7650).

[0893] FIG. 103 and FIG. 104 are flowcharts of the search processing of surrounding points (S7614). First, the three-dimensional data encoding device classifies a plurality of second three-dimensional points in the higher LoD layer of the first three-dimensional point to be encoded into a plurality of groups each including M points (M is an integer of 1 or more) (S7651).

[0894] Next, the three-dimensional data encoding device selects an initial group from the plurality of groups (S7652).

[0895] Next, the three-dimensional data encoding device selects N three-dimensional point candidates for predicted value generation (S7653).

[0896] Next, the three-dimensional data encoding device sets T=1 (S7654).

[0897] Next, the three-dimensional data encoding device calculates the distance distG between the initial group-T and the first three-dimensional point to be processed (S7655).

[0898] Next, the three-dimensional data encoding device determines whether or not the distance distG is smaller than dist (N-1) of the three-dimensional point candidate [N-1] (S7656).

[0899] Next, when the distance distG is smaller than dist (N-1) (Yes in S7656), the three-dimensional data encoding device calculates the distance between each of a plurality of second three-dimensional points in the initial group-T and the first three-dimensional point, and updates the three-dimensional point candidates for predicted value generation (S7657). On the other hand, when the distance is equal to or more than dist (N-1) (No in S7656), the three-dimensional data encoding device proceeds to step S7658.

[0900] Next, the three-dimensional data encoding device calculates the distance distG between the initial group+T and the first three-dimensional point to be processed (S7658).

[0901] Next, the three-dimensional data encoding device determines whether or not the distance distG is smaller than dist (N-1) of the three-dimensional point candidate [N-1] (S7659).

[0902] Next, when the distance distG is smaller than dist (N-1) (Yes in S7659), the three-dimensional data encoding device calculates the distance between each of a plurality of second three-dimensional points in the initial group+T and the first three-dimensional point, and updates the three-dimensional point candidates for predicted value generation

(S7660). On the other hand, when the distance is equal to or more than dist (N-1) (No in S7659), the three-dimensional data encoding device proceeds to step S7661.

[0903] Next, the three-dimensional data encoding device determines whether or not all the referable groups have been processed in the higher LoD layer (S7661).

[0904] Next, when not all the referable groups have been processed (No in S7661), the three-dimensional data encoding device updates T to the value obtained by incrementing the present T by one (S7662). On the other hand, when all the referable groups have been processed (Yes in S7661), the three-dimensional data encoding device proceeds to step S7663.

[0905] Next, the three-dimensional data encoding device determines whether or not EnableReferringSameLoD is 1 (S7663).

[0906] Next, when EnableReferringSameLoD is 1 (Yes in S7663), the three-dimensional data encoding device classifies a plurality of second three-dimensional points in the same LoD layer as the first three-dimensional point to be encoded into a plurality of groups each including M points (S7664).

[0907] Next, the three-dimensional data encoding device selects a plurality of second three-dimensional points belonging to the same group as the first three-dimensional point to be encoded (S7665).

[0908] Next, the three-dimensional data encoding device calculates the distance between each of a plurality of second three-dimensional points in the same group as the first three-dimensional point to be encoded, and the first three-dimensional point, and selects the three-dimensional point candidates for predicted value generation (S7666).

[0909] Next, the three-dimensional data encoding device sets T=1 (S7667).

[0910] Next, the three-dimensional data encoding device calculates the distance distG between the same group-T and the first three-dimensional point to be processed (S7668).

[0911] Next, the three-dimensional data encoding device determines whether or not the distance distG is smaller than dist (N-1) of the three-dimensional point candidate [N-1] (S7669).

[0912] Next, when the distance distG is smaller than dist (N-1) (Yes in S7669), the three-dimensional data encoding device calculates the distance between each of the plurality of second three-dimensional points in the same group-T and the first three-dimensional point, and updates the three-dimensional point candidates for predicted value generation (S7670). On the other hand, when the distance is equal to or more than dist (N-1) (No in S7669), the three-dimensional data encoding device proceeds to step S7671.

[0913] Next, the three-dimensional data encoding device determines whether or not all the referable groups in the same LoD layer have been processed (S7671).

[0914] Next, when not all the referable groups have been processed (No in S7671), the three-dimensional data encoding device updates T to the value obtained by incrementing the present T by one (S7672). On the other hand, when all the referable groups have been processed (Yes in S7671), the three-dimensional data encoding device ends the search processing of surrounding points.

[0915] Note that the search processing of surrounding points is also performed in the three-dimensional data decoding device in step S7644 in a manner similar to the above. That is, in the description of the search processing of

surrounding points using FIG. 103 and FIG. 104, the three-dimensional data encoding device can also be read as the three-dimensional data decoding device.

[0916] FIG. 105 is a block diagram illustrating the configuration of attribute information encoder 7600 included in the three-dimensional data encoding device. Note that FIG. 105 only illustrates the details of the attribute information encoder among a geometry information encoder, an attribute information re-assigner, and the attribute information encoder included in the three-dimensional data encoding device.

[0917] Attribute information encoder 7600 includes LoD generator 7601, surrounding searcher 7602, predictor 7603, prediction residual calculator 7604, quantizer 7605, arithmetic encoder 7606, inverse quantizer 7607, decoded value generator 7608, and memory 7609.

[0918] LoD generator 7601 generates LoDs by using the geometry information (geometry) of three-dimensional points.

[0919] Surrounding searcher 7602 searches for a nearby three-dimensional point adjacent to each three-dimensional point by using the generation result of the LoDs by LoD generator 7601, and the distance information indicating the distance to each three-dimensional point.

[0920] Predictor 7603 generates a predicted value of the attribute information of a current three-dimensional point to be encoded. Specifically, predictor 7603 assigns predicted values to prediction modes whose prediction mode values are indicated by “0” to “M-1”, and selects a prediction mode. Predictor 7603 outputs the selected prediction mode, specifically, the prediction mode value indicating the prediction mode, to the arithmetic encoder. Predictor 7603 performs, for example, the processing in step S7615. Note that, in the calculation of the predicted value, the predicted value may be calculated without using the prediction mode. For example, one of three-dimensional point candidates may be selected, and the attribute information of the selected three-dimensional point may be calculated as the predicted value.

[0921] Prediction residual calculator 7604 calculates (generates) the prediction residual of the predicted value of the attribute information generated by predictor 7603. Prediction residual calculator 7604 performs the processing in step S7616.

[0922] Quantizer 7605 quantizes the prediction residual of the attribute information calculated by prediction residual calculator 7604.

