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OBJECT DETERMINATION APPARATUS AND OBJECT DETERMINATION METHOD

Abstract

An object determination apparatus includes: a calculator that calculates a difference in time of flight of a plurality of ultrasonic waves reflected by an object and received by a plurality of sonar apparatuses, or a difference in distance corresponding to the time of flight; and a determiner that determines a type of the object based on the difference.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to an object determination apparatus and an object determination method.

BACKGROUND ART

[0002] In an existing automatic brake system, waveform of a reflected wave is normalized according to attenuation characteristic information of an ultrasonic wave based on with the distance from a vehicle to an object that reflects the ultrasonic wave, and it is determined that there is an object when the reflection intensity is equal to or greater than a predetermined threshold. In this case, it is possible to detect walls or the like other than curbs, by setting the threshold equal to or greater than the intensity of a reflection wave from a curb where it is not necessary to activate the brake (see PTL 1).

CITATION LIST

Patent Literature

PTL 1

[0003] Japanese Patent Application Laid-Open No. 2022-142252

SUMMARY OF INVENTION

Technical Problem

[0004] However, the intensity of the reflected wave is weak in the case of an object with a complex shape, such as a human. For this reason, there is a possibility that the intensity of the reflection wave is equal to or less than the threshold value also in the case of such an object, and the brake is not activated, resulting in a collision of the vehicle with the object.

[0005] On the other hand, when the threshold is set less than the intensity of the reflection wave from the curb, the brake is activated for a person, and a collision with a person can be avoided, but the brake is also activated for the curb.

[0006] A non-limiting embodiment of the present disclosure contributes to providing a determination apparatus and a determination method capable of accurately determining an object.

Solution to Problem

[0007] Accordingly, one aspect of an object determination apparatus according to the present disclosure includes: a calculator that calculates the differences in Time of Flight (TOF) or the distances corresponding to the TOF of a plurality of ultrasonic waves reflected by an object and received by a plurality of sonar apparatuses in one transmission period, or with respect to a transmission wave of a certain sonar apparatus; and a determiner that determines a type of the object based on the difference.

[0008] Further, one aspect of an object determination method according to the present disclosure includes: calculating the differences in Time of Flight (TOF) or the distances corresponding to the TOF of a plurality of ultrasonic waves reflected by an object and received by a plurality of sonar apparatuses; and determining a type of the object based on the difference.

Advantageous Effects of Invention

[0009] According to the present disclosure, it is possible to accurately determine the type of an object.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0010] FIG. **1** illustrates brake control thresholds in a current sonar system;

[0011] FIG. **2** illustrates installation positions of sonar apparatuses;

[0012] FIG. **3** illustrates reflection of ultrasound by a pedestrian;
[0013] FIG. **4**A illustrates an example of the dimensions of a pedestrian;
[0014] FIG. **4**B illustrates a positional relationship between a pedestrian and a vehicle;
[0015] FIG. **5**A illustrates a difference in the X-direction of reflection points;
[0016] FIG. **5**B illustrates the influence of the difference in the X-direction of the reflection points;
[0017] FIG. **6**A illustrates a difference in the Y-direction of reflection points;
[0018] FIG. **6**B illustrates the influence of the difference in the Y-direction of the reflection points;
[0019] FIG. **7**A illustrates a difference in the Z-direction of reflection points;
[0020] FIG. **7**B illustrates the influence of the difference in the Z-direction of the reflection points;
[0021] FIG. **8**A illustrates reflection of ultrasound by a pedestrian;
[0022] FIG. **8**B illustrates a difference value of TOF that changes over time;
[0023] FIG. **9** illustrates a fluctuation in a difference value of TOF with respect to a pedestrian;
[0024] FIG. **10** illustrates reflection of ultrasonic waves by a curb;
[0025] FIG. **11**A illustrates a positional relationship between a vehicle and a curb;
[0026] FIG. **11**B illustrates a positional relationship between a vehicle and a curb;
[0027] FIG. **11**C illustrates the maximum value of the difference in TOF with respect to the curb;
[0028] FIG. **12**A illustrates the transmission period of each sonar apparatus;
[0029] FIG. **12**B illustrates a fluctuation in a difference value of TOF with respect to a curb;
[0030] FIG. **13** illustrates a positional relationship between a pole and a vehicle;
[0031] FIG. **14**A illustrates a positional relationship between a pole and a vehicle;
[0032] FIG. **14**B illustrates a positional relationship between a pole and a vehicle;
[0033] FIG. **14**C illustrates the maximum value of the difference in TOF with respect to the pole;
[0034] FIG. **15** illustrates a fluctuation in a difference value of TOF with respect to a pole;
[0035] FIG. **16** illustrates an exemplary configuration of an object determination apparatus according to Embodiment 1;
[0036] FIG. **17** is a flowchart illustrating an example of object determination processing according to Embodiment 1;
[0037] FIG. **18** illustrates an exemplary configuration of an object determination apparatus according to Embodiment 2;
[0038] FIG. **19** is a flowchart illustrating an example of object determination processing according to Embodiment 2;
[0039] FIG. **20** illustrates an exemplary configuration of an object determination apparatus according to Embodiment 3;
[0040] FIG. **21** is a flowchart illustrating an example of object determination processing according to Embodiment 3;
[0041] FIG. **22** illustrates reflection of ultrasonic waves by a pedestrian;
[0042] FIG. **23** illustrates reflection of ultrasound by a pedestrian;
[0043] FIG. **24** illustrates an example of data used for determining whether an object is a pedestrian;
[0044] FIG. **25** illustrates a method for calculating a distance estimation value between a pedestrian and a sonar apparatus used for determining whether an object is a pedestrian;
[0045] FIG. **26** illustrates a calculation result of a difference between a measurement distance and an estimation distance for a moving object;
[0046] FIG. **27** illustrates a fluctuation in a difference value of TOF with respect to a stationary doll;
[0047] FIG. **28** illustrates an exemplary configuration of an object determination apparatus according to Embodiment 4; and
[0048] FIG. **29** is a flowchart illustrating an example of object determination processing according to Embodiment 4.

DESCRIPTION OF EMBODIMENTS

[0049] Hereinafter, embodiments of the present disclosure will be described with reference to the drawings. Note that each of the embodiments described below shows a specific example of the present disclosure. Therefore, each component, the arrangement position and the connection form of each component, as well as the steps and the order of the steps illustrated in the following embodiments are examples and are not intended to limit the present disclosure. Furthermore, among the components in the following embodiments, those which are not recited in the independent claims are described as arbitrary components.
[0050] Additionally, each figure is a schematic figure and is not necessarily a strict illustration. Note that, in the drawings, substantially the same components are denoted by the same reference numerals, and redundant descriptions thereof will be omitted or simplified.
[0051] To begin with, the current state of sonar systems will be described. As shown in FIG. **1**, Autonomous Emergency Braking is basically desired to operate against tall objects. At present, a threshold corresponding to the intensity of an ultrasonic wave reflected by a curb is set, and the brake is activated when the reflection intensity of the ultrasonic wave is equal to or greater than this threshold. For example, the brake does not operate for a step of 10 cm or 15 cm or less, but operates for a step higher than this.
[0052] However, there are objects such as a cylinder with a diameter of approximately $30 mm or a pedestrian, which are tall but have a reflection intensity below the threshold. In this case, if a threshold (second threshold) smaller than the threshold (first threshold) for the curb is set to avoid collision with a cylinder or a pedestrian, the brake will be activated for the curb.
[0053] As illustrated in FIG. **2**, sonar apparatuses are provided in the front and rear of vehicle **11**. Each of the sonar apparatuses includes a Time Of Flight (TOF) sensor that transmits ultrasonic waves, receives reflected waves reflected by an object, and measures the distance to the object based on the time of flight of the ultrasonic waves.
[0054] In the present embodiment, sonar apparatus **12** (hereinafter referred to as RRC) at the rear right center of vehicle **11**, sonar apparatus **13** (hereinafter referred to as RLC) at the rear left center, sonar apparatus **14** (hereinafter referred to as RR) at the rear right, and sonar apparatus **15** (hereinafter referred to as RL) at the rear left will be described as examples.
[0055] For example, the information on the TOF of the ultrasound is calculated in each of the following cases. [0056] (a-1) A case where the ultrasonic wave transmitted by RRC **12** is received by RRC **12**, or RLC **13** and RR **14**. Further, a case where the wave is received by RL **15** may be included. [0057] (a-2) A case where the ultrasonic wave transmitted by RLC **13** is received by RLC **13**, or by RRC **12** and RL **15**. Further, a case where RR **14** receives the wave may be included.
[0058] (a-3) A case where the ultrasound transmitted by RR **14** and RL **15** is received by RR **14**, RL **15**, RRC **12**, and RLC **13**.
[0059] Further, the coordinates information of the object is calculated by triangulation in each of the following cases. [0060] (b-1) A case where the ultrasound transmitted by RR **14** is received by RR **14** and RRC **12** (S**0** coordinate), and a case where the ultrasound transmitted by RL **15** is received by RR **15** and RLC **13** (S**5** coordinate). [0061] (b-2) A case where the ultrasound transmitted by RRC **12** is received by both RRC **12** and RR **14** (S**1** coordinate), and a case where the ultrasound transmitted by RRC **12** is received by RLC **13** (S**2** coordinate). [0062] (b-3) A case where the ultrasound transmitted by RLC **13** is received by RLC **13** and RRC **12** (S**3** coordinates), and a case where the ultrasound transmitted by RLC **13** is received by RL **15** (S**4** coordinates).
[0063] When the TOF of the ultrasound calculated in this manner is analyzed in a case where a person is the object, it is known that the TOF varies in each of cases (a-1) to (a-3) even for the same person. Further, it is also understood that the coordinates of S**0**, S**1**, S**4**, and S**5** vary in the width direction of vehicle **11**. For this reason, in the case of performing each measurement of (a-1) to (a-3) and (b-1) to (b-3), it is presumed that the position of the reflection point at which the ultrasound is reflected is likely to be different due to the complex shape of a person.
[0064] This point will be further considered in detail. As illustrated in FIG. **3**, the reflection point of

