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System and method for determining background

Abstract

A method for determining a background includes: receiving, via a sensor, a plurality of data points for a 3D space; dividing the 3D space into a plurality of rays extending from the sensor; defining a plurality of peaks for each ray; defining a catchment region for each peak for each ray and including a catchment distance from the corresponding peak towards and away from the sensor; and updating the catchment distance of the catchment region. Each data point is enclosed by a corresponding ray. Each peak is located at a peak distance from the sensor and includes a peak height. For each data point from the plurality of data points, the method includes: determining the corresponding ray enclosing the data point; determining a containing peak for which the data point lies within the catchment region; and incrementing the peak height of the containing peak by a peak increment value.

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Background/Summary

TECHNICAL FIELD

(1) The present disclosure relates to a system for determining a background in a three-dimensional (3D) space and a method thereof.

BACKGROUND

(2) Typically, a three-dimensional (3D) object detection system preprocesses point cloud data of a 3D space. Such preprocessing may improve an accuracy of predictions as well as reduce computational load of the 3D object detection system. This may be especially important if the 3D object detection system is on an embedded system, where computational resources may come at a premium.

(3) For high-resolution point cloud data, a very common and challenging preprocessing step is background detection. Background detection is used to identify background portions of the point cloud data that represent stationary objects or more precisely surfaces on them, such as buildings or ground, which are unlikely to ever move. Such background portions need to be differentiated from other portions of the point cloud data that represent objects that are in motion or have moved recently.

(4) The background portions of the point cloud data can subsequently be removed from the point cloud data in order to lessen the computational load of subsequent processing steps and/or improve a 3D perception (e.g., object detection) of the 3D object detection system.

(5) Conventional background detection techniques may not be accurate, may be slow, may be inefficient, and/or require extreme computational resources (e.g., intensive in memory use). Therefore, such conventional techniques may not be feasible for the embedded systems.

SUMMARY

(6) In a first aspect, the present disclosure provides a method for determining a background in a three-dimensional (3D) space. The method includes receiving, via a sensor, a point cloud data set for the 3D space. The point cloud data set includes a plurality of data points. The method further includes dividing the 3D space into a plurality of rays extending from the sensor. Each ray includes an azimuth and an elevation with respect to the sensor. Each data point is enclosed by a corresponding ray from the plurality of rays. The method further includes defining a plurality of peaks for each ray from the plurality of rays. Each peak from the plurality of peaks is located at a peak distance from the sensor and includes a peak height equal to a predetermined initial value. The method further includes defining a catchment region for each peak from the plurality of peaks for each ray from the plurality of rays. The catchment region for each peak includes a catchment distance from the corresponding peak towards the sensor and the catchment distance from the corresponding peak away from the sensor. For each data point from the plurality of data points, the method further includes: determining the corresponding ray from the plurality of rays enclosing the data point; determining a data point distance of the data point from the sensor; determining a peak increment value; determining a containing peak from the plurality of peaks of the corresponding ray for which the data point lies within the catchment region of the containing peak; incrementing the peak height of the containing peak by the peak increment value; and defining a new peak including a peak height equal to the peak increment value and a peak distance equal to the data point distance if the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray. The method further includes updating the catchment distance of the catchment region of each of the plurality of peaks of each of the plurality of rays.

(7) In a second aspect, the present disclosure provides a system for determining a background in a 3D space. The system includes a sensor configured to generate a point cloud data set for the 3D space. The point cloud data set includes a plurality of data points. The system further includes a processor communicably coupled to the sensor. The processor is configured to receive the point cloud data set from the sensor. The processor is further configured to divide the 3D space into a plurality of rays extending from the sensor. Each ray includes an azimuth and an elevation with

respect to the sensor. Each data point is enclosed by a corresponding ray from the plurality of rays. The processor is further configured to define a plurality of peaks for each ray from the plurality of rays. Each peak from the plurality of peaks is located at a peak distance from the sensor and includes a peak height equal to a predetermined initial value. The processor is further configured to define a catchment region for each peak from the plurality of peaks for each ray from the plurality of rays. The catchment region for each peak includes a catchment distance from the corresponding peak towards the sensor and the catchment distance from the corresponding peak away from the sensor. For each data point from the plurality of data points, the processor is further configured to: determine the corresponding ray from the plurality of rays enclosing the data point; determine a data point distance of the data point from the sensor; determine a peak increment value; determine a containing peak from the plurality of peaks of the corresponding ray for which the data point lies within the catchment region of the containing peak; increment the peak height of the containing peak by the peak increment value; and define a new peak including a peak height equal to the peak increment value and a peak distance equal to the data point distance if the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray. The processor is further configured to update the catchment distance of the catchment region of each of the plurality of peaks of each of the plurality of rays.

(8) The details of one or more examples of the disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the disclosure will be apparent from the description and drawings, and from the claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Exemplary embodiments disclosed herein is more completely understood in consideration of the following detailed description in connection with the following figures. The figures are not necessarily drawn to scale. Like numbers used in the figures refer to like components. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labelled with the same number.

(2) FIG. **1** illustrates a schematic view of an exemplary background in a three-dimensional (3D) space;

(3) FIG. **2** illustrates a schematic block diagram of a system for determining the background in the 3D space, according to an embodiment of the present disclosure;

(4) FIG. **3** illustrates a schematic view of a sensor and a field of view (FOV) of the sensor in the 3D space, according to an embodiment of the present disclosure;

(5) FIG. **4**A illustrates a schematic representation of a corresponding ray from a plurality of rays enclosing a data point, according to an embodiment of the present disclosure;

(6) FIG. **4**B illustrates a schematic representation of the corresponding ray having a plurality of peaks including a containing peak for which the data point lies within a catchment region of the containing peak, according to an embodiment of the present disclosure;

(7) FIG. **4**C illustrates a schematic representation of the corresponding ray of the data point, while the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray, according to an embodiment of the present disclosure;

(8) FIG. **4**D illustrates a schematic representation of the corresponding ray including a new peak, according to an embodiment of the present disclosure;

(9) FIG. **4**E illustrates a schematic representation of a ray from the plurality of rays having the catchment region including an updated catchment distance for each peak from the plurality of peaks, according to an embodiment of the present disclosure;

(10) FIG. **5** illustrates an expected noise distribution around one peak from the plurality of peaks,

according to an embodiment of the present disclosure;
(11) FIG. **6** illustrates a schematic view of a statistical data pool, according to an embodiment of the present disclosure;
(12) FIG. **7**A illustrates a schematic flow diagram depicting various steps performed by a processor for updating a catchment distance of the catchment region, according to an embodiment of the present disclosure;
(13) FIG. **7**B illustrates a schematic flow diagram depicting various steps performed by the processor for updating the catchment distance of the catchment region, according to another embodiment of the present disclosure;
(14) FIG. **8** illustrates a schematic flow diagram depicting various steps performed by the system for determining the background in the 3D space, according to an embodiment of the present disclosure; and
(15) FIG. **9** illustrates a flowchart depicting a method for determining the background in the 3D space, according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

(16) In the following description, reference is made to the accompanying figures that form a part thereof and in which various embodiments are shown by way of illustration. It is to be understood that other embodiments are contemplated and is made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense.
(17) In the following disclosure, the following definitions are adopted.
(18) As used herein, all numbers should be considered modified by the term “about”. As used herein, “a,” “an,” “the,” “at least one,” and “one or more” are used interchangeably.
(19) As used herein as a modifier to a property or attribute, the term “generally”, unless otherwise specifically defined, means that the property or attribute would be readily recognizable by a person of ordinary skill but without requiring absolute precision or a perfect match (e.g., within +/−20% for quantifiable properties).
(20) As used herein, the terms “first” and “second” are used as identifiers. Therefore, such terms should not be construed as limiting of this disclosure. The terms “first” and “second” when used in conjunction with a feature or an element can be interchanged throughout the embodiments of this disclosure.
(21) As used herein, “at least one of A and B” should be understood to mean “only A, only B, or both A and B”.
(22) As used herein, the terms “communicably coupled to” and “communicably connected to” refers to direct coupling between components and/or indirect coupling between components via one or more intervening components. Such components and intervening components may comprise, but are not limited to, junctions, communication paths, components, circuit elements, circuits, functional blocks, and/or devices. As an example of indirect coupling, a signal conveyed from a first component to a second component may be modified by one or more intervening components by modifying the form, nature, or format of information in a signal, while one or more elements of the information in the signal are nevertheless conveyed in a manner that can be recognized by the second component.
(23) As used herein, the term “communication device” generally includes a transceiver, and/or other devices for communicating with other devices directly or via a network, and/or a user interface for communicating with one or more users.
(24) As used herein, the term “azimuth” refers to an angle between a point projected onto a reference plane and a reference direction on the reference plane.
(25) As used herein, the term “elevation” refers to an angle above or below the reference plane.
(26) Typically, a three-dimensional (3D) object detection system preprocesses point cloud data of a 3D space. Such preprocessing may improve an accuracy of predictions as well as reduce

computational load of the 3D object detection system. This may be especially important if the 3D object detection system is on an embedded system, where computational resources may come at a premium.