[0923] Arithmetic encoder 3106 arithmetically encodes the prediction residual after quantization by quantizer 3105. Arithmetic encoder 7606 outputs a bitstream including the arithmetically encoded prediction residual to, for example, the three-dimensional data decoding device.

[0924] Note that the prediction residual may be binarized by, for example, quantizer 7605, before being arithmetically encoded by arithmetic encoder 7606. Note that arithmetic encoder 7606 may generate and encode various kinds of header information. Additionally, arithmetic encoder 7606 may obtain the prediction mode used for encoding from Prediction block, arithmetically encode the prediction mode, and add the prediction mode to a bitstream.

[0925] Inverse quantizer 7607 inverse quantizes the prediction residual after quantization by quantizer 7605. Inverse quantizer 7607 performs the processing in step S7619.

[0926] Decoded value generator 7608 generates a decoded value by adding the predicted value of the attribute information generated by predictor 7603, and the prediction residual after inverse quantization by inverse quantizer 7607.

[0927] Memory 7609 is a memory that stores the decoded value of the attribute information of each three-dimensional point decoded by decoded value generator 7608. For example, when generating the predicted value of a three-dimensional point that has not been encoded yet, predictor 7603 generates the predicted value by utilizing the decoded value of the attribute information of each three-dimensional point stored in memory 7609.

[0928] FIG. 106 is a block diagram illustrating the configuration of attribute information decoder 7610 included in the three-dimensional data decoding device. Note that FIG. 106 illustrates the details of the attribute information decoder of a geometry information decoder and an attribute information decoder included in the three-dimensional data decoding device.

[0929] Attribute information decoder 7610 includes LoD generator 7611, surrounding searcher 7612, predictor 7613, arithmetic decoder 7614, inverse quantizer 7615, decoded value generator 7616, and memory 7617.

[0930] LoD generator 7611 generates LoDs by using the geometry information of three-dimensional points decoded by the geometry information decoder (not illustrated).

[0931] Surrounding searcher 7612 searches for a nearby three-dimensional point adjacent to each three-dimensional point by using the generation result of LoDs by LoD generator 7611, and the distance information indicating the distance to each three-dimensional point.

[0932] Predictor 7613 generates a predicted value of the attribute information of a current three-dimensional point to be decoded. Predictor 7613 performs, for example, the processing in step S7645.

[0933] Arithmetic decoder 7614 arithmetically decodes the prediction residual in the bitstream obtained from attribute information encoder 7600. Arithmetic decoder 7614 may decode various kinds of header information. Additionally, arithmetic decoder 7614 may output the arithmetically decoded prediction mode to predictor 7613. In this case, predictor 7613 may calculate a predicted value by using the prediction mode obtained by being arithmetically decoded in arithmetic decoder 7614.

[0934] Inverse quantizer 7615 inverse quantizes the prediction residual arithmetically decoded by arithmetic decoder 7614.

[0935] Decoded value generator 7616 adds the predicted value generated by predictor 7613 and the prediction residual after inverse quantization by inverse quantizer 7615 to generate a decoded value. Decoded value generator 7616 outputs the decoded attribute information data to other devices.

[0936] Memory 7617 is a memory that stores the decoded value of the attribute information of each three-dimensional point decoded by decoded value generator 7616. For example, when generating the predicted value of a three-dimensional point that has not been decoded yet, predictor 7613 generates the predicted value by utilizing the decoded value of the attribute information of each three-dimensional point stored in memory 7617.

[0937] As stated above, the three-dimensional data encoding device according to the present embodiment performs

the process shown by FIG. 107. The three-dimensional data encoding device is a three-dimensional data encoding device that encodes three-dimensional points, and selects, as one or more candidates for calculating a predicted value of attribute information of a first three-dimensional point, N second three-dimensional points in order of closest distance to the first three-dimensional point, from second three-dimensional points surrounding the first three-dimensional point among the three-dimensional points (S7681). The three-dimensional data encoding device calculates a predicted value using pieces of attribute information of the N second three-dimensional points selected as the one or more candidates (S7682). The three-dimensional data encoding device calculates a prediction residual that is a difference between the attribute information of the first three-dimensional point and the predicted value calculated (S7683). The three-dimensional data encoding device generates a bitstream including the prediction residual (S7684). In the selecting (S7681), when the second three-dimensional points include a plurality of third three-dimensional points having an equal distance from the first three-dimensional point, the three-dimensional data encoding device selects the one or more candidates from the plurality of three-dimensional points in a preferential order based on a first Morton code of the first three-dimensional point.

[0938] Accordingly, since it is possible to select the second three-dimensional point close to the first three-dimensional point to be encoded as a candidate to be used for calculating the predicted value, the coding efficiency can be improved.

[0939] For example, the preferential order is an order that is specified by Morton codes of the plurality of third three-dimensional points, and is the order of the plurality of third three-dimensional points having the Morton codes close to the first Morton code.

[0940] For example, the preferential order is an order of the plurality of three-dimensional points that is close to a second Morton code when the one or more candidates are selected one at a time alternately from a first group and a second group, the first group including, among the plurality of third three-dimensional points, third three-dimensional points having Morton codes lower than the second Morton code of fourth three-dimensional points having Morton codes close to the first Morton code, the second group including, among the plurality of third three-dimensional points, three-dimensional points having Morton codes higher than the second Morton code.

[0941] For example, the first three-dimensional point and the third three-dimensional points belong to mutually different layers.

[0942] For example, the preferential order is an order that is specified by Morton codes of third three-dimensional points, and is the order of the third three-dimensional points having the Morton codes close to the first Morton code, the third three-dimensional points being included in the plurality of third three-dimensional points and belonging to one of a first group and a second group, the first group including, among the plurality of third three-dimensional points, third three-dimensional points having Morton codes lower than the first Morton code, the second group including, among the plurality of third three-dimensional points, third three-dimensional points having Morton codes higher than the first Morton code.

[0943] For example, the first three-dimensional point and the third three-dimensional points belong to a same layer.

[0944] For example, the three-dimensional data encoding device includes a processor and memory, and the processor performs the above process using the memory.

[0945] The three-dimensional data decoding device according to the present embodiment performs the process shown by FIG. 108. The three-dimensional data decoding device is a three-dimensional data decoding device that decodes three-dimensional points, and obtains a prediction residual of a first three-dimensional point among the three-dimensional points by obtaining a bitstream (S7691). The three-dimensional data decoding device selects, as one or more candidates for calculating a predicted value of attribute information of the first three-dimensional point, N second three-dimensional points in order of closest distance to the first three-dimensional point, from second three-dimensional points surrounding the first three-dimensional point among the three-dimensional points (S7692). The three-dimensional data decoding device calculates a predicted value using pieces of attribute information of the N second three-dimensional points selected as the one or more candidates (S7693). The three-dimensional data decoding device calculates the attribute information of the first three-dimensional point by adding the predicted value and the prediction residual (S7694). In the selecting (S7692), when the second three-dimensional points include a plurality of third three-dimensional points having an equal distance from the first three-dimensional point, the three-dimensional data decoding device selects the one or more candidates from the plurality of three-dimensional points in a preferential order based on a first Morton code of the first three-dimensional point.