pedestrian **21** varies depending on the sonar apparatus that transmits the ultrasonic wave, the sonar apparatus that receives the reflected wave, the position of pedestrian **21**, or the posture of pedestrian **21**. Further, since both vehicle **11** and pedestrian **21** move, it is extremely difficult to determine whether the object is pedestrian **21** or not based on the TOF of the ultrasonic wave received by one sonar apparatus. Further, the intensity of the reflected wave from pedestrian **21** is weak, and the shape of pedestrian **21** is also complex, making it even more difficult to detect pedestrian **21**.

[0065] Accordingly, the technique of the present disclosure focuses on the following points. Here, in each transmission period in which TOF is measured, there is one sonar apparatus that transmits the ultrasonic wave, and there are a plurality of sonar apparatuses that receive the ultrasonic wave. Further, in the following, the time of flight or the flight distance (distance to the object) of a sound wave to the object measured by the TOF sensor of the sonar apparatus will be represented by TOF.

[0066] Reflection points from a human body are different in almost all the cases, and when the TOF of the ultrasonic wave received by a first sonar apparatus is defined as TOF.sub.sonar1 and the TOF of the ultrasonic wave received by a second sonar apparatus is defined as TOF.sub.sonar2, it is understood that following relation a and relation b are present. [0067] a. Two TOFs are different. [00001]diff = $TOF_{sonar1} - TOF_{sonar2} \neq 0$ [0068] b. The difference between the two TOFs is within a certain range.

[00002] .Math. $TOF_{sonar1} - TOF_{sonar2}$ .Math. $<$ threshold

[0069] Note that threshold is determined by the distance between pedestrian **21** and vehicle **11**, the positional relationship between the sonar apparatus that transmits the wave and the sonar apparatus that receives the wave, and the size of pedestrian **21**.

[0070] That such TOF difference value is smaller than a predetermined threshold is the first key point in the technology of the present disclosure.

[0071] Further, since vehicle **11** and pedestrian **21** move, the reflection surface is not stable. For this reason, the TOF detected by each sonar apparatus varies randomly within a predetermined range over time. This is the second key point in the technology of the present disclosure.

[0072] Further, the geometric shape of pedestrian **21** is complicated, and it is common that the reflection point of the ultrasonic wave is different between a case where the ultrasonic wave transmitted by a certain sonar apparatus is received by this certain sonar apparatus and a case where the ultrasonic wave transmitted by a certain sonar apparatus is received by another sonar apparatus.

[0073] In addition, in a case where the object is pedestrian **21**, the reflection part (head, shoulder, abdomen, thigh, knee, foot, and the like) changes depending on the distance to pedestrian **21** and the posture of pedestrian **21**. For example, as shown in FIG. **3**, when pedestrian **21** walks in the Y-direction, the changes in the distances of the reflection points in the X-, Y-, and Z-directions caused by the movement of limbs are approximately 0.6 m, 0.9 m, and 1.8 m, respectively. The difference in the TOF of the ultrasonic wave between different sonar apparatuses randomly changes within a predetermined range due to such changes of the reflection points in the X-, Y-, and Z-directions.

[0074] Hereinafter, two sonar apparatuses, RRC **12** and RLC **13**, will be described as examples, and the influence of differences in the X-, Y-, and Z-directions of reflection points on the TOF will be described in detail.

[0075] As illustrated in FIG. **4**A, the dimensions of pedestrian **21** are 0.6 meters in the width direction (X-direction), 0.8 meters in the front-back direction (Y-direction), and 1.8 meters in the height direction (Z-direction)

[0076] Further, in order to understand the equations for distances b1 and b2 described below, the positional relationship between reflection point **22** and reflection point **23** will be described assuming that pedestrian **21** is cube **24**, as illustrated in FIG. **4**B. Here, difference diff in the TOF of the ultrasonic wave between RRC **12** and RLC **13** is represented as diff=TOF.sub.RLC−TOF.sub.RRC, where TOF.sub.RRC is the TOF of the ultrasonic wave received by RRC **12**, and TOF.sub.RLC is the TOF of the ultrasonic wave received by RLC **13**.

[0077] Here, the maximum value of difference diff in TOF between two reflection points **22** and **23**, whose coordinates differ by Δx, Δy, and Δz in the X-, Y-, and Z-directions, respectively, is determined by the distance between pedestrian **21** and vehicle **11**, dimensions Δx, Δy, and Δz of pedestrian **21** in the X-, Y-, and Z-directions, and distance d.sub.s between RRC **12** and RLC **13**. Dimensions Δx, Δy, and Δz correspond to the width, thickness, and height of pedestrian **21**, respectively.

[0078] Hereinafter, TOF.sub.RRC and TOF.sub.RLC represent values obtained by dividing by 2 the distance corresponding to the time it takes for the ultrasonic wave transmitted by RRC **12** to be reflected by pedestrian **21** and received by RRC **12** and RLC **13**.

[0079] First, TOF.sub.RRC is minimized when the ultrasonic wave is reflected at reflection point **22**, which is the closest to vehicle **11**. For example, when a is the distance from RRC **12** to reflection point **22** and D is the distance from vehicle **11** to pedestrian **21**, min TOF.sub.RRC=a=D.

[0080] Further, the maximum value of TOF.sub.RLC is represented as follows:

[00003] $\max TOF_{RLC} = \frac{b1 + b2}{2}.$

[0081] Here, b1 and b2 are represented as follows:

[00004] $b1 = \sqrt{(D + \ x)^2 + \ z^2 + \ y^2}; \text{and} \ b2 = \sqrt{(D + \ x)^2 + \ z^2 + (\ y - d_s)^2}.$

[0082] Accordingly, the maximum value of TOF difference diff at reflection points **22** and **23** is as follows:

[00005]

$$\max(\text{diff}) = \frac{\sqrt{(D + \ x)^2 + \ z^2 + \ y^2} + \sqrt{(D + \ x)^2 + \ z^2 + (\ y - d_s)^2}}{2} - D \quad (\text{Equation}1)$$

[0083] Further, when the equation of the maximum value of difference diff is partially differentiated with respect to Δx, Δy, and Δz, the following equations are obtained:

[00006] $\frac{\partial(\max(\text{diff}))}{x} = \frac{D + \ x}{2} * \frac{1}{b_1} + \frac{D + \ x}{2} * \frac{1}{b_2}$ $\frac{\partial(\max(\text{diff}))}{y} = \frac{\ y}{2} * \frac{1}{b_1} + \frac{.\text{Math.} \ y - d_s \ .\text{Math.}}{2} * \frac{1}{b_2}$ $\frac{\partial(\max(\text{diff}))}{z} = \frac{\ z}{2} * \frac{1}{b_1} + \frac{\ z}{2} * \frac{1}{b_2}.$

[0084] From the results of these partial differentials, the influence on the maximum value of difference diff is the largest for Δx, and the influence is equal between Δy and Δz. In a case where the object is pedestrian **21**, Δz corresponding to the height of pedestrian **21** is larger than Δy corresponding to the thickness of pedestrian **21**, and thus, the influence on the maximum value of difference diff is greatest in the order of Δx, Δz, and Δy.