(27) For high-resolution point cloud data, a very common and challenging preprocessing step is background detection. Background detection is used to identify background portions of the point cloud data that represent stationary objects or more precisely surfaces on them, such as buildings or ground, which are unlikely to ever move. Such background portions need to be differentiated from other portions of the point cloud data that represent objects that are in motion or have moved recently. The background portions of the point cloud data can subsequently be removed from the point cloud data in order to lessen the computational load of subsequent processing steps and/or improve a 3D perception (e.g., object detection) of the 3D object detection system.

(28) Conventional background detection techniques may not be accurate, may be slow, may be inefficient, and/or require extreme computational and memory resources. Therefore, such conventional techniques may not be feasible for the embedded systems. Therefore, it may be advantageous to detect background with high accuracy, in real-time, and with reduced computational and memory resource requirements.

(29) The present disclosure provides a system and a method for determining a background in a three-dimensional (3D) space.

(30) The method includes receiving, via a sensor, a point cloud data set for the 3D space. The point cloud data set includes a plurality of data points. The method further includes dividing the 3D space into a plurality of rays extending from the sensor. Each ray includes an azimuth and an elevation with respect to the sensor. Each data point is enclosed by a corresponding ray from the plurality of rays. The method further includes defining a plurality of peaks for each ray from the plurality of rays. Each peak from the plurality of peaks is located at a peak distance from the sensor and includes a peak height equal to a predetermined initial value. The method further includes defining a catchment region for each peak from the plurality of peaks for each ray from the plurality of rays. The catchment region for each peak includes a catchment distance from the corresponding peak towards the sensor and the catchment distance from the corresponding peak away from the sensor. For each data point from the plurality of data points, the method further includes: determining the corresponding ray from the plurality of rays enclosing the data point; determining a data point distance of the data point from the sensor; determining a peak increment value; determining a containing peak from the plurality of peaks of the corresponding ray for which the data point lies within the catchment region of the containing peak; incrementing the peak height of the containing peak by the peak increment value; and defining a new peak including a peak height equal to the peak increment value and a peak distance equal to the data point distance if the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray. The method further includes updating the catchment distance of the catchment region of each of the plurality of peaks of each of the plurality of rays.

(31) The method of the present disclosure may use minimal computational and memory resources, such that the method may be suitable for running or implementing on the system, such as an embedded computer system, where computational resources may come at a premium. The most frequent operations of the method may be short and include additions and subtractions, as well as multiplications or divisions by powers of 2 of integer numbers. This may further minimize utilization of the computational and memory resources. The method may also be able to accurately track the static objects or background visible to the sensor in arbitrarily complex environments even in the presence of multiple distances reported by the sensor with each measurement. The system may further be simple to set-up and configure. Specifically, no particular setup or measurement may be required for implementing the method in a new or a different location.

(32) The method may further provide estimates of precision/noise level (e.g., due to environmental effects) of the sensor and may continuously optimize the operation according to the current noise

level. The method may also be adaptive to changes in the background (e.g., when an object is placed in view of the sensor and is stationary afterwards). Further, the method may be able to distinguish between the static and dynamic/non-static objects with a very high resolution. Furthermore, by tracking the noise level of the sensor, the high resolution should be at or close to an optimal separation limit (as allowed by the noise level of the sensor).

(33) Further by updating the catchment distance, the method may help to optimize the catchment distance and adapt the system to changing environmental noise (e.g., from rain, fog, or lighting conditions), slow drifts or differences in performance of the sensor, or similar. In some cases, the updated values of the catchment distances may also be provided to a sensor health or performance monitoring system as high sensor noise levels may be indicative of sensor degradation or failures.

(34) Therefore, the system and the method of the present disclosure may be computationally efficient, highly accurate and adaptive to changing environments, and provide real-time estimates.

(35) Referring now to figures, FIG. **1** illustrates a schematic view of an exemplary three-dimensional (3D) space **105**. The 3D space **105** includes various objects. In some cases, the objects may include static objects, i.e., the objects that are stationary and are unlikely to ever move. For example, the static objects may include buildings, roads, posts, grounds, etc., in the 3D space **105**. In some cases, the objects may include dynamic objects (not shown), i.e., the objects that are moving or are likely to move. The 3D space **105** includes a background **101**. The background **101** includes the static objects or specifically, surfaces of the static objects. In some cases, the objects may include also include semi-static objects, i.e., the objects that may sway. For example, the semi-static objects may include plants, trees, etc., in the 3D space **105**. In some cases, the background **101** may also include the semi-static objects. In the illustrated example of FIG. **1**, the 3D space is an outdoor space (i.e., a street). However, in some other examples, the 3D space **105** may be an indoor space (e.g., a part of a floor area in a building).

(36) FIG. **2** illustrates a schematic block diagram of a system **100** for determining the background **101** (shown in FIG. **1**) in the 3D space **105** (shown in FIG. **1**), according to an embodiment of the present disclosure.

(37) The system **100** includes a sensor **110** configured to generate a point cloud data set **112** for the 3D space **105**. The point cloud data set **112** includes a plurality of data points **114**. In some embodiments, the sensor **110** includes a 3D sensor. In an example, the 3D sensor is a light detection and ranging (LIDAR) sensor (e.g., frequency-modulated continuous-wave LIDAR), a radio detection and ranging (RADAR) sensor, an ultrasonic sensor array, a 3D camera (e.g., a time-of-flight camera, a depth camera, a stereo camera, etc.), or a combination thereof.

(38) The system **100** further includes a processor **120**. In some embodiments, the processor **120** may be implemented in a computing device A. The processor **120** is communicably coupled to the sensor **110**. Specifically, in some embodiments, the computing device A is communicably coupled to the sensor **110**. The processor **120** is configured to receive the point cloud data set **112** from the sensor **110**. In other words, the processor **120** is configured to receive the plurality of data points **114**.

(39) In some embodiments, the computing device A may include a system-on-chip (SOC), a computer processing unit (CPU), a graphical processing unit (GPU), a tensor processing unit (TPU), a neuromorphic chip, a vector accelerator, or any other processing system. Examples of the computing device A may include a personal computer (PC), a laptop, a tablet, a touch pad, a portable computer, a handheld computer, a palmtop computer, a personal digital assistant (PDA), a smart device (e.g., smart phone, smart tablet, or smart mobile television), a mobile internet device (MID), a data communication device, a server, a desktop computer, an edge computing device, and so forth. In some examples, the computing device A also may include devices that are configured to be worn by a person. In some embodiments, the computing device A may be capable of executing other applications, as well as voice communications and/or data communications.

(40) In the illustrated embodiment of FIG. **2**, the system **100** includes a plurality of sensors **110** and

a corresponding plurality of processors **120**. However, the system **100** may include any number of sensors and processors, as per desired application attributes. The plurality of sensors **110** is configured to generate a corresponding plurality of point cloud data sets **112** for the 3D space **105** shown in FIG. **1**. Further, the corresponding plurality of processors **120** is configured to receive the corresponding plurality of point cloud data sets **112** from the plurality of sensors **110**.

(41) In some other embodiments, one or more of the plurality of sensors **110** may be communicably coupled to one processor **120** from the plurality of processors **120**. Each of the plurality of processors **120** is capable of executing an algorithm that causes the processor **120** to perform one or more of the actions, operations, methods, or functions described herein. In some embodiments, one instance of the algorithm is used for each sensor **110**.

(42) In some embodiments, at least one of the plurality of processors **120** may be implemented in a computing device B. In some embodiments, the computing device B may be substantially similar to the computing device A. However, in some other embodiments, the computing device B may be different from the computing device A.

(43) In some embodiments, the system **100** may further include a point cloud fusion module **180**. The point cloud fusion module **180** may fuse outputs **125** from each of the plurality of processors **120** to obtain a fused cloud data set **185**.

(44) In some embodiments, the system **100** may further include an object detection module **190**. In some embodiments, the object detection module **190** is configured to provide one or more perception outputs **195** based on the fused cloud data set **185**. In some embodiments, the one or more perception outputs **195** may include object detection, semantic segmentation, such as object boundaries and pose estimation, or any other information about the objects in the 3D space **105**. Therefore, the system **100** may be used for people-tracking applications in a static setting to object detection applications in an autonomous vehicle.