[0946] According to this, the attribute information of the first three-dimensional point to be processed can be appropriately decoded.

[0947] For example, the preferential order is an order that is specified by Morton codes of the plurality of third three-dimensional points, and is the order of the plurality of third three-dimensional points having the Morton codes close to the first Morton code.

[0948] For example, the preferential order is an order of the plurality of three-dimensional points that is close to a second Morton code when the one or more candidates are selected one at a time alternately from a first group and a second group, the first group including, among the plurality of third three-dimensional points, third three-dimensional points having Morton codes lower than the second Morton code of fourth three-dimensional points having Morton codes close to the first Morton code, the second group including, among the plurality of third three-dimensional points, three-dimensional points having Morton codes higher than the second Morton code.

[0949] For example, the first three-dimensional point and the third three-dimensional points belong to mutually different layers.

[0950] For example, the preferential order is an order that is specified by Morton codes of third three-dimensional points, and is the order of the third three-dimensional points having the Morton codes close to the first Morton code, the third three-dimensional points being included in the plurality of third three-dimensional points and belonging to one of a first group and a second group, the first group including, among the plurality of third three-dimensional points, third

three-dimensional points having Morton codes lower than the first Morton code, the second group including, among the plurality of third three-dimensional points, third three-dimensional points having Morton codes higher than the first Morton code.

[0951] For example, the first three-dimensional point and the third three-dimensional points belong to a same layer.

[0952] For example, the three-dimensional data decoding device includes a processor and memory, and the processor performs the above process using the memory.

[0953] Although a layer higher than the LoD<sub>n</sub> layer is defined as the LoD(n-1) layer in the embodiment, a layer higher than the LoD<sub>n</sub> layer may be defined as an LoD(n+1) layer. In other words, a smaller value represented by n may indicate a higher layer, and a larger value represented by n may indicate a higher layer.

#### Embodiment 12

[0954] In this embodiment, another example of encoding of attribute information on a three-dimensional point with a low processing amount will be described.

[0955] FIG. 109 is a diagram for illustrating an example of a process of encoding attribute information on a three-dimensional point.

[0956] With the three-dimensional data encoding device according to Embodiment 8 described above, a layered structure (also referred to here as a hierarchical structure) is generated by classifying a plurality of three-dimensional points by generating LoD layers based on geometry information on the plurality of three-dimensional points, and the layered structure is used to encode attribute information on the plurality of three-dimensional points. However, the present disclosure is not limited thereto.

[0957] For example, in the method according to Embodiment 8 (described above with reference to FIGS. 51 to 53), the three-dimensional data encoding device may skip the process of generating an LoD layered structure (also referred to as an LoD hierarchical structure), instead of calculating distance information between the input three-dimensional points to generate LoD layers and applying predictive encoding. The three-dimensional data encoding device may skip the generation of predicted values and directly encode attribute information.

[0958] In another example, the three-dimensional data encoding device may skip the predicted value generation process by setting search\_range described in Embodiment 11, which indicates the maximum number of three-dimensional points that can be referred to for predicted value generation or the search range of three-dimensional points, at 0. Alternatively, the three-dimensional data encoding device may calculate a prediction residual by setting a predicted value at 0 and subtracting the predicted value of 0 from the attribute information on the three-dimensional point to be encoded, or may designate the attribute information on the three-dimensional point to be encoded as a prediction residual as it is without subtracting a predicted value from the attribute information and apply quantization or binary arithmetic encoding to the calculated prediction residual. In this way, the attribute information can be encoded without performing the predicted value generation process, and the processing amount of the encoding can be reduced.

[0959] The three-dimensional data decoding device may decode attribute information by skipping the predicted value

generation process, when the value of search\_range added to the header or the like is 0. For example, when the value of search\_range is 0, the three-dimensional data decoding device may decode a prediction residual for attribute information from the bitstream by applying entropy decoding, such as binary arithmetic decoding, or inverse quantization, and designate the value resulting from the decoding as decoding result of the attribute information. In this way, the three-dimensional data decoding device can decode attribute information without performing the predicted value generation process, and the processing amount of the decoding can be reduced.

[0960] Note that the three-dimensional data encoding device or the three-dimensional data decoding device may set the layer of the LoD layered structure to be 1, in addition to setting the value of search\_range at 0. In that case, the three-dimensional data encoding device or the three-dimensional data decoding device does not need to perform the process of generating an LoD layered structure based on the geometry information on a plurality of three-dimensional points to be encoded or decoded, and the processing amount of the encoding or decoding can be reduced.

[0961] The three-dimensional data encoding device or the three-dimensional data decoding device may encode or decode attribute information on a plurality of three-dimensional points to be encoded or decoded without performing predicted value generation after re-ordering the plurality of three-dimensional points to be encoded or decoded in Morton order (after re-ordering the three-dimensional points in the order of the Morton codes thereof). By performing the encoding by re-ordering the plurality of three-dimensional points to be encoded or decoded in Morton order, the three-dimensional data encoding device can substantially encode attribute information in ascending order of the distances between the three-dimensional points. As a result, the values of the attribute information that occur are close to each other, and therefore, the encoding efficiency of the entropy encoding can be improved.

[0962] Note that the three-dimensional data encoding device or the three-dimensional data decoding device may encode or decode attribute information on a plurality of three-dimensional points without re-ordering the plurality of three-dimensional points to be encoded or decoded in Morton order based on the geometry information on the plurality of three-dimensional points. For example, the three-dimensional data encoding device may encode a plurality of three-dimensional points in the order of input, and the three-dimensional data decoding device may decode a plurality of encoded three-dimensional points in the order of encoding. In that case, the three-dimensional data encoding device or the three-dimensional data decoding device can encode or decode a plurality of three-dimensional points to be encoded or decoded without re-ordering the three-dimensional points in Morton order, so that the processing amount of the encoding or decoding can be reduced.

[0963] FIG. 110 is a flowchart of a three-dimensional data encoding process according to this embodiment.

[0964] First, the three-dimensional data encoding device encodes geometry information (geometry) (S8101). For example, the three-dimensional data encoding device performs the encoding using an octree representation.