[0085] Next, the influence of the positional difference of the reflection point in the X-direction when detecting pedestrian **21** with the dimensions shown in FIG. **5**A will be described. Here, the dimension of pedestrian **21** in the width direction (X-direction) is 0.6 m, the dimension in the front-back direction (Y-direction) is 0.8 m (corresponding to a case where the hands and legs are extended), and the dimension in the height direction (Z-direction) is 1.8 m.

[0086] First, TOF.sub.RRC is minimized when the ultrasonic wave is reflected at reflection point **22**, which is the closest to vehicle **11**. For example, min TOF.sub.RRC=a=D.

[0087] Further, the maximum value of TOF.sub.RLC is represented as follows. Here, W is the width of pedestrian **21**, and corresponds to Δx described above.

[00007] $\max TOF_{RLC} = \frac{b1 + b2}{2} = \frac{a + W + \sqrt{d_s^2 + (a + W)^2}}{2} = \frac{D + W + \sqrt{d_s^2 + (D + W)^2}}{2}$

[0088] Accordingly, the maximum value of difference diff due to the position difference in the X-direction of reflection points **22** and **23** is as follows:

[00008] $\max(\text{diff}) = \frac{D + W + \sqrt{d_s^2 + (D + W)^2}}{2} - D.$

[0089] FIG. **5**B illustrates the maximum value (max_diff) of difference diff that varies according to distance D from vehicle **11** to pedestrian **21**. The maximum value of difference diff is a large value, and the position difference between reflection points **22** and **23** in the X-direction is substantially reflected in the maximum value of difference diff. Note that the actual distance between reflection points **22** and **23** is often smaller than width W of pedestrian **21**.

[0090] Next, the influence of the positional difference of the reflection point in the Y-direction when detecting pedestrian **21** with the dimensions shown in FIG. **6**A will be described. Here, the dimension of pedestrian **21** in the width direction (X-direction) is 0.6 m, the dimension in the front-back direction (Y-direction) is 0.8 m, and the dimension in the height direction (Z-direction) is 1.8 m.
[0091] First, TOF.sub.RRC is minimized when the ultrasonic wave is reflected at reflection point **22**, which is the closest to vehicle **11**. For example, min TOF.sub.RRC=a=D.
[0092] Further, the maximum value of TOF.sub.RLC is represented as follows. Here, T is the thickness of pedestrian **21**, and corresponds to Δy described above.
[00009] $$\max TOF_{RLC}=\frac{b1+b2}{2}=\frac{\sqrt{D^2+T^2}+\sqrt{D^2+(d_s-T)^2}}{2}$$
[0093] Accordingly, the maximum value of difference diff due to the difference in the Y-direction positions of reflection points **22** and **23** is as follows:
[00010] $$\max(\mathrm{diff})=\frac{\sqrt{D^2+T^2}+\sqrt{D^2+(d_s-T)^2}}{2}-D.$$
[0094] FIG. **6**B illustrates the maximum value (max_diff) of difference diff that varies according to distance D from vehicle **11** to pedestrian **21**. The influence of the positional differences in the Y-direction at reflection points **22** and **23** varies depending on distance D between pedestrian **21** and vehicle **11**, with the influence increasing as the distance decreases.
[0095] Next, the influence of the positional difference in the Z-direction of the reflection point when detecting pedestrian **21** having the dimensions shown in FIG. **7**A will be described. Here, the dimension of the pedestrian in the width direction (X-direction) is 0.6 m, the dimension in the front-back direction (Y-direction) is 0.8 m, and the dimension in the height direction (Z-direction) is 1.8 m.
[0096] First, TOF.sub.RRC is minimized when the ultrasonic wave is reflected at reflection point **22**, which is the closest to vehicle **11**. For example, min TOF.sub.RRC=a=D.
[0097] Further, the maximum value of TOF.sub.RLC is represented as follows. Here, H is the height of pedestrian **21**, and corresponds to Δz described above. Further, d.sub.s is the distance between RRC **12** and RLC **13**, and h.sub.s is the height at which RRC **12** and RLC **13** are installed.
[00011] $$\max TOF_{RLC}=\frac{b1+b2}{2}=\frac{\sqrt{D^2+(H-h_s)^2}+\sqrt{D^2+(H-h_s)^2+d_s^2}}{2}$$
[0098] Accordingly, the maximum value of difference diff due to the positional difference in the Z-direction of reflection points **22** and **23** is as follows:
[00012] $$\max(\mathrm{diff})=\frac{\sqrt{D^2+(H-h_s)^2}+\sqrt{D^2+(H-h_s)^2+d_s^2}}{2}-D.$$
[0099] FIG. **7**B illustrates the maximum value (max_diff) of difference diff that varies according to distance D from vehicle **11** to pedestrian **21**. The influence of the positional difference in the Z-direction between reflection points **22** and **23** varies depending on distance D between pedestrian **21** and vehicle **11**, and the closer the distance, the greater the influence.
[0100] Next, the temporal fluctuation of difference diff in the TOF of the ultrasound will be described. As illustrated in FIG. **8**A, a case where pedestrian **21**′ is behind vehicle **11** will be considered.
[0101] Further, as indicated by the dotted line, the ultrasonic wave transmitted by RR **14** is reflected at reflection point **26** on the right elbow of pedestrian **21**′, and the reflected wave is received by RRC **12**. Height h.sub.1 of the reflection point on the right elbow is 1.1 m.
[0102] Further, it is assumed that the ultrasonic wave transmitted by RRC **12** in another transmission frame is reflected at reflection point **27** on the right thigh of pedestrian **21**′, and the reflection wave is received by RLC **13**. Height h.sub.2 of the reflection point on the right thigh is 0.7 m.
[0103] Further, the interval between RLC **13** and RL **15**, and the interval between RRC **12** and RR **14** are 0.4 m, the interval between RRC **12** and RLC **13** is 0.5 m, the installation heights of RR **14** and RL **15** are 0.5 m, the installation heights of RRC **12** and RLC **13** are 0.55 m, and the

differences Δx, Δy, and Δz in the X-, Y-, and Z-directions of two reflection points **26** and **27** are 0 m, 0.2 m, and 0.4 m, respectively.
[0104] In this case, TOF.sub.RRC of the ultrasonic wave received by RRC **12** and TOF.sub.RLC of the ultrasonic wave received by RLC **13** are represented by the following equations, which are the same as in aforementioned Equation 1:

[00013]
$$\mathrm{TOF}_{\mathrm{RLC}} = \frac{a_1 + a_2}{2} = \frac{\left(\sqrt{D^2 + (d_{s1} + \frac{d_{s2}}{2})^2 + (h_1 - h_{s1})^2} + \sqrt{D^2 + (\frac{d_{s2}}{2})^2 + (h_1 - h_{s2})^2}\right)}{2} = \frac{\sqrt{D^2 + 0365} + \sqrt{D^2 + 04225}}{2}$$
$$\mathrm{TOF}_{\mathrm{RRC}} = \frac{b_1 + b_2}{2} = \frac{\left(\sqrt{D^2 + (d_{s1} + \frac{d_{s2}}{2})^2 + (h_2 - h_{s1})^2} + \sqrt{D^2 + (\frac{d_{s2}}{2})^2 + (h_2 - h_{s2})^2}\right)}{2} = \frac{\sqrt{D^2 + 04625} + \sqrt{D^2 + 0085}}{2}$$