(45) FIG. **3** illustrates a schematic view of the sensor **110** and a field of view (FOV) **111** of the sensor in the 3D space **105**, according to an embodiment of the present disclosure. The FOV **111** may be representative of an angular range the sensor **110** (e.g., the LIDAR sensor) covers in one measurement or frame.

(46) Referring to FIGS. **1**, **2**, and **3**, the processor **120** is further configured to divide the 3D space **105** into a plurality of rays **130** extending from the sensor **110**. In the illustrated embodiment of FIG. **3**, only one ray **130** is shown for clarity purposes.

(47) Each ray **130** includes an azimuth **132** and an elevation **134** with respect to the sensor **110**. In other words, the processor **120** is configured to divide the 3D space **105** by the azimuth **132** and the elevation **134** as measured with respect to the sensor **110** to obtain the plurality of rays **130** extending from the sensor **110**. In some embodiments, the azimuth **132** and the elevation **134** may be less than about 0.2 degrees, less than about 0.1 degrees, or less than about 0.05 degrees. Therefore, each of the plurality of rays **130** may be very narrow.

(48) Further, each data point **114** is enclosed by a corresponding ray **130**C (shown in FIG. **4**A) from the plurality of rays **130**.

(49) In the illustrated embodiment of FIG. **3**, a portion of the 3D space **105** encompassed by each of the plurality of rays **130** is an approximately square pyramid with its tip at the sensor **110**. However, as discussed above, each of the plurality of rays **130** may be very narrow, and therefore will be treated as a one-dimensional representation. A ray typically refers to a line that has a fixed starting point but no endpoint. Similarly, the rays **130** extend from the sensor **110**.

(50) FIG. **4**A illustrates a schematic representation of the corresponding ray **130**C from the plurality of rays **130** enclosing the data point **114** from the plurality of data points **114**, according to an embodiment of the present disclosure. As shown in FIG. **4**A, the plurality of rays **130** extends from the sensor **110**.

(51) Now referring to FIGS. **1** to **4**A, the processor **120** is further configured to define a plurality of peaks **140** for each ray **130** from the plurality of rays **130**. In the illustrated embodiment of FIG.

4A, the processor **120** is configured to define three peaks **140** for each ray **130** from the plurality of rays **130**. However, the processor **120** may be configured to define any number of the peaks **140** for each ray **130**, as per desired application attributes. In an example, storing one peak **140** in 4 bytes of storage space may be sufficiently accurate for almost all applications of the sensor **110**. Assuming the three peaks **140** for each ray **130** and 2048×64 rays **130** within the FOV **111** of the sensor **110**, a very modest memory usage of less than 1536 kilobytes (kB) may be required. Therefore, the algorithm may be suitable for the system **100** even if the system **100** is the embedded system.

(52) Each peak **140** from the plurality of peaks **140** is located at a peak distance **142** from the sensor **110** and includes a peak height **144** equal to a predetermined initial value **145**. Upon initialization of the algorithm, the plurality of peaks **140** may be located at any arbitrary peak distance **142** from the sensor **110** and may include any arbitrary peak height **144**. For example, upon initialization, the predetermined initial value **145** of the peak height **144** may be equal to zero. In the illustrated embodiment of FIG. **4**A, the peak distance **142** and the peak height **144** are shown for just one peak for clarity purposes. However, it should be noted that each peak **140** from the plurality of peaks **140** includes the peak distance **142** and the peak height **144**.

(53) The processor **120** is further configured to define a catchment region **150** for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130**. The catchment region **150** for each peak **140** includes a catchment distance **152** from the corresponding peak **140** towards the sensor **110** and the catchment distance **152** from the corresponding peak **140** away from the sensor **110**. Therefore, the catchment region **150** is twice the catchment distance **152.** In the illustrated embodiment of FIG. **4**A, the catchment region **150** and the catchment distance **152** are shown for just one peak **140** for clarity purposes. However, it should be noted that each peak **140** from the plurality of peaks **140** includes the catchment region **150** and the catchment distance **152**.

(54) In some embodiments, the catchment distance **152** for a peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** is defined based upon the peak distance **142** of the peak **140**, i.e., the catchment distance **152**=f(p), where p is the peak distance **142**.

(55) In some embodiments, upon initialization of the algorithm, the catchment distance **152** may have any generic initial value. In some cases, the initial value may be based on a type of the sensor **110**. In some examples, the initial value of the catchment distance **152** may be equal to about 0.10 meters (m), 0.15 m, or 0.20 m.

(56) Further, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to determine the corresponding ray **130**C from the plurality of rays **130** enclosing the data point **114**. Further, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to determine a data point distance **116** of the data point **114** from the sensor **110**.

(57) For each data point **114** from the plurality of data points **114**, the processor **120** is further configured to determine a containing peak **140**C from the plurality of peaks **140** of the corresponding ray **130**C for which the data point **114** lies within the catchment region **150** of the containing peak **140**C.

(58) In some embodiments, the processor **120** is configured to store the data point distance **116** of the data point **114** in a statistical data pool **165** (shown in FIG. **6**) when the data point **114** lies within the catchment region **150** of the containing peak **140**C. In some embodiments, the processor **120** may be configured to subsample the data points **114** lying within the catchment region **150** of the containing peak **140**C for storing respective data point distances **116** of the data points **114** in the statistical data pool **165**. For example, the processor **120** may be configured to store only a fraction of data point distances **116** corresponding to the fraction of the data points **114** lying within the catchment region **150** of the containing peak **140**C in the statistical data pool **165**. This may further reduce the computational load of the system **100**. Specifically, this may reduce the

computational load of the processor **120**.

(59) In some embodiments, in case the data point **114** lies within the catchment region **150** of multiple peaks **140** from the plurality of peaks **140** of the corresponding ray **130**C, the processor **120** is further configured to determine the containing peak **140**C based on at least one of the peak heights **144** of the multiple peaks **140**, the peak distances **142** of the multiple peaks **140**, and a distance of the data point **114** from each of the multiple peaks **140**. In some other examples, the processor **120** may select the containing peak **140**C from the multiple peaks **140** randomly.

(60) FIG. **4**B illustrates a schematic representation of the corresponding ray **130**C having the containing peak **140**C for which the data point **114** lies within the catchment region **150** of the containing peak **140**C, according to an embodiment of the present disclosure.

(61) Now referring to FIGS. **1** to **4**B, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to determine a peak increment value **146**. In some embodiments, the processor **120** may determine a greater peak increment value **146** for the data point **114** farther from the sensor **110** as compared to a data point **114** closer to sensor **110**. In other words, the peak increment value **146** for the farther data points **114** may be greater than that of the closer data points **114**. This is because the static objects of the background **101** are typically the farthest in the FOV **111** of the sensor **110** and the dynamic and the semi-static objects tend to move and are visible in front of the static objects of the background **101**.

(62) For each data point **114** from the plurality of data points **114**, the processor **120** is further configured to increment the peak height **144** of the containing peak **140**C by the peak increment value **146**.

(63) In some embodiments, the processor **120** is further configured to update the peak distance **142** of the containing peak **140**C based at least on the data point distance **116** of the data point **114** lying within the catchment region **150** of the containing peak **140**C. In some embodiments, the peak distance **142** of the containing peak **140**C is updated based on a difference between the peak distance **142** of the containing peak **140**C and the data point distance **116** of the data point **114** lying within the catchment region **150** of the containing peak **140**C. For example, the peak distance **142** of the containing peak **140**C is updated from an initial peak distance **143**A (shown in FIG. **4**A) to an updated peak distance **143**B. As is apparent from FIG. **4**B, the containing peak **140**C follows or moves towards the data point **114** when the peak distance **142** of the containing peak **140**C is updated.

(64) In some embodiments, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to determine a backgroundness of the data point **114**. The backgroundness of the data point **114** refers to a likelihood that the data point **114** is a result of the measurement of the static object/surface in the 3D space **105**. In some embodiments, the processor **120** is further configured to determine the backgroundness of the data point **114** based at least on the peak height **144**, the peak distance **142**, and the catchment distance **152** of the catchment region **150** for the containing peak **140**C, if the data point **114** lies within the catchment region **150** of the containing peak **140**C. In some embodiments, the backgroundness is determined further based on a magnitude of a difference between the data point distance **116** and the peak distance **142** of the containing peak **140**C. In other words, the backgroundness may be determined further based on a closeness of the data point **114** to the containing peak **140**C. The system **100** may provide accurate and real-time estimates for the backgroundness of the data point **114**. In other words, the system **100** may provide accurate and real-time estimates for the likelihood of the data point **114** belonging to either the static object/surfaces or to dynamic objects, including when the dynamic objects may be moving discontinuously (e.g., the dynamic object may stop for periods of time).

