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(54) Title: SYSTEMS AND METHODS FOR COLLISION DETECTION USING A CONNECTED LIGHTING SYSTEM

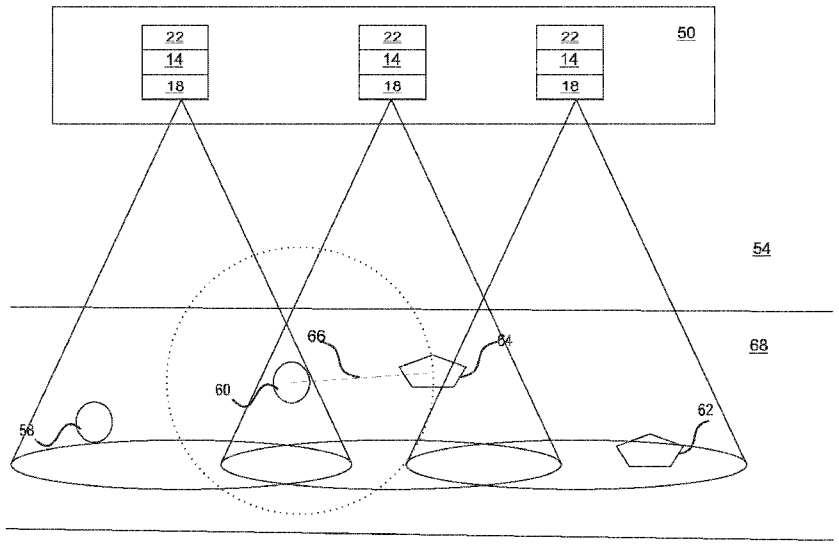


Fig. 2

(57) Abstract: The present disclosure is directed to inventive systems and methods for use in a connected lighting network for collision detection. The connected lighting system for near miss and collision detection includes one or more lighting fixtures, one or more radar sensors, and one or more controllers. The radar sensors are configured to collect data related to position and speed of a plurality of objects within an environment at a first time. The controllers are configured to receive data from the one or more sensors, predict position and speed of the first object at a second time, determine whether the first object is within a predetermined range for near miss or collision with a second object, and provide a signal to an alarm output if the first object is within the predetermined range for near miss or collision with the second object.

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SYSTEMS AND METHODS FOR COLLISION DETECTION USING A CONNECTED LIGHTING SYSTEM

FIELD OF THE INVENTION

The present disclosure is directed to systems and methods for near miss and collision detection within an environment using radar sensors in a connected lighting network.

BACKGROUND

In industrial environments, such as warehouses or manufacturing facilities, damage or injury caused by collisions can be catastrophic and costly. The injury or damage could be caused by collisions between people and machinery operated by individuals, such as a forklift, or between people and autonomous machinery, such as robots, which are becoming more and more widely used in the industrial environment. Thousands of collisions take place every year in the United States alone. Therefore, improving the safety of an industrial workplace is critical.

Cameras, LiDAR, Time of Flight (ToF), and other sensors can be used for near miss or collision detection, but cameras raise privacy issues, and they are not permitted in some countries. Thermopile sensors raise fewer privacy issues, but the ranges for thermopile sensors are typically less than 6 meters. LiDAR or ToF sensors have been widely used in the automatic driving industry, but their cost is still too high for high volume use, such as for use in a large grid needed for detection in large industrial work environments. In addition, the performance of LiDAR or ToF sensors can be severely impacted by weather such as rain or snow.

Accordingly, there is a continued need in the art for systems and methods that improve near miss and collision detection.

SUMMARY OF THE INVENTION

The present disclosure is directed to inventive systems and methods for collision detection using radar sensors with a connected lighting system. For example, embodiments of the present invention are directed to improved detection of collisions and

near misses to improve safety for industrial workplaces. Various embodiments and implementations herein are directed to a collision detection system including one or more lighting fixtures, one or more radar sensors, and one or more controllers. The term "collision detection" refers to both the detection of current and future collisions and the detection of current and future near misses, where two objects are in close enough proximity to each other that a collision may occur.