[0105] FIG. **8**B illustrates the difference value of TOF (TOF.sub.RLC−TOF.sub.RRC) that varies according to distance D from vehicle **11** to pedestrian **21**′. It is understood that the difference value of TOF is small, and the difference value of TOF fluctuates as vehicle **11** approaches pedestrian **21**′ and distance D decreases over time.
[0106] FIG. **9** illustrates a graph of the temporal change in the difference of TOF. The transmission is performed, for example, in the order of RRC **12**, RLC **13**, and RR **14**/RL **15** at a period of 50 ms, and after simultaneous transmission from both RR **14** and RL **15** is performed, the transmission from RRC **12** is performed again. RR **14**/RL **15** or RR/RL means that two sonar apparatuses transmit simultaneously in one transmission period.
[0107] In each transmission frame of an ultrasound as described above, the difference value of TOF increases as distance D decreases according to above-described Equation 1, but is smaller than a predetermined threshold. Further, due to the irregularity in the shape of pedestrian **21**, the reflection point changes randomly, causing the difference value of the TOF to fluctuate within a predetermined range over time.
[0108] Next, a difference of TOF in a case where the ultrasonic wave is reflected by a curb will be described. As illustrated in FIG. **10**, the reflection by curb **31** is basically a reflection by a plane, and in a case where the reflection surface is parallel to a line connecting the two sonar apparatuses, the coordinates in the X-direction of the two reflection points are the same (Δx=0).
[0109] Further, the first wave received by the sonar apparatus is a reflection wave that reaches the sonar apparatus via the shortest route, and since the height of curb **31** is less than 0.2 m, the coordinates of the two reflection points in the Z-direction are also substantially the same (Δz=0).
[0110] Here, as illustrated in FIGS. **11**A and **11**B, when the TOF of the ultrasonic wave received by RRC **12** is defined as TOF.sub.RRC and the TOF of the ultrasonic wave received by RLC **13** is defined as TOF.sub.RLC, diff=TOF.sub.RLC−TOF.sub.RRC.
[0111] As described above, in the case of curb **31**, the reflector is a surface, and when curb **31** is perpendicular to the vehicle moving direction, the differences Δx and Δz between two reflection points **32** and **33** in the X-direction and the Z-direction are substantially 0, and thus, Δx=Δz=0.
[0112] Further, since the first wave received by the sonar apparatus is a reflection wave of the shortest route, Δy is ½ of the distance between RRC **12** and RLC **13**.
[00014] $y = d_s / 2$
[0113] First, TOF.sub.RRC is minimized when the ultrasonic wave is reflected at reflection point **32**, which is the closest to vehicle **11**. For example, when “a” is the distance from RRC **12** to reflection point **32** and D is the distance from vehicle **11** to curb **31**, min TOF.sub.RRC=a=D.
[0114] Further, the maximum value of TOF.sub.RLC is represented as follows:
[00015] $\max \mathrm{TOF}_{\mathrm{RLC}} = \frac{b1 + b2}{2} b1 = b2 = \sqrt{D^2 + y^2} = \sqrt{D^2 + (\frac{d_s}{2})^2}$
[0115] Accordingly, the maximum value of difference diff due to the positional difference in the Y-direction of reflection points **32** and **33** is as follows:

[00016] $\max(\text{diff}) = \sqrt{D^2 + (\frac{d_s}{2})^2} - D.$ (Equation2)

[0116] FIG. **11**C illustrates the maximum value (max_diff) of difference diff that varies according to distance D from vehicle **11** to curb **31**. It can be seen that the maximum value of difference diff in TOF with respect to curb **31** is much smaller than the maximum value of the difference in TOF with respect to person **21**.

[0117] As illustrated in FIG. **12**A, the transmissions of the sonar apparatuses are repeated at 50 ms intervals in the order of RRC **12**, RLC **13**, and both RL **15** and RR **14**, RRC **12**, and so forth. FIG. **12**B illustrates a graph of the temporal change in the difference in TOF with respect to curb **31**, calculated in the same manner as in FIG. **9** under the above-described conditions. The difference value of TOF increases as distance D decreases according to above-described Equation 2, but it can be seen that the range of fluctuation is considerably smaller than that in the case of pedestrian **21** illustrated in FIG. **9**.

[0118] Next, a difference in TOF in a case where the ultrasonic wave is reflected by a pole will be described. As illustrated in FIGS. **13**, **14**A, and **14**B, the first wave received by the sonar apparatus is a reflection that reaches the sonar apparatus via the shortest route. Further, since the shape of pole **41** is a cylinder, the reflection point in a case where the ultrasonic wave transmitted by a certain sonar apparatus is received by this certain sonar apparatus and the reflection point in a case where the ultrasonic wave transmitted by the certain sonar apparatus is received by another sonar apparatus are substantially the same.

[0119] Thus, in a case where the object to be detected is pole **41**, the reflection point is the same, and thus, there is no positional difference in the reflection point, and Δx=Δy=Δz=0 may be set. In this case, the factor that affects the difference in the TOF of the ultrasonic wave received by RRC **12** and RLC **13** is the relative positional relationship between pole **41**, RRC **12**, and RLC **13**.

[0120] In this case, TOF.sub.RRC of the ultrasonic wave received by RRC **12** and TOF.sub.RLC of the ultrasonic wave received by RLC **13** are as follows:

[00017]

$$TOF_{RRC} = a = \sqrt{(x - x_{s1})^2 + (y - y_{s1})^2} \quad TOF_{RLC} = \frac{b1 + b2}{2} = \frac{\sqrt{(x - x_{s1})^2 + (y - y_{s1})^2} + \sqrt{(x - x_{s2})^2 + (y - y_{s2})^2}}{2}$$

[0121] Accordingly, difference diff in the TOF of the ultrasound received by RRC **12** and RLC **13** is as follows:

[00018]

$$\begin{aligned} \text{diff} &= TOF_{RLC} - TOF_{RRC} \\ &= \frac{b1 + b2}{2} - a \\ &= \frac{\sqrt{(x - x_{s2})^2 + (y - y_{s2})^2} - \sqrt{(x - x_{s1})^2 + (y - y_{s1})^2}}{2} \end{aligned}$$

[0122] Here, the minimum value of TOF.sub.RRC is the distance between pole **41** and vehicle **11**, and thus min TOF.sub.RRC=a=D. Further, when the interval between RRC **12** and RLC **13** is d.sub.s, the maximum value of TOF.sub.RLC is as follows:

[00019] $\max TOF_{RLC} = \sqrt{D^2 + ds^2}.$

[0123] Accordingly, the maximum value of difference diff in TOF is as follows:

[00020] $\max(\text{diff}) = \frac{\sqrt{D^2 + ds^2} - D}{2}.$ (Equation3)

[0124] FIG. **14**C illustrates the maximum value (max_diff) of difference diff that varies according to distance D from vehicle **11** to pole **41**. It can be seen that the maximum value of difference diff in TOF with respect to pole **41** is much smaller than the maximum value of the difference in TOF with respect to pedestrian **21**.

[0125] FIG. **15** illustrates a graph of the temporal change in the difference in TOF with respect to pole **41**, calculated in the same manner as in FIG. **9**. The difference value of TOF increases slightly as distance D decreases according to above-described Equation 3, but the increase is a few centimeters, and the range of fluctuation is found to be considerably smaller than that in the case of

pedestrian **21** illustrated in FIG. **9**.
[0126] Hereinafter, embodiments implemented based on such findings will be described in detail.
Embodiment 1
[0127] FIG. **16** illustrates an exemplary configuration of determination apparatus **51** according to Embodiment 1. Determination apparatus **51** includes a plurality of sonar apparatuses **52**, input section **53**, difference calculator **54**, shortest-distance calculator **55**, object threshold calculator **56**, object determiner **57**, and output section **58**.
[0128] Each of sonar apparatuses **52** transmits ultrasonic waves, receives ultrasonic waves reflected by an object to be detected, and outputs information corresponding to the TOF and the reflection intensity. Sonar apparatuses **52** correspond respectively to RRC **12**, RLC **13**, RR **14**, and RL **15** described above.
[0129] Input section **53** receives an input of the TOF and the reflection intensity information output from each sonar apparatus **52**. Difference calculator **54** acquires information such as the number of sonar apparatuses from sonar mounting information **59** stored in a storage, calculates the difference between TOFs output from sonar apparatuses **52**, and outputs the result to object determiner **57**.
[0130] Shortest-distance calculator **55** calculates the shortest distance from the vehicle to the object based on information of the first wave reflected by the object, and outputs the result to object threshold calculator **56**.
[0131] Object threshold calculator **56** calculates the threshold of the difference in TOF for each object corresponding to the shortest distance calculated by shortest-distance calculator **55**, based on object threshold information **60** stored in the storage. Here, information on the shortest distance and the threshold of the difference in TOF is registered in object threshold information **60** in association with the type of the object. By changing the threshold according to the minimum distance, it is possible to accurately determine the object.
[0132] Object determiner **57** compares the value of each difference calculated by difference calculator **54** with the threshold of the difference in TOF for each object calculated by object threshold calculator **56**, and determines the type of the object.
[0133] Output section **58** outputs information of the determination result by object determiner **57** to an electronic control unit (ECU) of the vehicle or the like. This information is used for control of Autonomous Emergency Braking and the like.
[0134] Next, type determination processing on the object performed by determination apparatus **51** will be described. As illustrated in FIG. **17**, first, object threshold calculator **56** of determination apparatus **51** acquires sonar mounting information **59** and object threshold information **60** (step S**1**).
[0135] Then, input section **53** receives the input of information on reflection intensity P.sub.i (i=1, . . . , N) of the ultrasonic wave measured by each sonar apparatus **52** and distance TOF.sub.i (i=1, . . . , N) to the object (step S**2**). Here, it is assumed that there are N sonar apparatuses.
[0136] Subsequently, difference calculator **54** determines whether reflection intensity P.sub.i is within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**3**). Thresholds Th.sub.1 and Th.sub.2 are set in advance. Note that, threshold Th.sub.1 and threshold Th.sub.2 are different depending on the distance to the object.
[0137] In a case where reflection intensity P.sub.i is not within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**3**, NO), the processing in step S**2** is executed again.
[0138] In a case where reflection intensity P.sub.i is within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**3**, YES), difference calculator **54** calculates difference value diff(i, j) (i, j=1, . . . , N) for each TOF.sub.i, and shortest-distance calculator **55** calculates minimum value TOF.sub.min of distance TOF.sub.i (step S**4**). Here, diff(i, j)=|TOF.sub.i−TOF.sub.j|(i≠j).
[0139] Subsequently, object threshold calculator **56** calculates the threshold of the difference in

TOF for the object corresponding to minimum value TOF.sub.min of the distance based on object threshold information **60** (step S**5**). Here, three objects are pedestrian **21**, curb **31**, and pole **41**, and thresholds Th.sub.ped, Th.sub.curb, and Th.sub.pole corresponding to minimum value TOF.sub.min of the distance are set for them, respectively.