(65) FIG. **4**C illustrates a schematic representation of the corresponding ray **130**C of the data point **114**, while the data point **114** is outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C, according to an embodiment of the present disclosure. FIG. **4**D illustrates a schematic representation of the corresponding ray **130**C including a new peak **140**N,

according to an embodiment of the present disclosure.
(66) Referring to FIGS. **2**, **4**C, and **4**D, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to define the new peak **140**N including a peak height **144**N equal to the peak increment value **146** and a peak distance **142**N equal to the data point distance **116** if the data point **114** is outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C.
(67) In some embodiments, in order to define the new peak **140**N, the processor **120** is further configured to remove the peak **140** from the plurality of peaks **140** including the peak height **144** less than the peak height **144** of each of the other peaks **140** from the plurality of peaks **140** of the corresponding ray **130**C.
(68) In some embodiments, the processor **120** is further configured to set the backgroundness equal to zero if the data point **114** is outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C. In other words, the processor **120** determines that the data point **114** outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C does not to belong to any static object. Therefore, the system **100** may not require high computational or memory intensive resources.
(69) FIG. **4**E illustrates a schematic representation of the ray **130** from the plurality of rays **130** having the catchment region **150** including an updated catchment distance **152**U for each peak **140** from the plurality of peaks **140**, according to an embodiment of the present disclosure. In the illustrated embodiment of FIG. **4**E, the catchment region **150**, the catchment distance **152**, and the updated catchment distance **152**U are shown for just one peak **140** for clarity purposes.
(70) The processor **120** is further configured to update the catchment distance **152** of the catchment region **150** of each of the plurality of peaks **140** of each of the plurality of rays **130**. In other words, the processor **120** is further configured to determine the updated catchment distance **152**U of each of the plurality of peaks **140** of each of the plurality of rays **130**. By updating the catchment distance **152**, the system **100** may optimize the catchment distance **152** and may further adapt to changing environmental noise (e.g., from rain, fog, or lighting conditions), slow drifts or differences in performance of the sensor, or similar. In the illustrated embodiment of FIG. **4**E, the updated catchment distance **152**U is greater than the catchment distance **152**. However, the updated catchment distance **152**U may be smaller than the catchment distance **152**.
(71) In some embodiments, the processor **120** is configured to update the catchment distance **152** of the catchment region **150** after determining if a data point **114** from the plurality of data points **114** lies within the catchment region **150** of the containing peak **140**C (as shown in FIG. **4**A) or if the data point **114** is outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C (as shown in FIG. **4**C) for a predetermined number of data points **114** from the plurality of data points **114**. For example, the processor **120** may be configured to update the catchment distance **152** of the catchment region **150** after processing one, fifty, hundred, or thousand data points **114**, as per desired application attributes. In some cases, the processor **120** may be configured to update the catchment distance **152** of the catchment region **150** after processing each data point **114** of the one measurement or the frame of the sensor **110**.
(72) Details related to updating the catchment distance **152** of the catchment region **150** will be provided below.
(73) FIG. **5** illustrates an expected noise distribution **160** around one peak **140** from the plurality of peaks **140**, according to an embodiment of the present disclosure.
(74) In some embodiments, the expected noise distribution **160** may be based on a distribution of the data points **114** around the peak **140** (i.e., the containing peak **140**C). In some embodiments, the expected noise distribution **160** may be based on one or more distance noise parameters of the sensor **110**. The one or more sensor parameters may be indicative of an effect of at least one of a signal to noise ratio of the sensor **110** for different distances, a reflection strength of the sensor **110** for different distances, a sensor temperature of the sensor **110** for different distances, a

measurement energy of the sensor **110** for different distances, a light accumulation time of the sensor **110** of the sensor **110** for different distances, a sensor motion of the sensor **110** for different distances, a vibration level of the sensor **110** of the sensor **110** for different distances, and so forth. In some embodiments, the expected noise distribution **160** may be based on one or more environmental parameters of the 3D space **105**. The one or more environmental parameters may be indicative of an effect of at least one of a lighting of the environment, a time of day, a current atmospheric condition of the environment, a current weather condition of the environment, and so forth. In some embodiments, the expected noise distribution **160** may be based on a distance noise. This is because the sensor **110** may have a distance measurement accuracy that may decrease with an increase in a distance and a noise level that grows with an increase in the distance. In the illustrated embodiment of FIG. **5**, the expected noise distribution **160** is monomodal. In some embodiments, the expected noise distribution **160** is a normal distribution.

(75) Referring to FIGS. **1** to **5**, in some embodiments, the catchment region **150** for the peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** is defined based upon the expected noise distribution **160** of at least one of the one or more distance noise parameters of the sensor **110** and the one or more environmental parameters of the 3D space **105**. In some embodiments, the catchment region **150** for a peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** is defined based upon the expected noise distribution **160** of the distance noise at a distance from the sensor **110**.

(76) In some embodiments, the processor **120** is configured to define a first center match region **150**A for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130**. The first center match region **150**A includes a first center match distance **152**A from the corresponding peak **140**C towards the sensor **110** and the first center match distance **152**A from the corresponding peak **140**C away from the sensor **110**. Therefore, the first center match region **150**A is twice the first center match distance **152**A. The first center match distance **152**A is a first fraction of the catchment distance **152**. In some examples, the first fraction may be about 0.25, about 0.5, about 0.75, or about 0.9.

(77) In some embodiments, the processor **120** is configured to define a second center match region **150**B for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130**. The second center match region **150**B includes a second center match distance **152**B from the corresponding peak **140**C towards the sensor **110** and the second center match distance **152**B from the corresponding peak **140**C away from the sensor **110**. Therefore, the second center match region **150**B is twice the second center match distance **152**B. The second center match distance is a second fraction of the catchment distance **152**. Further, the second fraction is greater than the first fraction. In some examples, the second fraction may be about 0.25, about 0.5, about 0.75, or about 0.99. In some cases, the second fraction may be equal to about 1. In an example, the first fraction may be 0.25 and the second fraction may be 1.

(78) In some embodiments, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to classify the data point **114** as a center match **154** if the data point **114** lies within the first center match region **150**A for the containing peak **140**C.

(79) In some embodiments, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to classify the data point **114** as a fringe match **156** if the data point **114** is outside the first center match region **150**A for the containing peak **140**C but lies within the second center match region **150**B for the containing peak **140**C.

(80) In some embodiments, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to classify the data point **114** as an invalid match **158** if the data point **114** is outside the second center match region **150**B for the containing peak **140**C but lies within the catchment region **150** of the containing peak **140**C.

(81) FIG. **6** illustrates a schematic view of the statistical data pool **165**, according to an embodiment of the present disclosure.

(82) Referring to FIGS. **1** to **6**, in some embodiments, the processor **120** is configured to determine a center peak count **154**A of a total number of peaks **140** having the center matches **154**. In the illustrated embodiment of FIG. **6**, two peaks have center matches **154**. In some embodiments, the processor **120** is configured to determine a fringe peak count **156**A of a total number of peaks **140** having the fringe matches **156**. In the illustrated embodiment of FIG. **6**, two peaks have fringe matches **156**. The processor **120** may determine the center peak count **154**A and the fringe peak count **156**A based on the data stored in the statistical data pool **165**.
(83) In some embodiments, the processor **120** is further configured to define at least one catchment region update size β1 for the catchment region **150** of each peak **140** from the plurality of peaks **140**. In some embodiments, the catchment distance **152** of the containing peak **140**C is updated further based upon the at least one catchment region update size β1 of the containing peak **140**C. In some embodiments, the catchment region update size β1 may be greater than or equal to 0.005, 0.01, 0.05, 0.1, 0.5. Therefore, the catchment region update size β1 may determine the magnitude of update of the catchment distance **152** for each update step. This may control how quickly the catchment distance **152** is adapted over time.
(84) In some embodiments, the processor **120** is configured to update the catchment distance **152** of the catchment region **150** for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** based upon a ratio of the center peak count **154**A to the fringe peak count **156**A. Therefore, the processor **120** may uniformly update the catchment distance **152** of the catchment region **150** for each peak **140**. Ideally, in some cases, a desired ratio X of the center peak count **154**A to the fringe peak count **156**A should be 1:1. However, the desired ratio X may be modified as per desired application attributes. In cases the desired ratio is set to be 1:1, the updated catchment distance **152** may be determined by the following equation:
(85) $c_{\text{new}} = c_{\text{old}} + {}_{1}$ .Math. $(X - a/(a+b))$ where, c.sub.new is the updated catchment distance **152**U; c.sub.old is the catchment distance **152**; β1 is the catchment region update size; X is a desired ratio of the center peak count **154**A to the fringe peak count **156**A; a is the center peak count **154**A; and b is the fringe peak count **156**A.
(86) The value of X for the desired ratio 1:1 is 0.5. If the center peak count **154**A is substantially greater than the fringe peak count **156**A, the catchment distance **152** is decreased as the catchment distance **152** may be too large as fewer data points **114** are "near the edge" of the catchment region **150**. Similarly, if the fringe peak count **156**A is substantially greater than the center peak count **154**A, the catchment distance **152** is increased as the catchment distance **152** may be too small as more data points **114** are "near the edge" of the catchment region **150**. By updating the catchment distance **152** in such manner, the catchment distance **152** may converge to a value of the catchment distance **152** that may represent any desired coverage of the expected noise distribution **160**. In the illustrated embodiment of FIG. **6**, the ratio of the center peak count **154**A to the fringe peak count **156**A is 1:1. Therefore, the catchment distance **152** may be optimized.
(87) As discussed above, in some embodiments, the processor **120** is configured to store the data point distance **116** of the data point **114** in the statistical data pool **165** when the data point **114** lies within the catchment region **150** of the containing peak **140**C. In some embodiments, the processor **120** is further configured to store the catchment distance **152** for each peak **140** in the statistical data pool **165**.
(88) In some embodiments, for each data point **114** from the plurality of data points **114**, the processor **120** is further configured to store the data point distance **116** of the data point **114** in the statistical data pool **165** if the data point **114** is classified as the center match **154** or the fringe match **156**. In some embodiments, for each data point **114** from the plurality of data points **114**, the processor **120** may be further configured to store the data point distance **116** of the data point **114** in the statistical data pool **165** if the data point **114** is classified as the invalid match **158**.
(89) In some embodiments, the processor **120** is further configured to update the catchment distance **152** of the catchment region **150** after a total number of the data point distances **116** stored