[0965] The three-dimensional data encoding device then performs a process of transforming attribute information (S8102). For example, after the encoding of geometry

information, if the position of a three-dimensional point is changed due to quantization or the like, the three-dimensional data encoding device reassigns attribute information of the original three-dimensional point to the three-dimensional point after the change.

[0966] Note that the three-dimensional data encoding device may interpolate values of attribute information according to the amount of change in position to re-assign the attribute information. For example, the three-dimensional data encoding device detects N pre-change three-dimensional points close to the three-dimensional position of the three-dimensional point changed in position, performs weighted averaging of the values of attribute information on the N three-dimensional points based on the distances from the position of the three-dimensional point changed in position to the respective positions of the N three-dimensional points, and determines the resulting weighted average value to be the value of the attribute information on the three-dimensional point changed in position. When the positions of two or more three-dimensional points are changed to the same three-dimensional position through quantization or the like, the three-dimensional data encoding device may assign the average value of the attribute information on the pre-change two or more three-dimensional points as the values of the attribute information on the post-change three-dimensional points.

[0967] The three-dimensional data encoding device then encodes attribute information (S8130).

[0968] Note that the three-dimensional data encoding device may encode attribute information by changing the value of search\_range for each attribute information. For example, when encoding color information as attribute information, the three-dimensional data encoding device may encode color information by generating (calculating) a predicted value of the color information by generating a LoD layered structure by setting search\_range to be a value greater than 0. And when encoding reflectance information as attribute information, the three-dimensional data encoding device may encode reflectance information without calculating a predicted value by setting search\_range to be 0. In this way, a plurality of pieces of attribute information can be encoded by balancing the encoding efficiency and the processing amount required for the encoding.

[0969] Note that the values of search\_range of a plurality of pieces of attribute information may be added to header information, such as APS. This allows the three-dimensional data decoding device to decode each piece of attribute information in accordance with the decoded value of search\_range for the piece of attribute information.

[0970] FIG. 111 is a flowchart of a process of encoding attribute information (S8130 in FIG. 110) according to this embodiment.

[0971] First, the three-dimensional data encoding device sets an LoD (S8111). That is, the three-dimensional data encoding device assigns each three-dimensional point to any of a plurality of LoDs (more specifically, LoD layers). Note that when search\_range=0, the three-dimensional data encoding device may set the number of LoD layers to be 1, and may classify the plurality of three-dimensional points to be processed into one LoD layer or need not generate a LoD layered structure. This allows reduction of the processing amount of the process of generating a LoD layered structure. The three-dimensional data encoding device may set the

value of sampling, which will be described later, to be 1 and set the number of LoD layers to be 1.

[0972] The three-dimensional data encoding device then starts a loop on an LoD basis (S8112). That is, the three-dimensional data encoding device repeatedly performs the process from step S8113 to step S8122 for each LoD.

[0973] The three-dimensional data encoding device then starts a loop on a basis of a three-dimensional point (S8113). That is, the three-dimensional data encoding device repeatedly performs the process from step S8114 to step S8121 for each three-dimensional point in a LoD. Note that FIG. 111 shows encoding for current three-dimensional point P to be encoded.

[0974] The three-dimensional data encoding device then determines whether or not search\_range=0 (S8114).

[0975] When the value of search\_range is not 0 (No in S8114), the three-dimensional data encoding device searches for a plurality of peripheral points, which are three-dimensional points present in the periphery of the current three-dimensional point, that are to be used for calculation of a predicted value of the current three-dimensional point to be processed (S8115).

[0976] The three-dimensional data encoding device then calculates a predicted value of the current three-dimensional point (S8116). Specifically, the three-dimensional data encoding device calculates a weighted average of values of the attribute information on the plurality of peripheral points, and sets the obtained value as a predicted value.

[0977] When search\_range=0 (Yes in S8114), or when step S8116 is completed, the three-dimensional data encoding device proceeds to step S8117.

[0978] The three-dimensional data encoding device then calculates a prediction residual, which is the difference between the attribute information and the predicted value of the current three-dimensional point (S8117). When search\_range=0, the three-dimensional data encoding device may calculate a prediction residual by setting the predicted value to be 0. When search\_range=0, the three-dimensional data encoding device may set the value of the attribute information itself as the prediction residual. This allows reduction of the processing amount of the encoding.

[0979] The three-dimensional data encoding device then calculates a quantized value by quantizing the prediction residual (S8118).

[0980] The three-dimensional data encoding device then arithmetically encodes the quantized value (S8119).

[0981] The three-dimensional data encoding device then calculates an inverse-quantized value by inverse-quantizing the quantized value (S8120).

[0982] The three-dimensional data encoding device then generates a decoded value by adding the predicted value to the inverse-quantized value (S8121).

[0983] The three-dimensional data encoding device then ends the loop on a basis of a three-dimensional point (S8122).

[0984] The three-dimensional data encoding device also ends the loop on a LoD basis (S8123).

[0985] LoD layers in a case where the number of samples is 4 (sampling=4) will be described.

[0986] For example, the three-dimensional data encoding device may select a three-dimensional point belonging to each LoD layer in the steps described below.

[0987] Step 1. First, the three-dimensional data encoding device arranges input three-dimensional points in Morton order.

[0988] Step 2. The three-dimensional data encoding device then selects a three-dimensional point belonging to the (n+1)-th and higher LoD layers from the three-dimensional points arranged in Morton order, in accordance with the value of sampling information (sampling). For example, the three-dimensional data encoding device selects every m three-dimensional points, where m represents the value of sampling, determines the selected three-dimensional points to be three-dimensional points belonging to (n+1)-th and higher LoD layers, and determines the remaining three-dimensional points to be three-dimensional points belonging to an n-th LoD layer (such as the lowermost layer). Specifically, for example, when sampling=4, the three-dimensional data encoding device selects every four three-dimensional points from the plurality of input three-dimensional points arranged in Morton order, determines the selected three-dimensional points to be three-dimensional points belonging to (n+1)-th and higher LoD layers, and determines the remaining three-dimensional points as belonging to an n-th LoD layer (such as the lowermost layer).

[0989] Step 3. The three-dimensional data encoding device then selects a three-dimensional point belonging to (n+2)-th and higher LoD layers in accordance with the value of the sampling information (sampling). For example, the three-dimensional data encoding device selects every m three-dimensional points, where m represents the value of sampling, from the three-dimensional points selected in Step 2 described above, determines the selected three-dimensional points to be three-dimensional points belonging to (n+2)-th and higher LoD layers, and determines the remaining three-dimensional points as belonging to the (n+1)-th LoD layer. Specifically, for example, when sampling=4, the three-dimensional data encoding device selects every four three-dimensional points from the three-dimensional points selected in Step 2 described above, determines the selected three-dimensional points to be three-dimensional points belonging to (n+2)-th and higher LoD layers, and determines the remaining three-dimensional points as belonging to an (n+1)-th LoD layer.