[0140] Then, object determiner **57** determines whether all of difference values diff(i, j) (i, j=1, . . . , N) are smaller than threshold Th.sub.pole of pole **41** (step S**6**).

[0141] In a case where all of difference values diff(i, j) are smaller than threshold Th.sub.pole of pole **41** (step S**6**, YES), object determiner **57** further calculates S**0** coordinate, S**1** coordinate, S**4** coordinate, and S**5** coordinate using the above-described triangulation (step S**13**), determines whether the y-axis (vehicle width direction) values of the calculated coordinates varies beyond a predetermined range (step S**14**), and in a case where the y-axis values do not vary beyond the range (step S**14**, NO), determines that the object is pole **41** (step S**15**), and output section **58** outputs the determination result (step S**10**). In a case where the variation occurs (step S**14**, YES), the process moves to step S**7**.

[0142] In a case where any of difference values diff(i, j) (i, j=1, . . . , N) is equal to or larger than threshold Th.sub.pole of pole **41** (step S**6**, NO), or in a case where the values of the y-axes (vehicle width direction) of the calculated S**0** coordinate, S**1** coordinate, S**4** coordinate, and S**5** coordinate vary beyond the predetermined range, object determiner **57** determines whether all of difference values diff(i, j) (i, j=1, . . . , N) are smaller than threshold Th.sub.curb of curb **31** (step S**7**).

[0143] In a case where all of difference values diff(i, j) (i, j=1, . . . , N) are smaller than threshold Th.sub.curb of curb **31** (step S**7**, YES), object determiner **57** determines that the object is curb **31** (step S**12**), and output section **58** outputs the determination result (step S**10**).

[0144] In a case where any of difference values diff(i, j) (i, j=1, . . . , N) is equal to or larger than threshold Th.sub.curb of curb **31** (step S**7**, NO), object determiner **57** determines whether all of difference values diff(i, j) (i, j=1, . . . , N) are smaller than threshold Th.sub.ped of pedestrian **21** (step S**8**).

[0145] In a case where all of the difference values diff(i, j) (i, j=1, . . . , N) are smaller than threshold Th.sub.ped of pedestrian **21** (step S**8**, YES), object determiner **57** determines that the object is pedestrian **21** (step S**11**), and output **58** section outputs the determination result (step S**10**).

[0146] In a case where any of difference values diff(i, j) (i, j=1, . . . , N) is equal to or larger than threshold Th.sub.ped of pedestrian **21** (step S**8**, NO), object determiner **57** determines that the object is an object other than pedestrian **21**, curb **31**, and pole **41** (step S**9**), and output sections **58** outputs the determination result (step S**10**).

[0147] As described above, by performing the determination of the object based on the difference value of the distance to the object measured by each sonar apparatus, determination apparatus **51** can accurately perform the determination of the object.

Embodiment 2

[0148] FIG. **18** illustrates an exemplary configuration of determination apparatus **61** according to Embodiment 2. As illustrated in FIG. **18**, determination apparatus **61** further includes cache **62** in addition to the configuration of determination apparatus **51** in Embodiment 1.

[0149] Cache **62** receives information of the difference value of the TOF at each time t from difference calculator **54**, and buffers the difference values of the TOFs of the past M transmission frames.

[0150] Object determiner **57** calculates the maximum difference value among the difference values of the TOFs of the past M transmission frames buffered in cache **62**. Note that, as illustrated in FIG. **12**A, the sonar apparatus that transmits the wave is switched in each transmission frame. Then, the determination of the object is performed by comparing the maximum difference value with the threshold value of the difference in TOF for each object.

[0151] Next, the type determination processing on the object performed by determination apparatus **61** will be described. As illustrated in FIG. **19**, first, object threshold calculator **56** of determination

apparatus **61** acquires sonar mounting information **59** and object threshold information **60** (step S**21**).
[0152] Then, input section **53** receives the input of information on reflection intensity P.sub.i (i=1, . . . , N) of the ultrasonic wave measured by each sonar apparatus **52** at time t and distance TOF; (t) (i=1, . . . , N) to the object (step S**22**). Here, it is assumed that there are N sonar apparatuses.
[0153] Subsequently, difference calculator **54** determines whether reflection intensity P.sub.i is within a predetermined range that is greater than threshold Th.sub.1 and less than threshold Th.sub.2 (step S**23**). Thresholds Th.sub.1 and Th.sub.2 are set in advance.
[0154] In a case where reflection intensity P.sub.i is not within the predetermined range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**23**, NO), the processing in step S**22** is executed again.
[0155] In a case where reflection intensity P.sub.i is within the predetermined range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**23**, YES), difference calculator **54** calculates difference value diff(i, j, t) (i, j=1, . . . , N) for each TOF.sub.i(t), and shortest-distance calculator **55** calculates minimum value TOF.sub.min of distance TOF.sub.i(t) and outputs the minimum value to object threshold calculator **56**. Object threshold calculator **56** calculates the threshold of the difference in TOF for the object corresponding to input distance minimum value TOF.sub.min based on object threshold information **60** obtained in step S**21**. Cache **62** buffers difference value diff(i, j, t) of the distances in the past M transmission frames and the threshold of the difference in TOF for the objects corresponding to the minimum value TOF.sub.min (step S**24**). Here, diff(i, j, t)=|TOF.sub.i(t)−TOF.sub.j(t)|(i≠j).
[0156] Subsequently, object determiner **57** calculates maximum value diff.sub.max(t) of difference value diff(i, j, t) of the distance in the past M transmission frames including time t (step S**25**). Here, diff.sub.max(t)=max (diff(i, j, t−(M−1)), . . . , diff(i, j, t)).
[0157] Then, object determiner **57** determines whether maximum value diff.sub.max(t) is smaller than threshold Th.sub.pole of pole **41** (step S**26**). Note that threshold Th.sub.pole is set in advance.
[0158] In a case where maximum value diff.sub.max(t) is smaller than threshold Th.sub.pole of pole **41** (step S**26**, YES), object determiner **57** further calculates the S**0** coordinate, the S**1** coordinate, the S**4** coordinate, and the S**5** coordinate using the triangulation described above (step S**33**), determines whether the y-axis (vehicle width direction) values of the calculated coordinates varies beyond a predetermined range (step S**34**), and in a case where the y-axis values do not vary beyond the range (step S**34**, NO), determines that the object is pole **41** (step S**35**), and output section **58** outputs the determination result (step S**30**). In a case where the variation occurs (step S**34**, YES), the process moves to step S**27**.
[0159] In a case where maximum value diff.sub.max(t) is equal to or larger than threshold Th.sub.pole of pole **41** (step S**26**, NO), or in a case where the values of the y-axes (vehicle width direction) of the calculated S**0** coordinate, S**1** coordinate, S**4** coordinate, and S**5** coordinate vary beyond the predetermined range, object determiner **57** determines whether maximum value diff.sub.max(t) is smaller than threshold Th.sub.curb of curb **31** (step S**27**).
[0160] In a case where maximum value diff.sub.max(t) is smaller than threshold Th.sub.curb of curb **31** (step S**27**, YES), object determiner **57** determines that the object is curb **31** (step S**32**), and output section **58** outputs the determination result (step S**30**).
[0161] In a case where maximum value diff.sub.max(t) is equal to or larger than threshold Th.sub.curb of curb **31** (step S**27**, NO), object determiner **57** determines whether maximum value diff.sub.max(t) is smaller than threshold Th.sub.ped of pedestrian **21** (step S**28**).
[0162] In a case where maximum value diff.sub.max(t) is smaller than threshold Th.sub.ped of pedestrian **21** (step S**28**, YES), object determiner **57** determines that the object is pedestrian **21** (step S**31**), and output section **58** outputs the determination result (step S**30**).
[0163] In a case where maximum value diff.sub.max(t) is equal to or larger than threshold Th.sub.ped of pedestrian **21** (step S**28**, NO), object determiner **57** determines that the object is

something other than pedestrian **21**, curb **31**, or pole **41** (step S**29**), and output section **58** outputs the determination result (step S**30**).