in the statistical data pool **165** is equal to a predefined number. For example, if the processor **120** may update the catchment distance **152** of the catchment region **150** after hundred data point distances **116** are stored in the statistical data pool **165**. The predefined number may be adjusted as per desired application attributes.

(90) In some embodiments, the processor **120** is further configured to empty the statistical data pool **165** after the total number of the data point distances **116** stored in the statistical data pool **165** is equal to the predefined number. For example, the processor **120** may empty the statistical data pool **165** after hundred data point distances **116** are stored in the statistical data pool **165**.

(91) FIG. **7**A illustrates a schematic flow diagram **250** depicting various steps performed by the processor **120** shown in FIG. **2** for updating the catchment distance **152** of the catchment region **150**, according to an embodiment of the present disclosure.

(92) Referring to FIGS. **1** to **7**A, in some embodiments, the processor **120** is further configured to define a regression model **200** for the catchment distance **152** of the catchment region **150**. In the illustrated embodiment of FIG. **7**A, the regression model **200** is a function of the peak distance **142**. Further, the regression model **200** includes a plurality of parameters **210**. For example, the regression model **200** may be defined as:

(93) thecatchmentdistance152 = $xp^2 + yp + z$,

where p is the peak distance **142** and x, y, and z are the plurality of parameters **210**.

(94) In some embodiments, the regression model **200** may be a simple linear regression model or any other regression model that can be adapted and sampled fast enough for real-time use on the system **100**. Some examples of the regression model **200** include a polynomial regression model, a decision tree model, a support vector machine (SVM)-based regression model, a neural network model, a gaussian process model, a quantile regression model, a piecewise polynomial regression model, a spline fitting model, a ridge regression model, and so forth.

(95) As shown in block **252**, in some embodiments, for each center match **154** of the peak **140**, the processor **120** is further configured to determine a difference catchment distance **220** as a difference between the catchment distance **152** and a product of the catchment distance **152** and the catchment region update size β1, i.e., c.sub.new=c.sub.old−c.sub.old.Math.β1.

(96) In some embodiments, for each fringe match **156** of the peak **140**, the processor **120** is further configured to determine a sum catchment distance **230** as a sum of the catchment distance **152** and a product of the catchment distance **152** and the catchment region update size β1, i.e., c.sub.new=c.sub.old+c.sub.old.Math.β1.

(97) As shown in block **254**, in some embodiments, the processor **120** is further configured to determine a plurality of estimated parameters **212** for the regression model **200** based on the difference catchment distances **220**, the sum catchment distances **230**, and the peak distances **142** of the plurality of peaks **140**. For example, the processor **120** may determine the plurality of estimated parameters **212** for the regression model **200** using least squares method.

(98) As shown in block **256**, in some embodiments, the processor **120** is further configured to determine a plurality of updated parameters **214** for the regression model **200** based on the plurality of parameters **210** and the plurality of estimated parameters **212** for the regression model **200**. The processor **120** may determine the plurality of updated parameters **214** using a weighted average.

(99) As shown in block **258**, in some embodiments, the processor **120** is further configured to update the catchment distance **152** of the catchment region **150** based on the plurality of updated parameters **214**. In other words, the processor **120** is further configured to determine the updated catchment distance **152**U based on the plurality of updated parameters **214**. Therefore, the processor **120** is configured to determine a variable distance-dependent catchment distance **152** that is adapted by the peak distance **142** of the peak **140** from the sensor **110**. In other words, the processor **120** is configured to determine the updated catchment distance **152**U individually for each peak **140** based on the peak distance **142** of the peak **140** from the sensor **110**. This is because, as discussed above, the sensor **110** may have the distance measurement accuracy that may decrease

with the increase in the distance and the noise level that grows with the increase in the distance. The regression model **200** may accurately capture the important relationship between the distance and the noise level.
(100) In some embodiments, the processor **120** is further configured to provide the updated catchment distance **152**U of the catchment region **150** for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** to a sensor monitoring system (not shown). This is because high sensor noise levels may be indicative of sensor degradation or failures.
(101) FIG. **7**B illustrates a schematic flow diagram **260** depicting various steps performed by the processor **120** shown in FIG. **2** for updating the catchment distance **152** of the catchment region **150**, according to another embodiment of the present disclosure.
(102) The schematic flow diagram **260** is substantially similar to the schematic flow diagram **250** of FIG. **7**A. However, according to the flow diagram **260**, the regression model **200** is a function of at least one of one or more peak parameters **140**P, one or more data point parameters **114**P, and one or more noise parameters **160**P. Therefore, the processor **120** is configured to determine the catchment distance **152** that is adapted by the one or more peak parameters **140**P, the one or more data point parameters **114**P, and the one or more noise parameters **160**P. Thus, the regression model **200** of FIG. **7**B may be a higher dimensional model and may improve a quality of detection of the background **101**. However, the regression model **200** of FIG. **7**B may have higher computational requirements.
(103) In some embodiments, the one or more peak parameters **140**P may include any parameter related to the peak **140**, such as the peak distance **142**, the peak height **144**, etc. In some embodiments, the one or more data point parameters **114**P may include any parameter related to the data point **114**, such as the data point distance **116**, a signal to noise ratio of the data points **114**, and so forth. In some embodiments, the one or more noise parameters **160**P may include any parameter related to a noise at the data point **114**, for example, due to a noise of the sensor **110** or a noise in the environment surrounding the sensor **110**. For example, the one or more noise parameters **160**P may include one or more of a reflection strength, a sensor temperature, a point sensor receiver channel, a measurement energy, a light accumulation time of the sensor **110**, a sensor motion (direction, speed, acceleration), a cumulative system run time, a vibration level of the sensor **110**, a lighting condition of the environment, a time of day, a current atmospheric condition of the environment, and so forth.
(104) FIG. **8** illustrates a schematic flow diagram **270** depicting various steps performed by the system **100** shown in FIG. **2** for determining the background **101** (shown in FIG. **1**) in the 3D space **105** (shown in FIG. **1**), according to an embodiment of the present disclosure.
(105) FIG. **9** illustrates a flowchart depicting a method **300** for determining the background **101** (shown in FIG. **1**) in the 3D space **105** (shown in FIG. **1**), according to an embodiment of the present disclosure. The method **300** will be further described with reference to FIGS. **1** to **8**.
(106) At step **302**, the method **300** includes receiving, via the sensor **110**, the point cloud data set **112** for the 3D space **105**. The point cloud data set **112** includes the plurality of data points **114**.
(107) At step **304**, the method **300** includes dividing the 3D space **105** into the plurality of rays **130** extending from the sensor **110**. Each ray **130** includes the azimuth **132** and the elevation **134** with respect to the sensor **110**. Each data point **114** is enclosed by the corresponding ray **130**C from the plurality of rays **130**.
(108) At block **272** of the flow diagram **270** of FIG. **8**, the method **300** starts. Specifically, the step **304** of the method **300** may be followed by the block **272** of FIG. **8**.
(109) At step **306**, the method **300** includes defining the plurality of peaks **140** for each ray **130** from the plurality of rays **130**. Each peak **140** from the plurality of peaks **140** is located at the peak distance **142** from the sensor **110** and includes the peak height **144** equal to the predetermined initial value **145**.
(110) At step **308**, the method **300** includes defining the catchment region **150** for each peak **140**

from the plurality of peaks **140** for each ray **130** from the plurality of rays **130**. The catchment region **150** for each peak **140** includes the catchment distance **152** from the corresponding peak **140** towards the sensor **110** and the catchment distance **152** from the corresponding peak **140** away from the sensor **110**.