[0990] Step 4. The three-dimensional data encoding device then repeats the process in Step 3 described above, and can end the generation of LoDs when a condition is satisfied. For example, the three-dimensional data encoding device may generate LoD layers until the number of three-dimensional points belonging to the higher layers is smaller than a predetermined threshold  $\alpha$ . Specifically, if it is determined in advance that  $\alpha=\text{sampling}$ , for example, the three-dimensional data encoding device ends the generation of LoDs when the number of three-dimensional points in the higher layers is smaller than the value of sampling.

[0991] Note that the three-dimensional data encoding device may encode threshold a and add encoded threshold a to the header of the bitstream or the like.

[0992] This allows the three-dimensional data decoding device to properly decode the bitstream by generating the same number of LoD layers as in the three-dimensional data encoding device by performing the same process as in the three-dimensional data encoding device by decoding thresh-old a in the header or the like.

[0993] FIG. 112 is a flowchart of a three-dimensional data decoding process according to this embodiment.

[0994] First, the three-dimensional data decoding device decodes geometry information (geometry) from the bit-stream (S8131). For example, the three-dimensional data decoding device performs the decoding using an octree representation.

[0995] The three-dimensional data decoding device then decodes attribute information from the bitstream (S8132).

[0996] Note that the three-dimensional data decoding device may decode each piece of attribute information in accordance with the value of search\_range added to the bitstream (or the header of the bitstream). For example, when search\_range of color information as attribute information is set to be a value greater than 0, the three-dimensional data decoding device may decode the color information by generating an LoD layered structure and generating (calculating) a predicted value of the color information. When search\_range of reflectance information as attribute information is set to be 0, the three-dimensional data decoding device may decode the reflectance information without calculating a predicted value. In this way, a plurality of pieces of attribute information can be decoded from the bitstream by balancing the decoding efficiency and the processing amount required for the decoding.

[0997] FIG. 113 is a flowchart of a process of decoding attribute information (S8132) according to this embodiment.

[0998] First, the three-dimensional data decoding device sets an LoD (S8141). That is, the three-dimensional data decoding device assigns each three-dimensional point having decoded geometry information to any of a plurality of LoDs (more specifically, LoD layers). For example, the method of the assignment is the same as the method of the assignment used in the three-dimensional data encoding device. Note that when the value of search\_range decoded from the header of the bitstream or the like is 0, the three-dimensional data decoding device may set the number of LoD layers to be 1, and may classify the plurality of three-dimensional points to be processed into one LoD layer or need not generate a LoD layered structure. This allows reduction of the processing amount of the process of generating a LoD layered structure. Note that when the value of sampling decoded from the header of the bitstream or the like is set at 1, the three-dimensional data decoding device may set the number of LoD layers to be 1, and may classify the plurality of three-dimensional points to be processed into one LoD layer or need not generate a LoD layered structure.

[0999] The three-dimensional data decoding device then starts a loop on an LoD basis (S8142). That is, the three-dimensional data decoding device repeatedly performs the process from step S8143 to step S8150 for each LoD.

[1000] The three-dimensional data decoding device then starts a loop on a basis of a three-dimensional point (S8143). That is, the three-dimensional data decoding device repeatedly performs the process from step S8144 to step S8149 for each three-dimensional point. Note that FIG. 113 shows decoding for current three-dimensional point P to be decoded.

[1001] The three-dimensional data decoding device then determines whether or not search\_range=0 (S8144).

[1002] When the value of search\_range is not 0 (No in S8144), the three-dimensional data decoding device searches for a plurality of peripheral points, which are three-dimensional points present in the periphery of the current three-dimensional point, that are to be used for

calculation of a predicted value of current three-dimensional point P to be processed (S8145).

[1003] The three-dimensional data encoding device then determines a predicted value of current three-dimensional point P (S8146). Specifically, the three-dimensional data decoding device calculates a weighted average of values of the attribute information on the plurality of peripheral points, and sets the obtained value as a predicted value. Note that this process is the same as the process in the three-dimensional data encoding device.

[1004] When search\_range=0 (Yes in S8144), or when step S8146 is completed, the three-dimensional data decoding device proceeds to step S8147.

[1005] The three-dimensional data decoding device then arithmetically decodes a quantized value from the bitstream (S8147). Note that when search\_range=0, the three-dimensional data decoding device may decode attribute information by setting the predicted value to be 0. When search\_range=0, the three-dimensional data decoding device may set the inverse-quantized value of the attribute information itself as the decoded value of the attribute information. This allows reduction of the processing amount of the decoding.

[1006] The three-dimensional data encoding device then calculated an inverse-quantized value by inverse-quantizing the decoded quantized value (S8148).

[1007] The three-dimensional data decoding device then generated a decoded value by adding the predicted value to the inverse-quantized value (S8149).

[1008] The three-dimensional data decoding device then ends the loop on a basis of a three-dimensional point (S8150).

[1009] The three-dimensional data decoding device also ends the loop on a LoD basis (S8151).

[1010] In this embodiment, an example has been shown in which the three-dimensional data encoding device or the three-dimensional data decoding device encodes or decodes attribute information without performing the process of generating a LoD layered structure or the predicted value generation process when the value of search\_range is 0. However, the present disclosure is not limited to this example. For example, the three-dimensional data encoding device or the three-dimensional data decoding may device add information (direct\_coding\_mode) that indicates whether to encode the value of attribute information as it is or not to the header (bitstream) or the like, perform the encoding or decoding without the process of generating a LoD layered structure or the predicted value generation when direct\_coding\_mode=1, and perform the encoding or decoding by performing the process of generating a LoD layered structure or the predicted value generation process when direct\_coding\_mode=0. Thus, the value of direct\_coding\_mode can be appropriately set for the application, and the three-dimensional data encoding device can perform the encoding in accordance with the appropriately set value of direct\_coding\_mode, so that the balance between the encoding efficiency and the processing amount required for the encoding can be adjusted.