[0164] As described above, by performing the determination of the object based on the maximum value of the difference in the distance to the object from the M buffered frames measured by each sonar apparatus, determination apparatus **61** can accurately perform the determination of the object.

Embodiment 3

[0165] FIG. **20** illustrates an exemplary configuration of determination apparatus **71** according to Embodiment 3. As illustrated in FIG. **20**, determination apparatus **71** includes pedestrian determiner **72** and transmission control output **73** in addition to the configuration of determination apparatus **61** of Embodiment 2.

[0166] Pedestrian determiner **72** determines whether the object is pedestrian **21** based on the latest information of difference values of TOF. In a case where the object is determined to be pedestrian **21**, transmission control output **73** causes the transmission apparatus corresponding to the latest TOF to continue transmitting ultrasound in the next transmission period.

[0167] Next, the type determination processing on the object performed by determination apparatus **71** will be described. As illustrated in FIG. **21**, first, object threshold calculator **56** of determination apparatus **71** acquires sonar mounting information **59** and object threshold information **60** (step S**41**).

[0168] Then, input section **53** receives the input of information on reflection intensity P.sub.i (i=1, . . . , N) of the ultrasonic wave measured by each sonar apparatus **52** at time t and distance TOF.sub.i(t) (i=1, . . . , N) to the object (step S**42**). Here, it is assumed that there are N sonar apparatuses.

[0169] Subsequently, difference calculator **54** determines whether reflection intensity P.sub.i is within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**43**). Thresholds Th.sub.1 and Th.sub.2 are set in advance.

[0170] In a case where reflection intensity P.sub.i is not within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**43**, NO), the processing in step S**42** is executed again.

[0171] In a case where reflection intensity P.sub.i is within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**43**, YES), difference calculator **54** calculates difference value diff(i, j, t) (i, j=1, . . . , N) for each TOF.sub.i(t), and shortest-distance calculator **55** calculates minimum value TOF.sub.min of distance TOF.sub.i(t) and outputs the minimum value to object threshold calculator **56**. Object threshold calculator **56** calculates the threshold of the difference in TOF for the objects corresponding to the minimum input distance value TOF.sub.min, based on object threshold information **60** obtained in step S**41**. Cache **62** buffers difference value diff(i, j, t) of the distances in the past M transmission frames and the threshold of the difference in TOF for the objects corresponding to the minimum value TOF.sub.min (step S**44**). Here, diff(i, j, t)=|TOF.sub.i(t)−TOF.sub.j(t)|(i≠j).

[0172] Further, difference calculator **54** calculates maximum value diff.sub.max(t, 1) of difference value diff(i, j, t) at time t, and object determiner **57** calculates maximum value diff.sub.max(t, M) of distance difference value diff(i, j, t) of the past M transmission frames buffered in cache **62** (step S**45**).

[0173] Here, diff.sub.max(t, 1)=max (diff(i, j, t)) (i, j=1, . . . , N), and diff.sub.max(t, M)=max (diff (i, j, t−(M−1)), . . . , diff(i, j, t)) (i, j=1, . . . , N).

[0174] Then, pedestrian determiner **72** determines whether maximum value diff.sub.max(t, 1) of difference value diff(i, j, t) at time t is larger than threshold Th.sub.curb of curb **31** and is smaller than threshold Th.sub.ped of pedestrian **21** (step S**46**). Note that threshold Th.sub.curb and threshold Th.sub.ped are set in advance.

[0175] In a case where maximum value diff.sub.max(t, 1) is larger than threshold Th.sub.curb of curb **31** and is smaller than threshold Th.sub.ped of pedestrian **21** (step S**46**, YES), there is a high possibility that pedestrian **21** is accurately detected.

[0176] Thus, transmission controller **73** changes a control signal for each sonar apparatus **52** in order to maintain the current good detection state for pedestrian **21** in the next transmission period, and controls each sonar apparatus **52** such that sonar apparatus **52** currently performing transmission continues to perform transmission without switching of sonar apparatus **52** that performs transmission (step S**55**).

[0177] After the processing in step S**55**, or in a case where maximum value diff.sub.max(t, 1) is equal to or less than threshold Th.sub.curb of curb **31** or is equal to or greater than threshold Th.sub.ped of pedestrian **21** in step S**46** (step S**46**, NO), object determiner **57** determines whether maximum value diff.sub.max(t, M) is smaller than threshold Th.sub.pole of pole **41** (step S**47**). Note that threshold Th.sub.pole is set in advance. In this case, in the next transmission period, the switching of sonar apparatus **52** that is to perform transmission is performed as illustrated in FIG. **12**A.

[0178] In a case where maximum value diff.sub.max(t, M) is smaller than threshold Th.sub.pole of pole **41** (step S**47**, YES), object determiner **57** further calculates S**0** coordinate, S**1** coordinate, S**4** coordinate, and S**5** coordinate using the above-described triangulation (step S**56**), determines whether the y-axis (vehicle width direction) values of the calculated coordinates varies beyond a predetermined range (step S**57**), and in a case where the y-axis values do not vary (step S**57**, NO) beyond the range, determines that the object is pole **41** (step S**58**), and output section **58** outputs the determination result (step S**51**). In a case where the variation occurs (step S**57**, YES), the process moves to step S**48**.

[0179] In a case where maximum value diff.sub.max(t, M) is equal to or larger than threshold Th.sub.pole of pole **41** (step S**47**, NO), or in a case where the values of the y-axes (vehicle width direction) values of the calculated S**0** coordinate, S**1** coordinate, S**4** coordinate, and S**5** coordinate vary beyond the predetermined range, object determiner **57** determines whether maximum value diff.sub.max(t, M) is smaller than threshold Th.sub.curb of curb **31** (step S**48**).

[0180] In a case where maximum value diff.sub.max(t, M) is smaller than threshold Th.sub.curb of curb **31** (step S**48**, YES), object determiner **57** determines that the object is curb **31** (step S**53**), and output section **58** outputs the determination result (step S**51**).

[0181] In a case where maximum value diff.sub.max(t, M) is equal to or larger than threshold Th.sub.curb of curb **31** (step S**48**, NO), object determiner **57** determines whether maximum value diff.sub.max(t, M) is smaller than threshold Th.sub.ped of pedestrian **21** (step S**49**).

[0182] In a case where maximum value diff.sub.max(t, M) is smaller than threshold Th.sub.ped of pedestrian **21** (step S**49**, YES), object determiner **57** determines that the object is pedestrian **21** (step S**52**), and output section **58** outputs the determination result (step S**51**).

[0183] In a case where maximum value diff.sub.max(t, M) is equal to or larger than threshold Th.sub.ped of pedestrian **21** (step S**49**, NO), object determiner **57** determines that the object is something other than person **21**, curb **31**, and pole **41** (step S**50**), and output section **58** outputs the determination result (step S**51**).

[0184] In this manner, in a case where the possibility that pedestrian **21** is detected is high, the current good detection state for pedestrian **21** can be maintained by continuing the transmission with sonar apparatus **52**, which is currently performing transmission, in the next transmission period.

Embodiment 4

[0185] In Embodiment 4, a case where a walking action of a pedestrian is detected using distance information detected by one or more sonar apparatuses will be described. When a person walks, the hands and legs move, and the reflection point changes over time. Thus, the detected distance changes.

[0186] FIG. **22** illustrates a case where, for example, the sonar apparatus that transmits a wave is RRC **12**, and the sonar apparatus that receives a wave is RLC **13**. In this example, the reflection point of the transmitted ultrasound is right knee **101** of pedestrian **21**. Further, in FIG. **23**, the reflection point changes, and the reflection point of the transmitted ultrasonic wave is head **102** of pedestrian **21**. As described above, the reflection point of the ultrasonic wave changes from right knee **101** to head **102** due to the walking motion of pedestrian **21**, and the detected distance becomes larger than that in the previous transmission frame, for example.