(111) In some embodiments, the catchment region **150** for the peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** is defined based upon the peak distance **142** of the peak **140**.

(112) In some embodiments, the catchment region **150** for the peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** is defined based upon the expected noise distribution **160** of at least one of the one or more distance noise parameters of the sensor **110** and the one or more environmental parameters of the 3D space **105**.

(113) In some embodiments, the catchment region **150** for the peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** is defined based upon the expected noise distribution **160** of the distance noise at the distance from the sensor **110**.

(114) At block **274** of the flow diagram **270** of FIG. **8**, the method **300** is initialized. Specifically, the block **274** includes the steps **306** and **308** of the method **300**.

(115) Further, at block **276** of the flow diagram **270** of FIG. **8**, the method **300** receives new measurement. Specifically, the block **276** includes the step **302** of the method **300**.

(116) At step **310**, the method **300** includes, for each data point **114** from the plurality of data points **114**, determining the corresponding ray **130**C from the plurality of rays **130** enclosing the data point **114**.

(117) At step **312**, the method **300** includes, for each data point **114** from the plurality of data points **114**, determining the data point distance **116** of the data point **114** from the sensor **110**. In some embodiments, the corresponding ray **130**C from the plurality of rays **130** enclosing the data point **114** from the plurality of rays **130** may be determined based on the data point distance **116** of the data point **114**, the azimuth **132**, and the elevation **134**.

(118) At step **314**, the method **300** includes, for each data point **114** from the plurality of data points **114**, determining the peak increment value **146**.

(119) At step **316**, the method **300** includes, for each data point **114** from the plurality of data points **114**, determining the containing peak **140**C from the plurality of peaks **140** of the corresponding ray **130**C for which the data point **114** lies within the catchment region **150** of the containing peak **140**C. In some embodiments, in case the data point **114** lies within the catchment region **150** of the multiple peaks **140** from the plurality of peaks **140** of the corresponding ray **130**C, the containing peak **140**C is determined based on at least one of the peak heights **144** of the multiple peaks **140**, the peak distances **142** of the multiple peaks **140**, and the distance of the data point **114** from each of the multiple peaks **140**.

(120) At step **318**, the method **300** includes, for each data point **114** from the plurality of data points **114**, incrementing the peak height **144** of the containing peak **140**C by the peak increment value **146**.

(121) At step **320**, the method **300** includes, for each data point **114** from the plurality of data points **114**, defining the new peak **140**N including the peak height **144**N equal to the peak increment value **146** and the peak distance **142**N equal to the data point distance **116** if the data point **114** is outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C. In some embodiments, defining the new peak **140**N further includes removing the peak **140** from the plurality of peaks **140** including the peak height **144** less than the peak height **144** of each of the other peaks **140** from the plurality of peaks **140** of the corresponding ray **130**C. In some embodiments, the method **300** further includes updating the peak distance **142** of the containing peak **140**C based at least on the data point distance **116** of the data point **114** lying within the catchment region **150** of the containing peak **140**C.

(122) At block **278** of the flow diagram **270** of FIG. **8**, the method **300** collects data. Specifically,

the block **264** includes the steps **310**, **312**, **314**, **316**, **318**, and **320** of the method **300**.

(123) In some embodiments, the method **300** further includes storing the data point distance **116** of the data point **114** in the statistical data pool **165** when the data point **114** lies within the catchment region **150** of the containing peak **140**C (as shown in block **279** of FIG. **8**). Specifically, the line connecting the blocks **278** and **279** schematically illustrates flow of the data from the block **278** to the block **279**.

(124) In some embodiments, the method **300** further includes defining the first center match region **150**A for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130**. The first center match region **150**A includes the first center match distance **152**A from the corresponding peak **140**C towards the sensor **110** and the first center match distance **152**A from the corresponding peak **140**C away from the sensor **110**. Further, as discussed above, the first center match distance **152**A is the first fraction of the catchment distance **152**.

(125) In some embodiments, the method **300** further includes defining the second center match region **150**B for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130**. The second center match region **150**B includes the second center match distance **152**B from the corresponding peak **140**C towards the sensor **110** and the second center match distance **152**B from the corresponding peak **140**C away from the sensor **110**. The second center match distance **152**B is the second fraction of the catchment distance **152**. Further, the second fraction is greater than the first fraction.

(126) In some embodiments, for each data point **114** from the plurality of data points **114**, the method **300** further includes classifying the data point **114** as the center match **154** if the data point **114** lies within the first center match region **150**A for the containing peak **140**C.

(127) In some embodiments, for each data point **114** from the plurality of data points **114**, the method **300** further includes classifying the data point **114** as the fringe match **156** if the data point **114** is outside the first center match region **150**A for the containing peak **140**C but lies within the second center match region **150**B for the containing peak **140**C.

(128) In some embodiments, for each data point **114** from the plurality of data points **114**, the method **300** further includes classifying the data point **114** as the invalid match **158** if the data point **114** is outside the second center match region **150**B for the containing peak **140**C but lies within the catchment region **150** of the containing peak **140**C.

(129) In some embodiments, for each data point **114** from the plurality of data points **114**, the method **300** further includes storing the data point distance **116** of the data point **114** in the statistical data pool **165** if the data point **114** is classified as the center match **154** or the fringe match **156**.

(130) In some embodiments, at the block **278**, the method **300** may further include determining the backgroundness for each data point **114** from the plurality of data points **114**. In some embodiments, determining the backgroundness of the data point **114** further includes setting the backgroundness equal to zero if the data point **114** is outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C.

(131) In some embodiments, determining the backgroundness of the data point **114** further includes determining the backgroundness of the data point **114** based at least on the peak height **144**, the peak distance **142**, and the catchment distance **152** of the catchment region **150** for the containing peak **140**C if the data point **114** lies within the catchment region **150** of the containing peak **140**C. In some embodiments, the backgroundness is determined further based on the magnitude of the difference between the data point distance **116** and the peak distance **142** of the containing peak **140**C.

(132) At block **280** of the flow diagram **270** of FIG. **8**, the method **300** determines if the total number of the data point distances **116** stored in the statistical data pool **165** is equal to the predefined number.

(133) The flow diagram **270** of FIG. **8** further illustrates two different paths in which the method

300 may proceed if the total number of the data point distances **116** stored in the statistical data pool **165** is equal to the predefined number and if the total number of the data point distances **116** stored in the statistical data pool **165** is not equal to the predefined number. Specifically, "YES" refers to a case in which the total number of the data point distances **116** stored in the statistical data pool **165** is equal to the predefined number and "NO" refers to a case in which the total number of the data point distances **116** stored in the statistical data pool **165** is not equal to the predefined number. More specifically, the method **300** proceeds to block **282** if the total number of the data point distances **116** stored in the statistical data pool **165** is equal to the predefined number and the method **300** proceeds to block **284** if the total number of the data point distances **116** stored in the statistical data pool **165** is not equal to the predefined number.

(134) At step **322**, the method **300** includes, updating the catchment distance **152** of the catchment region **150** of each of the plurality of peaks **140** of each of the plurality of rays **130** (shown in block **282** of FIG. **8**). In other words, the method **300** includes determining the updated catchment distance **152**U of the catchment region **150**. Specifically, in some embodiments, the catchment distance **152** of the catchment region **150** is updated after the total number of the data point distances **116** stored in the statistical data pool **165** is equal to the predefined number. In some embodiments, the method **300** further includes providing the updated the catchment distance **152**U of the catchment region **150** for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** to the sensor monitoring system (not shown).

(135) There is a bidirectional flow of the data between the blocks **279** and **282**. This is because, the data from the statistical data pool **165** may be required to update the catchment distance **152** of the catchment region **150** and the updated catchment distance **152**U may be further stored in the statistical data pool **165** for the next update.

(136) In some embodiments, the catchment distance **152** of the catchment region **150** is updated after determining if the data point **114** from the plurality of data points **114** lies within the catchment region **150** of the containing peak **140**C or if the data point **114** is outside the catchment region **150** of each of the plurality of peaks **140** of the corresponding ray **130**C for the predetermined number of data points from the plurality of data points **114**.

(137) In some embodiments, the method **300** further includes emptying the statistical data pool **165** after the total number of the data point distances **116** stored in the statistical data pool **165** is equal to the predefined number.