[1011] When direct\_coding\_mode=0, the three-dimensional data encoding device or the three-dimensional data decoding device may encode or decode attribute information on a plurality of three-dimensional points to be encoded or decoded without performing the process of generating a LoD layered structure or the predicted value generation process after re-ordering the plurality of three-dimensional

points in Morton order. By performing the encoding or decoding after re-ordering the plurality of three-dimensional points to be encoded or decoded in Morton order, the three-dimensional data encoding device can first encode attribute information on three-dimensional points closer to each other. As a result, the values of the attribute information that occur are closer to each other, so that the encoding efficiency of the entropy encoding can be improved.

[1012] Note that the three-dimensional data encoding device or the three-dimensional data decoding device may encode or decode attribute information on a plurality of three-dimensional points to be encoded or decoded without re-ordering the plurality of three-dimensional points in Morton order. For example, the three-dimensional data encoding device may encode a plurality of three-dimensional points in the order of input, and the three-dimensional data decoding device may decode the plurality of encoded three-dimensional points in the order of encoding. In that case, the three-dimensional data encoding device or the three-dimensional data decoding device can encode or decode a plurality of three-dimensional points to be encoded or decoded without re-ordering the three-dimensional points in Morton order, so that the processing amount of the encoding or decoding can be reduced.

[1013] Note that when encoding a plurality of pieces of attribute information, the three-dimensional data encoding device may add direct\_coding\_mode for each piece of attribute information to the header or the like and encode each piece of attribute information by changing the value of direct\_coding\_mode. In this way, the three-dimensional data encoding device can encode a plurality of pieces of attribute information by balancing the encoding efficiency and the processing amount required for the encoding.

[1014] Note that, when search\_range=0 or direct\_coding\_mode=0, the three-dimensional data encoding device does not perform the process of generating a LoD layered structure or the predicted value generation process, and therefore need not to add, to the header or the like, information required for the process of generating a LoD layered structure or the predicted value generation process. That is, the three-dimensional data encoding device may generate a bitstream that includes encoded attribute information but does not include layer information used for the generation of a LoD layered structure. The layer information includes a distance threshold value for classifying a plurality of three-dimensional points into layers in such a way that distances between three dimensional points fall within different distance ranges in different layers. The distance threshold is threshold THd in the foregoing embodiment, for example.

[1015] In this way, the three-dimensional data encoding device can reduce the code amount of the header and reduce the code amount of the bitstream.

[1016] In this embodiment, an example has been shown in which the three-dimensional data encoding device or the three-dimensional data decoding device uses LoD layers as a method of encoding or decoding attribute information on three-dimensional points. However, the present disclosure is not limited to this example. For example, the present disclosure can be applied to a method of encoding or decoding using a RAHT layered structure. In that case, specifically, the three-dimensional data encoding device or the three-dimensional data decoding device may add, to the header (bitstream) or the like, information (direct\_coding\_mode) indicating whether to encode the value of attribute informa-

tion as it is or not. And the three-dimensional data encoding device or the three-dimensional data decoding device may quantize or inverse-quantize or entropy-encode or entropy-decode the attribute information as it is without applying RAHT when `direct_coding_mode=1`, and encode or decode the attribute information by applying RAHT to the attribute information. Thus, the value of `direct_coding_mode` can be appropriately set for the application, and the three-dimensional data encoding device or the three-dimensional data decoding device can perform the encoding in accordance with the appropriately set value of `direct_coding_mode`, so that the balance between the encoding efficiency and the processing amount required for the encoding can be adjusted.

**[1017]** Note that when `direct_coding_mode=0`, the three-dimensional data encoding device or the three-dimensional data decoding device may perform the encoding or decoding without generating a RAHT layered structure after re-ordering a plurality of three-dimensional points to be encoded or decoded in Morton order. By performing the encoding after re-ordering the plurality of three-dimensional points to be encoded or decoded in Morton order, the three-dimensional data encoding device can first encode attribute information on three-dimensional points closer to each other. As a result, the values of the attribute information that occur are closer to each other, so that the encoding efficiency of the entropy encoding can be improved.

**[1018]** Note that the three-dimensional data encoding device or the three-dimensional data decoding device may perform the encoding or decoding without re-ordering a plurality of three-dimensional points to be encoded or decoded in Morton order. For example, the three-dimensional data encoding device may encode a plurality of three-dimensional points in the order of input, and the three-dimensional data decoding device may decode the plurality of encoded three-dimensional points in the order of encoding. In that case, the three-dimensional data encoding device or the three-dimensional data decoding device can encode or decode a plurality of three-dimensional points to be encoded or decoded without re-ordering the three-dimensional points in Morton order, so that the processing amount of the encoding or decoding can be reduced.

**[1019]** Note that the three-dimensional data encoding device or the three-dimensional data decoding device may change whether or not to set `search_range=0` or `direct_coding_mode=0` and encode or decode attribute information on a plurality of three-dimensional points to be encoded or decoded without performing the process of generating a layered structure or the predicted value generation process, in accordance with the application. For example, when the encoding needs to be performed with high efficiency even if it takes a long time, such as in a case of recording to a storage, the three-dimensional data encoding device or the three-dimensional data decoding device may encode or decode three-dimensional points with high efficiency by setting `search_range>0` or `direct_coding_mode=0`. For example, when the encoding needs to be performed with low delay, such as when a three-dimensional point is transmitted to a remote location in real time, the three-dimensional data encoding device or the three-dimensional data decoding device may encode or decode a three-dimensional point with low processing amount by setting `search_range=0` or `direct_coding_mode=1`. In this way, if the three-dimensional data encoding device or the three-dimensional data decoding

device has a mechanism for changing whether to perform the predicted value generation or not in accordance with the application, the three-dimensional data encoding device or the three-dimensional data decoding device can select an appropriate encoding or decoding method for the application.

**[1020]** In this embodiment, an example has been shown in which the three-dimensional data encoding device or the three-dimensional data decoding device encodes or decodes attribute information. However, the present disclosure is not limited to this example. For example, the present disclosure can also be applied to a case where the three-dimensional data encoding device or the three-dimensional data decoding device that encodes or decodes geometry information on a plurality of three-dimensional points to be encoded or decoded. For example, the three-dimensional data encoding device or the three-dimensional data decoding device may have a mode (`geometry_direct_coding_mode`) in which geometry information is directly quantized or inverse-quantized or entropy-encoded or entropy-decoded without generating an octree when encoding the geometry information.

**[1021]** For example, the three-dimensional data encoding device may encode geometry information by generating an octree for a plurality of three-dimensional points to be encoded when `geometry_direct_coding_mode=0`, and directly quantize or entropy-encode geometry information when `geometry_direct_coding_mode=1`. In this way, the three-dimensional data encoding device can encode geometry information with low processing amount. The three-dimensional data decoding device may change whether to generate an octree for decoding or not in accordance with the value of `geometry_direct_coding_mode`. In this way, the three-dimensional data decoding device can properly decode a bitstream.