[0187] Further, also in a case where the sonar apparatus that transmits a wave is RLC **13** and the sonar apparatus that receives a wave is RLC **13**, or in a case of another combination of sonar apparatuses, the hands and legs move and the reflection point changes with time when a person walks, and as a result, the detected distance changes.

[0188] FIG. **24** illustrates an example of data used for determining whether the object is a pedestrian. FIG. **24** is data used, for example, in determining whether the detected distance acquired by RLC **13** corresponds to a pedestrian. This data includes four pieces of information: the vehicle speed, the transmission time, the number of the transmission apparatus, and the detected distance. The number of the transmission apparatus is the number of the sonar apparatus that transmits the reflected wave received by RLC **13**.

[0189] To determine whether the object is a pedestrian, the difference between the actual measurement distance from the sonar apparatus to the pedestrian and the estimation distance from the sonar apparatus to the pedestrian is used. Hereinafter, the method will be described. FIG. **25** illustrates a method for calculating a distance estimation value from a sonar apparatus used for determining whether an object is a pedestrian to the pedestrian. Hereinafter, a method for determining whether an object is a pedestrian or not using the measurement distance obtained by receiving the ultrasonic wave transmitted by RRC **12** with RLC **13**, will be described.

[0190] First, the estimation distance is calculated from the information on the vehicle speed, the transmission time, and the measurement distance corresponding to the transmission apparatus number **10**, which is the number of RRC **12**. Here, the information on the measurement distance used in calculating the estimation distance is the information at the time of the previous transmission.

[0191] For example, estimation distance L is calculated by equation $L_{i-1} - v \times \Delta t$. Here, L_{i-1} is the measurement distance at the previous transmission timing, v is the vehicle speed, and Δt is the elapsed time between the previous transmission time and the transmission time for which the estimation distance is to be calculated. The estimation distance is the distance between the sonar apparatus and the object, assuming that the object is a stationary object.

[0192] In a case where the object is a stationary object, the probability that the reflection point changes is low in the same combination of a sonar apparatus that transmits ultrasonic waves and a sonar apparatus that receives the ultrasonic waves, and thus, the difference between the measurement distance and the estimation distance is small. In contrast, in the case of a moving object such as a pedestrian, the probability that the difference between the measurement distance and the estimation distance becomes large increases. Thus, by calculating the difference between the measurement distance and the estimation distance, it is possible to determine whether the object is moving or not.

[0193] FIG. **26** illustrates a calculation result of a difference between a measurement distance and an estimation distance for a moving object. FIG. **27** illustrates a calculation result of a difference between a measurement distance and an estimation distance for a stationary object. Here, a doll is used as the object in the experiment.

[0194] As illustrated in FIG. **26**, in the case of a moving object, the absolute value of the difference between the measurement distance and the estimation distance becomes larger. In contrast, in the case of a stationary object as illustrated in FIG. **27**, the absolute value of the difference between the measurement distance and the estimation distance is small. It is thus possible to determine whether the object is moving or not by setting a threshold and comparing the absolute value with the threshold.

[0195] FIG. **28** illustrates an exemplary configuration of determination apparatus **81** according to Embodiment 4. As illustrated in FIG. **28**, determination apparatus **81** includes one or more sonar apparatuses **52**, caches **111** corresponding in number to the sonar apparatuses, difference calculators **54** corresponding in number to the sonar apparatuses, vehicle movement information acquirer **112**, cache **62**, object threshold calculator **56**, object determiner **57**, and output section **58**.
[0196] Each sonar apparatus **52** receives the ultrasonic wave reflected by the object and outputs information on the reflection intensity corresponding to the TOF. Sonar apparatuses **52** corresponds respectively to RRC **12**, RLC **13**, RR **14**, and RL **15** described above.
[0197] Each cache **111** receives the input of information on the reflection intensity of the ultrasonic wave and distance TOF.sub.i (i=1, . . . , N) to the object measured by a sonar apparatus **52** corresponding to the cache **111**, and buffers the information.
[0198] Each difference calculator **54** acquires information such as the number of sonar apparatuses from sonar mounting information **59** stored in the storage, acquires information on the measurement distance to the object, the vehicle speed, and the transmission interval, and estimates the distance to the object. Further, each difference calculator **54** calculates the difference between the measurement distance and the estimation distance at the current time, and buffers the difference in cache **62**.
[0199] Vehicle movement information acquirer **112** acquires information such as the speed of the vehicle and outputs it to difference calculator **54**. Cache **62** buffers the difference information calculated by each difference calculator **54**.
[0200] Object threshold calculator **56** calculates the threshold of the difference calculated by difference calculator **54** based on object threshold information **60** stored in the storage. Here, information on the threshold of the difference is registered in object threshold information **60** in association with the type of the object.
[0201] Object determiner **57** calculates the maximum value of the past M differences, including time t buffered in cache **62**. Further, object determiner **57** compares the value of the difference calculated by difference calculator **54** with the threshold calculated by object threshold calculator **56**, and determines the type of the object.
[0202] Output section **58** outputs information on the determination result by object determiner **57** to an ECU of the vehicle or the like. This information is used for control of Autonomous Emergency Braking of a vehicle.
[0203] Next, the type determination processing on the object performed by determination apparatus **81** will be described. As illustrated in FIG. **29**, first, object threshold calculator **56** of determination apparatus **81** acquires sonar mounting information **59** and object threshold information **60** (step S**61**).
[0204] Then, each cache **111** receives the input of information on the reflection intensity P.sub.i (i=1, . . . , N) of the ultrasonic wave measured by sonar apparatus **52** corresponding to each cache apparatus **111** and distance TOF.sub.i (i=1, . . . , N) to the object (step S**62**), and buffers the information (step S**62**). Here, it is assumed that there are N (N>=1) sonar apparatuses.
[0205] Subsequently, difference calculator **54** determines whether reflection intensity P.sub.i is within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**63**). Thresholds Th.sub.1 and Th.sub.2 are set in advance.
[0206] In a case where reflection intensity P.sub.i is not within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**63**, NO), the processing in step S**62** is executed again.
[0207] In a case where reflection intensity P.sub.i is within the range larger than threshold Th.sub.1 and smaller than threshold Th.sub.2 (step S**63**, YES), difference calculator **54** acquires measurement distance TOF.sub.i(t−1) measured at one previous time t−1 from cache **111** corresponding to each sonar apparatus **52**, information on vehicle speed v from vehicle movement information acquirer **112**, and information on transmission interval Δt (=T.sub.i−T.sub.i−1) from

sonar apparatus **52**, and calculates estimation distance TOF_est.sub.i(t) corresponding to each sonar apparatus by the following equation (step S**64**):

[00021] $\mathrm{TOF\_est}_i(t) = \mathrm{TOF}_i(t-1) - v \times (T_i - T_{i-1})$.

[0208] Further, difference calculator **54** calculates difference diff.sub.TOF(i, t) between measurement value TOF.sub.i(t) at the current time and the estimation distance TOF_est.sub.i(t) according to the following equation, and buffers the difference in cache **62** (step S**65**).

[00022] $\mathrm{diff}_{\mathrm{TOF}}(i, t) = |\mathrm{TOF}_i(t) - \mathrm{TOF\_est}_i(t)|$

[0209] Subsequently, object determiner **57** calculates maximum value diff.sub.max(t) of past M differences diff.sub.TOF(i, t) including time t buffered in cache **62** (step S**66**). Here, diff.sub.max(t)=max (diff.sub.TOF(i, t−(M−1)), . . . , diff.sub.TOF(i, t)).

[0210] Then, object determiner **57** determines whether maximum value diff.sub.max(t) is smaller than threshold Th.sub.pole of pole **41** (step S**67**). Note that threshold Th.sub.pole is set in advance.

[0211] In a case where maximum value diff.sub.max(t) is smaller than threshold Th.sub.pole of pole **41** (step S**67**, YES), object determiner **57** determines that the object is pole **41** (step S**74**), and output section **58** outputs the determination result (step S**71**).

[0212] In a case where maximum value diff.sub.max(t) is equal to or larger than threshold Th.sub.pole of pole **41** (step S**67**, NO), object determiner **57** determines whether maximum value diff.sub.max(t) is smaller than threshold Th.sub.curb of curb **31** (step S**68**).

[0213] In a case where maximum value diff.sub.max(t) is smaller than threshold Th.sub.curb of curb **31** (step S**68**, YES), object determiner **57** determines that the object is curb **31** (step S**73**), and output section **58** outputs the determination result (step S**71**).

[0214] In a case where maximum value diff.sub.max(t) is equal to or larger than threshold Th.sub.curb of curb **31** (step S**68**, NO), object determiner **57** determines whether maximum value diff.sub.max(t) is smaller than threshold Th.sub.ped of pedestrian **21** (step S**69**).