(138) In some embodiments, the method **300** further includes determining the center peak count **154**A of the total number of peaks **140** having the center matches **154**. In some embodiments, the method **300** further includes determining the fringe peak count **156**A of the total number of peaks **140** having the fringe matches **156**. In some embodiments, the method **300** further includes updating the catchment distance **152** of the catchment region **150** for each peak **140** from the plurality of peaks **140** for each ray **130** from the plurality of rays **130** based upon the ratio of the center peak count **154**A to the fringe peak count **156**A.

(139) In some embodiments, the method **300** further includes defining the regression model **200** for the catchment distance **152** of the catchment region **150**. In some embodiments, the regression model **200** is the function of the peak distance **142**. In some embodiments, the regression model **200** is a function of at least one of the one or more peak parameters **140**P, the one or more data point parameters **114**P, and the one or more noise parameters **160**P. The regression model **200** includes the plurality of parameters **210**.

(140) In some embodiments, the method **300** further includes defining the at least one catchment region update size β1 for the catchment region **150** of each peak **140** from the plurality of peaks **140**. The catchment distance **152** of the containing peak **140**C is updated further based upon the at least one catchment region update size β1 of the containing peak **140**C.

(141) In some embodiments, the method **300** further includes, for each center match **154** of the peak **140**, determining the difference catchment distance **220** as the difference between the

catchment distance **152** and the product of the catchment distance **152** and the catchment region update size β1. In some embodiments, the method **300** further includes, for each fringe match **156** of the peak **140**, determining the sum catchment distance **230** as the sum of the catchment distance **152** and the product of the catchment distance **152** and the catchment region update size β1.

(142) In some embodiments, the method **300** further includes determining the plurality of estimated parameters **212** for the regression model **200** based on the difference catchment distances **220** and the sum catchment distances **230** and the peak distances **142** of the plurality of peaks **140**. In some embodiments, the method **300** further includes determining the plurality of updated parameters **214** for the regression model **200** based on the plurality of parameters **210** and the plurality of estimated parameters **212** for the regression model **200**. In some embodiments, the method **300** further includes updating the catchment distance **152** of the catchment region **150** based on the plurality of updated parameters **214**.

(143) Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified by the term "about". Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

(144) Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations can be substituted for the specific embodiments shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the specific embodiments discussed herein. Therefore, it is intended that this disclosure be limited only by the claims and the equivalents thereof.

(145) As used in this specification and the appended claims, the singular forms "a," "an," and "the" encompass embodiments having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

(146) Spatially related terms, including but not limited to, "proximate," "distal," "lower," "upper," "beneath," "below," "above," and "on top," if used herein, are utilized for ease of description to describe spatial relationships of an element(s) to another. Such spatially related terms encompass different orientations of the device in use or operation in addition to the particular orientations depicted in the figures and described herein. For example, if an object depicted in the figures is turned over or flipped over, portions previously described as below or beneath other elements would then be above or on top of those other elements.

(147) As used herein, when an element, component, or layer for example is described as forming a "coincident interface" with, or being "on," "connected to," "coupled with," "stacked on" or "in contact with" another element, component, or layer, it can be directly on, directly connected to, directly coupled with, directly stacked on, in direct contact with, or intervening elements, components or layers may be on, connected, coupled or in contact with the particular element, component, or layer, for example. When an element, component, or layer for example is referred to as being "directly on," "directly connected to," "directly coupled with," or "directly in contact with" another element, there are no intervening elements, components or layers for example. The techniques of this disclosure may be implemented in a wide variety of computer devices, such as servers, laptop computers, desktop computers, notebook computers, tablet computers, hand-held computers, smart phones, and the like. Any components, modules or units have been described to emphasize functional aspects and do not necessarily require realization by different hardware units. The techniques described herein may also be implemented in hardware, software, firmware, or any combination thereof. Any features described as modules, units or components may be implemented together in an integrated logic device or separately as discrete but interoperable logic devices. In

some cases, various features may be implemented as an integrated circuit device, such as an integrated circuit chip or chipset. Additionally, although a number of distinct modules have been described throughout this description, many of which perform unique functions, all the functions of all of the modules may be combined into a single module, or even split into further additional modules. The modules described herein are only exemplary and have been described as such for better ease of understanding.

(148) If implemented in software, the techniques may be realized at least in part by a computer-readable medium comprising instructions that, when executed in a processor, performs one or more of the methods described above. The computer-readable medium may comprise a tangible computer-readable storage medium and may form part of a computer program product, which may include packaging materials. The computer-readable storage medium may comprise random access memory (RAM) such as synchronous dynamic random access memory (SDRAM), read-only memory (ROM), non-volatile random access memory (NVRAM), electrically erasable programmable read-only memory (EEPROM), FLASH memory, magnetic or optical data storage media, and the like. The computer-readable storage medium may also comprise a non-volatile storage device, such as a hard-disk, magnetic tape, a compact disk (CD), digital versatile disk (DVD), Blu-ray disk, holographic data storage media, or other non-volatile storage device.

(149) The term “processor,” as used herein may refer to any of the foregoing structure or any other structure suitable for implementation of the techniques described herein. In addition, in some aspects, the functionality described herein may be provided within dedicated software modules or hardware modules configured for performing the techniques of this disclosure. Even if implemented in software, the techniques may use hardware such as a processor to execute the software, and a memory to store the software. In any such cases, the computers described herein may define a specific machine that is capable of executing the specific functions described herein. Also, the techniques could be fully implemented in one or more circuits or logic elements, which could also be considered a processor.

(150) In one or more examples, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over, as one or more instructions or code, a computer-readable medium and executed by a hardware-based processing unit. Computer-readable media may include computer-readable storage media, which corresponds to a tangible medium such as data storage media, or communication media including any medium that facilitates transfer of a computer program from one place to another, e.g., according to a communication protocol. In this manner, computer-readable media generally may correspond to (1) tangible computer-readable storage media, which is non-transitory or (2) a communication medium such as a signal or carrier wave. Data storage media may be any available media that can be accessed by one or more computers or one or more processors to retrieve instructions, code and/or data structures for implementation of the techniques described in this disclosure. A computer program product may include a computer-readable medium.

(151) By way of example, and not limitation, such computer-readable storage media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage, or other magnetic storage devices, flash memory, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if instructions are transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. It should be understood, however, that computer-readable storage media and data storage media do not include connections, carrier waves, signals, or other transient media, but are instead directed to

non-transient, tangible storage media. Disk and disc, as used, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc, where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

(152) Instructions may be executed by one or more processors, such as one or more digital signal processors (DSPs), general purpose microprocessors, application specific integrated circuits (ASICs), field programmable logic arrays (FPGAs), tensor processing units (TPUs), neuromorphic chips, vector accelerators, or other equivalent integrated or discrete logic circuitry. Accordingly, the term “processor”, as used may refer to any of the foregoing structure or any other structure suitable for implementation of the techniques described. In addition, in some aspects, the functionality described may be provided within dedicated hardware and/or software modules. Also, the techniques could be fully implemented in one or more circuits or logic elements.

(153) The techniques of this disclosure may be implemented in a wide variety of devices or apparatuses, including a wireless handset, an integrated circuit (IC) or a set of ICs (e.g., a chip set). Various components, modules, or units are described in this disclosure to emphasize functional aspects of devices configured to perform the disclosed techniques, but do not necessarily require realization by different hardware units. Rather, as described above, various units may be combined in a hardware unit or provided by a collection of interoperative hardware units, including one or more processors as described above, in conjunction with suitable software and/or firmware.

(154) It is to be recognized that depending on the example, certain acts or events of any of the methods described herein can be performed in a different sequence, may be added, merged, or left out altogether (e.g., not all described acts or events are necessary for the practice of the method). Moreover, in certain examples, acts or events may be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors, rather than sequentially.

(155) In some examples, a computer-readable storage medium includes a non-transitory medium. The term “non-transitory” indicates, in some examples, that the storage medium is not embodied in a carrier wave or a propagated signal. In certain examples, a non-transitory storage medium stores data that can, over time, change (e.g., in RAM or cache).

(156) Various examples have been described. These and other examples are within the scope of the following claims.