**[1022]** For example, when there is no need to generate an octree, such as when the number of a plurality of three-dimensional points to be encoded is small or when a plurality of three-dimensional points to be encoded are sparse, the three-dimensional data encoding device may encode the plurality of three-dimensional points by setting `geometry_direct_coding_mode=1`. In this way, the three-dimensional data encoding device can reduce the processing amount required for the encoding.

**[1023]** As described above, the three-dimensional data encoding device according to this embodiment performs the process shown in FIG. 114. The three-dimensional data encoding device performs a process based on a three-dimensional data encoding method of encoding three-dimensional points each having attribute information. The three-dimensional encoding device determines whether the three-dimensional points are classified into layers (S8161). (i) When the three-dimensional points are classified into layers (Yes in S8161), the three-dimensional data encoding device generates a layered structure by classifying each of the three-dimensional points into the layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer (S8162). Then, the three-dimensional data encoding device encodes the attribute information of each of the three-dimensional points, using the layered structure (S8163), and generates a bitstream including the attribute information encoded and layer information to be used in generating the layered structure (S8164). On the other hand, (ii) when the three-

dimensional points are not classified into the layers, such as when the three-dimensional points are classified into one layer or when no layer is generated (No in S8161), the three-dimensional data encoding device encodes the attribute information of each of the three-dimensional points without classifying the three-dimensional points into the layers (S8165), and generates a bitstream including the attribute information encoded and not including the layer information (S8166).

[1024] With this, when a plurality of three-dimensional points are not classified into layers, the three-dimensional data encoding device encodes attribute information on each of the plurality of three-dimensional points without performing the process of classifying the plurality of three-dimensional points into layers, and therefore, the processing load in the encoding can be reduced.

[1025] For example, the layer information includes a distance threshold value for classifying the three-dimensional points into in such a way that the distance between the three-dimensional points falls within a distance range that is different between the layers.

[1026] For example, in the encoding when the three-dimensional points are not classified into layers (S8165), the attribute information of each of the three-dimensional points are encoded without re-ordering the three-dimensional points in Morton order based on geometry information of the three-dimensional points. With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the encoding can be further reduced.

[1027] For example, the three-dimensional encoding device includes a processor and memory, and, using the memory, the processor performs the above-described process.

[1028] Furthermore, the three-dimensional data decoding device according to this embodiment performs the process shown in FIG. 115. The three-dimensional data decoding device performs a process based on a three-dimensional data decoding method of decoding encoded three-dimensional points each having attribute information. The three-dimensional decoding device obtains a bitstream including the encoded three-dimensional points (S8171). The three-dimensional data decoding device determines whether the encoded three-dimensional points are classified into layers (S8172). (i) When the encoded three-dimensional points are classified into layers (Yes in S8172), the three-dimensional data decoding device generates a layered structure using layer information included in the bitstream, for generating the layered structure by classifying the encoded three-dimensional points into the layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer (S8173). Then the three-dimensional data decoding device decodes the encoded three-dimensional points using the layered structure (S8174). On the other hand, (ii) when the encoded three-dimensional points are not classified into layers, such as when the three-dimensional points are classified into one layer or when no layer is generated (No in S8172), three-dimensional data decoding device decodes the encoded three-dimensional points without classifying the encoded three-dimensional points into the layers (S8175).

[1029] With this, when three-dimensional points are not classified into layers, three-dimensional points which have

been encoded without performing the process of classifying the three-dimensional points into layers are decoded, and thus, the processing load in the decoding can be reduced.

[1030] For example, the layer information includes a distance threshold value for classifying the three-dimensional points into in such a way that the distance between the three-dimensional points falls within a distance range that is different between the layers.

[1031] For example, in the decoding when the encoded three-dimensional points are not classified into layers (S8175), the encoded three-dimensional points are decoded without re-ordering the encoded three-dimensional points in Morton order based on geometry information of the encoded three-dimensional points. With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the decoding can be reduced.

[1032] For example, the three-dimensional decoding device includes a processor and memory, and, using the memory, the processor performs the above-described process.

[1033] The three-dimensional data encoding device according to another aspect of this embodiment performs the process shown in FIG. 116. The three-dimensional data encoding device performs a process based on a three-dimensional data encoding method of encoding three-dimensional points each having attribute information. When the three-dimensional points are classified into layers (Yes in S8181), the three-dimensional data encoding device re-orders the three-dimensional points in Morton order based on geometry information of the plurality of three-dimensional points (S8182). The three-dimensional data encoding device then encodes the attribute information of each of the three-dimensional points (S8183), and generates a bitstream including the encoded attribute information (S8184). On the other hand, when the three-dimensional points are not classified into layers, such as when there is one layer to be classified, or no layer is to be generated (No in S8181), the three-dimensional data encoding device encodes the attribute information of each of the three-dimensional points without re-ordering the three-dimensional points in Morton order based on the geometry information of the plurality of three-dimensional points (S8185), and generates a bitstream including the encoded attribute information (S8186).

[1034] With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the encoding can be further reduced.

[1035] For example, the three-dimensional data encoding device includes a processor and memory, and, using the memory, the processor performs the above-described process.

[1036] The three-dimensional data decoding device according to another aspect of this embodiment performs the process shown in FIG. 117. The three-dimensional data decoding device performs a process based on a three-dimensional data decoding method of decoding encoded three-dimensional points each having attribute information. The three-dimensional data decoding device obtains the bitstream including the encoded three-dimensional points (S8191). The three-dimensional data decoding device determines whether the three-dimensional points are classified into layers or not (S8192). When the three-dimensional points are classified into layers (Yes in S8192), the three-dimensional data decoding device re-orders the three-di-

dimensional points in Morton order based on the geometry information of the three-dimensional points (S8193). The three-dimensional data decoding device then decodes the encoded three-dimensional points (S8194). On the other hand, when the three-dimensional points are not classified into layers (No in S8192), such as when the three-dimensional points are classified into one layer or when no layer is generated, the three-dimensional data decoding device decodes the encoded three-dimensional points without re-ordering the three-dimensional points in Morton order based on the geometry information of the three-dimensional points (S8195). With this, since the process of re-ordering three-dimensional points in Morton order is not performed, the processing load in the encoding can be reduced.

[1037] For example, the three-dimensional data decoding device includes a processor and memory, and, using the memory, the processor performs the above-described process.

[1038] A three-dimensional data encoding device, a three-dimensional data decoding device, and the like according to the embodiments of the present disclosure have been described above, but the present disclosure is not limited to these embodiments.