[0215] In a case where maximum value diff.sub.max(t) is smaller than threshold Th.sub.ped of pedestrian **21** (step S**69**, YES), object determiner **57** determines that the object is pedestrian **21** (step S**72**), and output section **58** outputs the determination result (step S**71**).

[0216] In a case where maximum value diff.sub.max(t) is equal to or larger than threshold Th.sub.ped of pedestrian **21** (step S**69**, NO), object determiner **57** determines that the object is something other than person **21**, curb **31**, and pole **41** (step S**70**), and output section **58** outputs the determination result (step S**71**).

[0217] As described above, by calculating the difference between the actual measurement distance from the sonar apparatus to the pedestrian and the estimation distance from the sonar apparatus to the pedestrian, it is possible to determine whether the object is a pedestrian with higher accuracy.

[0218] Note that, here, the difference between the actual measurement distance from the sonar apparatus to the pedestrian and the estimated value of the distance from the sonar apparatus to the pedestrian is calculated, but the determination of whether the object is a pedestrian or not may be performed using the difference in the time of flight of the ultrasonic wave corresponding to those distances.

[0219] While the embodiments have been described in detail, the present disclosure is not limited to the embodiments. For example, determination apparatuses **51**, **61**, **71**, and **81** may be apparatuses configured to be mounted on a vehicle or apparatuses installed outside a vehicle.

[0220] Further, in the above embodiment, the determination of the object is performed based on the distance corresponding to the time of flight of the ultrasonic wave. However, since the distance is obtained by multiplying the time of flight of the ultrasonic wave by the velocity of the ultrasonic wave, the same determination can be easily performed even when the time of flight is used instead of the distance by adjusting the threshold used for the determination of the object.

[0221] Additionally, in the above embodiment, each component may be implemented by executing a software program suitable for each component. Each component may be realized by a program execution unit, such as a CPU or processor, reading and executing a software program recorded on

a recording medium, such as a hard disk or semiconductor memory.
[0222] In addition, these generic or specific aspects of the present disclosure may be achieved by an apparatus, a method, an integrated circuit, a computer program, or a computer-readable recording medium such as CD-ROM, and also by any combination of the apparatus, the method, the integrated circuit, the computer program, and the recording medium.
[0223] In the above descriptions, the expression “section” used for the components may be replaced with another expression such as “assembly,” “circuit (circuitry),” “device,” “unit,” or “module.” The apparatus may be configured to be performed by CPU using program accumulated in a memory.
[0224] In addition, the present disclosure also includes implementations obtained by applying various modifications conceived by those skilled in the art to each embodiment, or implementations realized by arbitrarily combining components and functions in each embodiment without departing from the spirit of the present disclosure.
[0225] The disclosures of Japanese Patent Application No. 2024-023146, filed on Feb. 19, 2024, and Japanese Patent Application No. 2024-199481, filed on Nov. 15, 2024, including the specification, drawings and abstract, are incorporated herein by reference in its entirety.
INDUSTRIAL APPLICABILITY
[0226] The present disclosure can be utilized in an object determination apparatus and an object determination method for determining an object.
REFERENCE SIGNS LIST
[0227] **11** Vehicle [0228] **12** RRC [0229] **13** RLC [0230] **14** RR [0231] **15** RL [0232] **21** Person (pedestrian) [0233] **22** Reflection point [0234] **31** Curb [0235] **41** Pole [0236] **51** Object determination apparatus [0237] **52** Sonar apparatus [0238] **53** Input Section [0239] **54** Difference calculator [0240] **55** Shortest-distance calculator [0241] **56** Object threshold calculator [0242] **57** Object determiner [0243] **58** Output Section [0244] **59** Sonar mounting information [0245] **60** Object threshold information [0246] **62** Cache [0247] **72** Pedestrian determiner [0248] **73** Transmission control output [0249] **111** Cache [0250] **112** Vehicle movement information acquirer

Claims

1. An object determination apparatus, comprising: a calculation circuitry which, in operation, calculates a difference in time of flight of a plurality of ultrasonic waves reflected by an object and received by a plurality of sonar apparatuses, or a difference in distance corresponding to the time of flight; and a determination circuitry which, in operation, determines a type of the object based on the difference.
2. The object determination apparatus according to claim 1, wherein the determination circuitry which, in operation, determines the type based on a maximum value of the difference in a plurality of transmission periods.
3. The object determination apparatus according to claim 1, further comprising: a control circuitry which, in operation, switches, among the plurality of sonar apparatuses, a sonar apparatus that transmits an ultrasonic wave of the plurality of ultrasonic waves for each transmission period, wherein the control circuitry which, in operation, causes the sonar apparatus that transmits the ultrasonic wave corresponding to the difference to continue transmission in a next transmission period in a case where the type is determined to be a pedestrian based on the difference.
4. The object determination apparatus according to claim 1, wherein the determination circuitry which, in operation, determines that the type is a pole in a case where the difference is smaller than a first threshold, and determines that the type is a pedestrian in a case where the difference is between a second threshold and a third threshold, the second threshold being larger than the first threshold, the third threshold being larger than the second threshold.
5. The object determination apparatus according to claim 4, wherein the determination circuitry

which, in operation, calculates coordinates of the object, and determines that the type is a pole in a case where the difference is smaller than the first threshold and the coordinates of the object do not vary beyond a predetermined range.
6. The object determination apparatus according to claim 4, wherein the determination circuitry which, in operation, determines that the type is a curb in a case where the difference is between the first threshold and the second threshold.
7. An object determination apparatus, comprising: a calculation circuitry which, in operation, calculates a difference between a time of flight of an ultrasonic wave reflected by an object and an estimated value of the time of flight obtained under an assumption that the object is a stationary object, or a difference between a distance corresponding to the time of flight and an estimated value of the distance obtained under the assumption that the object is a stationary object; and a determination circuitry which, in operation, determines a type of the object based on the difference.
8. The object determination apparatus according to claim 7, wherein the determination circuitry which, in operation, determines the type based on a maximum value of the difference in a plurality of transmission periods.
9. The object determination apparatus according to claim 7, wherein the determination circuitry which, in operation, determines that the type is a pole in a case where the difference is smaller than a first threshold, and determines that the type is a pedestrian in a case where the difference is between a second threshold and a third threshold, the second threshold being larger than the first threshold, the third threshold being larger than the second threshold.
10. The object determination apparatus according to claim 9, wherein the determination circuitry which, in operation, determines that the type is a curb in a case where the difference is between the first threshold and the second threshold.
11. An object determination method, comprising: calculating a difference in time of flight of a plurality of ultrasonic waves reflected by an object and received by a plurality of sonar apparatuses, or a difference in distance corresponding to the time of flight; and determining a type of the object based on the difference.
12. The object determination method according to claim 11, wherein the type is determined based on a maximum value of the difference in a plurality of transmission periods.
13. The object determination method according to claim 12, further comprising: causing a sonar apparatus that transmits an ultrasonic wave of the plurality of ultrasonic waves corresponding to the difference to continue transmission in a next transmission period in a case where the type is determined to be a pedestrian based on the difference.
14. The object determination method according to claim 11, wherein the type is determined to be a pole in a case where the difference is smaller than a first threshold, and the type is determined to be a pedestrian in a case where the difference is between a second threshold and a third threshold, the second threshold being larger than the first threshold, the third threshold being larger than the second threshold.
15. The object determination method according to claim 14, wherein coordinates of the object are calculated, and the type is determined to be a pole in a case where the difference is smaller than the first threshold and the coordinates of the object do not vary beyond a predetermined range.
16. The object determination method according to claim 14, wherein the type is determined to be a curb in a case where the difference is between the first threshold and the second threshold.
17. An object determination method, comprising: calculating a difference between a time of flight of an ultrasonic wave reflected by an object and an estimated value of the time of flight obtained under an assumption that the object is a stationary object, or a difference between a distance corresponding to the time of flight and an estimated value of the distance obtained under the assumption that the object is a stationary object; and determining a type of the object based on the difference.
18. The object determination method according to claim 17, wherein the type is determined based

on a maximum value of the difference in a plurality of transmission periods.

19. The object determination method according to claim 17, wherein the type is determined to be a pole in a case where the difference is smaller than a first threshold, and the type is determined to be a pedestrian in a case where the difference is between a second threshold and a third threshold, the second threshold being larger than the first threshold, the third threshold being larger than the second threshold.

20. The object determination method according to claim 19, wherein the type is determined to be a curb in a case where the difference is between the first threshold and the second threshold.