LIST OF ELEMENTS

(157) A Computing Device B Computing Device **100** System **101** Background **105** Three-Dimensional (3D) Space **110** Sensor **111** Field of View (FOV) **112** Point Cloud Data Set **114** Data Point **114**P Data Point Parameters **116** Data Point Distance **120** Processor **125** Output **130** Rays **130**C Corresponding Ray **132** Azimuth **134** Elevation **140** Peak **140**C Containing Peak **140**N New Peak **140**P Peak Parameters **142** Peak Distance **142**R Peak Distance **142**N Peak Distance **143**A Initial Peak Distance **143**B Updated Peak Distance **144** Peak Height **144**N Peak Height **145** Predetermined Initial Value **146** Peak Increment Value **150** Catchment Region **150**A First Center Match Region **150**B Second Center Match Region **152** Catchment Distance **152**A First Center Match Distance **152**B Second Center Match Distance **152**U Updated Catchment Distance **154** Center Match **154**A Center Peak Count **156** Fringe Match **156**A Fringe Peak Count **158** Invalid Match **160** Expected Noise Distribution **160**P Noise Parameters **165** Expected Noise Distribution **180** Point Cloud Fusion Module **185** Fused Cloud Data Set **190** Object Detection Module **195** Perception Output **200** Regression Model **210** Parameters **212** Estimated Parameters **214** Updated Parameters **220** Difference Catchment Distance **230** Sum Catchment Distance **250** Flow Diagram **252** Block **254** Block **256** Block **258** Block **260** Flow Diagram **270** Flow Diagram **272** Block **274** Block **276** Block **278** Block **279** Block **280** Block **282** Block **284** Block **300** Method **302** Step **304** Step **304** Step **306** Step **308** Step **310** Step **312** Step **314** Step **316** Step **314** Step **318** Step **320** Step **322** Step

Claims

1. A method for determining a background in a three-dimensional (3D) space, the method comprising: receiving, via a sensor, a point cloud data set for the 3D space, wherein the point cloud data set comprises a plurality of data points; dividing the 3D space into a plurality of rays extending from the sensor, wherein each ray comprises an azimuth and an elevation with respect to the sensor, and wherein each data point is enclosed by a corresponding ray from the plurality of rays; defining a plurality of peaks for each ray from the plurality of rays, wherein each peak from the plurality of peaks is located at a peak distance from the sensor and comprises a peak height equal to a predetermined initial value; defining a catchment region for each peak from the plurality of peaks for each ray from the plurality of rays, wherein the catchment region for each peak comprises a catchment distance from the corresponding peak towards the sensor and the catchment distance from the corresponding peak away from the sensor; wherein, for each data point from the plurality of data points, the method further comprises: determining the corresponding ray from the plurality of rays enclosing the data point; determining a data point distance of the data point from the sensor; determining a peak increment value; determining a containing peak from the plurality of peaks of the corresponding ray for which the data point lies within the catchment region of the containing peak; incrementing the peak height of the containing peak by the peak increment value; and defining a new peak comprising a peak height equal to the peak increment value and a peak distance equal to the data point distance if the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray; and updating the catchment distance of the catchment region of each of the plurality of peaks of each of the plurality of rays.
2. The method of claim 1, wherein the catchment region for a peak from the plurality of peaks for each ray from the plurality of rays is defined based upon the peak distance of the peak.
3. The method of claim 1, wherein the catchment region for a peak from the plurality of peaks for each ray from the plurality of rays is defined based upon an expected noise distribution of at least one of one or more distance noise parameters of the sensor and one or more environmental parameters of the 3D space.
4. The method of claim 1, wherein the catchment region for a peak from the plurality of peaks for each ray from the plurality of rays is defined based upon an expected noise distribution of a distance noise at a distance from the sensor.
5. The method of claim 1, wherein the catchment distance of the catchment region is updated after determining if a data point from the plurality of data points lies within the catchment region of the containing peak or if the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray for a predetermined number of data points from the plurality of data points.
6. The method of claim 1, further comprising storing the data point distance of the data point in a statistical data pool when the data point lies within the catchment region of the containing peak.
7. The method of claim 6, wherein the catchment distance of the catchment region is updated after a total number of the data point distances stored in the statistical data pool is equal to a predefined number.
8. The method of claim 7, further comprising emptying the statistical data pool after the total number of the data point distances stored in the statistical data pool is equal to the predefined number.
9. The method of claim 1, the method further comprising: defining a first center match region for each peak from the plurality of peaks for each ray from the plurality of rays, wherein the first center match region comprises a first center match distance from the corresponding peak towards the sensor and the first center match distance from the corresponding peak away from the sensor, and wherein the first center match distance is a first fraction of the catchment distance; and

defining a second center match region for each peak from the plurality of peaks for each ray from the plurality of rays, wherein the second center match region comprises a second center match distance from the corresponding peak towards the sensor and the second center match distance from the corresponding peak away from the sensor, wherein the second center match distance is a second fraction of the catchment distance, and wherein the second fraction is greater than the first fraction.

10. The method of claim 9, wherein, for each data point from the plurality of data points, the method further comprises: classifying the data point as a center match if the data point lies within the first center match region for the containing peak; classifying the data point as a fringe match if the data point is outside the first center match region for the containing peak but lies within the second center match region for the containing peak; classifying the data point as an invalid match if the data point is outside the second center match region for the containing peak but lies within the catchment region of the containing peak; and storing the data point distance of the data point in a statistical data pool if the data point is classified as the center match or the fringe match.

11. The method of claim 10, further comprising: determining a center peak count of a total number of peaks having the center matches; determining a fringe peak count of a total number of peaks having the fringe matches; and updating the catchment distance of the catchment region for each peak from the plurality of peaks for each ray from the plurality of rays based upon a ratio of the center peak count to the fringe peak count.

12. The method of claim 1 further comprising: defining a regression model for the catchment distance of the catchment region, wherein the regression model is a function of the peak distance, and wherein the regression model comprises a plurality of parameters; for each center match of the peak, determining a difference catchment distance as a difference between the catchment distance and a product of the catchment distance and a catchment region update size; for each fringe match of the peak, determining a sum catchment distance as a sum of the catchment distance and a product of the catchment distance and the catchment region update size; determining a plurality of estimated parameters for the regression model based on the difference catchment distances and the sum catchment distances and the peak distances of the plurality of peaks; determining a plurality of updated parameters for the regression model based on the plurality of parameters and the plurality of estimated parameters for the regression model; and updating the catchment distance of the catchment region based on the plurality of updated parameters.

13. The method of claim 1, further comprising defining at least one catchment region update size for the catchment region of each peak from the plurality of peaks, and wherein the catchment distance of the containing peak is updated further based upon the at least one catchment region update size of the containing peak.

14. The method of claim 1 further comprising defining a regression model for the catchment distance of the catchment region, wherein the regression model is a function of at least one of one or more peak parameters, one or more data point parameters, and one or more noise parameters.

15. The method of claim 1, further comprising providing the updated the catchment distance of the catchment region for each peak from the plurality of peaks for each ray from the plurality of rays to a sensor monitoring system.

16. A system for determining a background in a three-dimensional (3D) space, the system comprising: a sensor configured to generate a point cloud data set for the 3D space, wherein the point cloud data set comprises a plurality of data points; and a processor communicably coupled to the sensor, the processor configured to: receive the point cloud data set from the sensor; divide the 3D space into a plurality of rays extending from the sensor, wherein each ray comprises an azimuth and an elevation with respect to the sensor, and wherein each data point is enclosed by a corresponding ray from the plurality of rays; define a plurality of peaks for each ray from the plurality of rays, wherein each peak from the plurality of peaks is located at a peak distance from the sensor and comprises a peak height equal to a predetermined initial value; and define a

catchment region for each peak from the plurality of peaks for each ray from the plurality of rays, wherein the catchment region for each peak comprises a catchment distance from the corresponding peak towards the sensor and the catchment distance from the corresponding peak away from the sensor; wherein, for each data point from the plurality of data points, the processor is further configured to: determine the corresponding ray from the plurality of rays enclosing the data point; determine a data point distance of the data point from the sensor; determine a peak increment value; determine a containing peak from the plurality of peaks of the corresponding ray for which the data point lies within the catchment region of the containing peak; increment the peak height of the containing peak by the peak increment value; and define a new peak comprising a peak height equal to the peak increment value and a peak distance equal to the data point distance if the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray; and wherein the processor is further configured to update the catchment distance of the catchment region of each of the plurality of peaks of each of the plurality of rays.
17. The system of claim 16, wherein the catchment region for a peak from the plurality of peaks for each ray from the plurality of rays is defined based upon the peak distance of the peak.
18. The system of claim 16, wherein the catchment region for a peak from the plurality of peaks for each ray from the plurality of rays is defined based upon an expected noise distribution of at least one of one or more distance noise parameters of the sensor and one or more environmental parameters of the 3D space.
19. The system of claim 16, wherein the processor is configured to update the catchment distance of the catchment region after determining if a data point from the plurality of data points lies within the catchment region of the containing peak or if the data point is outside the catchment region of each of the plurality of peaks of the corresponding ray for a predetermined number of data points from the plurality of data points.
20. The system of claim 16, wherein the processor is further configured to: store the data point distance of the data point in a statistical data pool when the data point lies within the catchment region of the containing peak; update the catchment distance of the catchment region after a total number of the data point distances stored in the statistical data pool is equal to a predefined number; and empty the statistical data pool after the total number of the data point distances stored in the statistical data pool is equal to the predefined number.