[1039] Note that each of the processors included in the three-dimensional data encoding device, the three-dimensional data decoding device, and the like according to the above embodiments is typically implemented as a large-scale integrated (LSI) circuit, which is an integrated circuit (IC). These may take the form of individual chips, or may be partially or entirely packaged into a single chip.

[1040] Such IC is not limited to an LSI, and thus may be implemented as a dedicated circuit or a general-purpose processor. Alternatively, a field programmable gate array (FPGA) that allows for programming after the manufacture of an LSI, or a reconfigurable processor that allows for reconfiguration of the connection and the setting of circuit cells inside an LSI may be employed.

[1041] Moreover, in the above embodiments, the structural components may be implemented as dedicated hardware or may be realized by executing a software program suited to such structural components. Alternatively, the structural components may be implemented by a program executor such as a CPU or a processor reading out and executing the software program recorded in a recording medium such as a hard disk or a semiconductor memory.

[1042] The present disclosure may also be implemented as a three-dimensional data encoding method, a three-dimensional data decoding method, or the like executed by the three-dimensional data encoding device, the three-dimensional data decoding device, and the like.

[1043] Also, the divisions of the functional blocks shown in the block diagrams are mere examples, and thus a plurality of functional blocks may be implemented as a single functional block, or a single functional block may be divided into a plurality of functional blocks, or one or more functions may be moved to another functional block. Also, the functions of a plurality of functional blocks having similar functions may be processed by single hardware or software in a parallelized or time-divided manner.

[1044] Also, the processing order of executing the steps shown in the flowcharts is a mere illustration for specifically describing the present disclosure, and thus may be an order

other than the shown order. Also, one or more of the steps may be executed simultaneously (in parallel) with another step.

[1045] A three-dimensional data encoding device, a three-dimensional data decoding device, and the like according to one or more aspects have been described above based on the embodiments, but the present disclosure is not limited to these embodiments. The one or more aspects may thus include forms achieved by making various modifications to the above embodiments that can be conceived by those skilled in the art, as well forms achieved by combining structural components in different embodiments, without materially departing from the spirit of the present disclosure.

[1046] Although only some exemplary embodiments of the present disclosure have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of the present disclosure. Accordingly, all such modifications are intended to be included within the scope of the present disclosure.

#### INDUSTRIAL APPLICABILITY

[1047] The present disclosure is applicable to a three-dimensional data encoding device and a three-dimensional data decoding device.

What is claimed is:

1. A three-dimensional data encoding method, comprising:

- (i) in a case where a layered structure comprising a plurality of layers is generated based on an item of information used for generating the layered structure: encoding attribute information for the three-dimensional points in a first order, the first order being an order determined based on the layered structure; and generating a bitstream including the item of information used for the generating the layered structure; and
- (ii) in a case where the layered structure is not generated: encoding attribute information for the plurality of three-dimensional points in a second order.

2. The three-dimensional data encoding method according to claim 1, wherein

the layered structure is generated by assigning each of the plurality of three-dimensional points to a different one of the plurality of layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer.

3. The three-dimensional data encoding method according to claim 2, wherein

the item of information used for generating the layered structure includes a distance threshold value for assigning each of the plurality of three-dimensional points into a different one of the plurality of layers in such a way that the distance between the three-dimensional points falls within a distance range that is different between the layers.

4. The three-dimensional data encoding method according to claim 1, wherein

in the encoding when the layered structure is not generated, the three-dimensional points are encoded without being re-ordered in Morton order.

5. The three-dimensional data encoding method according to claim 1, wherein

the case where the layered structure is not generated is a case where the plurality of three-dimensional points are classified into one layer or where no layer is generated.

**6.** The three-dimensional data encoding method according to claim **1**, wherein

each layer of the layered structure is a Level of Detail (LoD) layer.

**7.** The three-dimensional data encoding method according to claim **1**, wherein

the attribute information includes information indicating at least one of a color, a reflectance, or a normal vector.

**8.** A three-dimensional data decoding method, comprising:

obtaining a bitstream including a plurality of three-dimensional points that have been encoded; and

(i) in a case where a layered structure comprising a plurality of layers is generated based on the item of information used for generating the layered structure: generating the layered structure using the item of information included in the bitstream and used for generating the layered structure; and

decoding attribute information for the plurality of three-dimensional points in a first order, the first order being an order determined based on the layered structure; and

(ii) in a case where the layered structure is not generated: decoding the attribute information for the plurality of three-dimensional points in a second order.

**9.** The three-dimensional data decoding method according to claim **8**, wherein

the layered structure is generated by assigning each of the plurality of three-dimensional points to a different one of the plurality of layers in such a way that a distance between three-dimensional points belonging to a higher layer is longer than a distance between three-dimensional points belonging to a lower layer.

**10.** The three-dimensional data decoding method according to claim **9**, wherein

the item of information used for generating the layered structure includes a distance threshold value for assigning each of the plurality of three-dimensional points into a different one of the plurality of layers in such a way that the distance between the three-dimensional points falls within a distance range that is different between the layers.

**11.** The three-dimensional data decoding method according to claim **8**, wherein

the case where the layered structure is not generated is a case where the plurality of three-dimensional points are classified into one layer or where no layer is generated.

**12.** The three-dimensional data decoding method according to claim **8**, wherein

each layer of the layered structure is a Level of Detail (LoD) layer.

**13.** The three-dimensional data decoding method according to claim **8**, wherein

the attribute information includes information indicating at least one of a color, a reflectance, or a normal vector.

**14.** A three-dimensional data encoding device, comprising:

a processor; and

memory, wherein

using the memory, the processor:

(i) in a case where a layered structure comprising a plurality of layers is generated based on an item of information used for generating the layered structure: encodes attribute information for the three-dimensional points in a first order, the first order being an order determined based on the layered structure; and generates a bitstream including the item of information used for the generating the layered structure; and

(ii) in a case where the layered structure is not generated: encodes attribute information for the plurality of three-dimensional points in a second order.

**15.** A three-dimensional data decoding device, comprising:

a processor; and

memory, wherein

using the memory, the processor:

obtains a bitstream including a plurality of three-dimensional points that have been encoded; and

(i) in a case where a layered structure comprising a plurality of layers is generated based on the item of information used for generating the layered structure: generates the layered structure using the item of information included in the bitstream and used for the generating the layered structure; and

decodes attribute information for the plurality of three-dimensional points in a first order, the first order being an order determined based on the layered structure; and

(ii) in a case where the layered structure is not generated: decodes the attribute information for the plurality of three-dimensional points in a second order.

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