Generally, in one aspect, a method for collision detection within an environment using a connected lighting network having a plurality of radar sensors is provided. The method involves obtaining, via at least one of the plurality of radar sensors, information about a first object within the environment including speed and position of the first object at a first time. The speed and position of the first object at a second time is predicted by the connected lighting network. Whether the first object is within a predetermined range for near miss or collision with a second object is determined by the connected lighting network. If the first object is within the predetermined range for near miss or collision with the second object, an alarm is provided within the environment.

According to an embodiment, the method further provides for the lighting network to comprise a plurality of lighting fixtures.

According to an embodiment, the method further involves tracking multiple objects within the environment and prioritizing which objects in the environment should be monitored to determine if they are within a predetermined range for near miss or collision.

According to an embodiment, the method further involves the step of generating a report identifying zones within the environment having one or more instances of near miss or collision between the first object and the second object.

According to an embodiment, the method further involves the step of providing data relating to one or more instances of near miss or collision between the first object and the second object to the first object or second object.

According to an embodiment, the method further provides for the plurality of radar sensors to comprise a first set of radar sensors positioned on one or more surfaces within the environment and configured to have vertical sensing coverage of objects within the environment.

According to an embodiment, the method further provides for the plurality of radar sensors to comprise a second set of radar sensors positioned to have horizontal sensing coverage on a surface or structure within the environment.

According to an embodiment, the method further provides for the first object and the second object to be both movable within the environment.

According to an embodiment, the method further provides for the first object to be movable within the environment and the second object to be fixed within the environment.

Generally, in another aspect, a method for collision detection within an environment using a connected lighting network having a plurality of radar sensors is provided. The method involves obtaining, via at least one of the plurality of radar sensors, information about a plurality of objects within the environment, including speed and position of the first object at a first time. Each of the plurality of objects is classified by the connected lighting network. The speed and position of each of the plurality of objects at a second time is predicted by the connected lighting network. Whether a first object is within a predetermined range for near miss or collision with a second object is determined by the connected lighting network. If the first object is within the predetermined range for near miss or collision with the second object, the severity level or priority level of the determined near miss or collision is determined. An alarm is provided within the environment based on the determined severity or priority level.

According to an embodiment, the method further provides for the lighting network to comprise a plurality of lighting fixtures.

According to an embodiment, the method further involves tracking multiple objects within the environment and prioritizing which objects in the environment should be monitored to determine if they are within a predetermined range for near miss or collision.

According to an embodiment, the method further involves the step of generating a report identifying zones within the environment having one or more instances of near miss or collision between the first object and the second object.

According to an embodiment, the method further involves the step of providing data relating to one or more instances of near miss or collision between the first object and the second object to the first object or second object.

Generally, in a further, a connected lighting system for collision detection is provided. The system includes (i) one or more lighting fixtures, (ii) one or more radar sensors, and (iii) one or more controllers. The radar sensors are configured to collect data related to position and speed of a plurality of objects within an environment at a first time. The controllers are configured to receive data from the one or more sensors, predict position and speed of the first object at a second time, determine whether the first object is within a

predetermined range for near miss or collision with a second object; and provide a signal to an alarm output if the first object is within the predetermined range for near miss or collision with the second object.

It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below (provided such concepts are not mutually inconsistent) are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter disclosed herein. It should also be appreciated that terminology explicitly employed herein that also may appear in any disclosure incorporated by reference should be accorded a meaning most consistent with the particular concepts disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

FIG. 1 is a schematic illustration of a connected lighting system according to aspects of the present disclosure.

FIG. 2 is a schematic illustration of an exemplary connected network according to aspects of the present disclosure.

FIG. 3 is a schematic illustration of an exemplary lighting network according to aspects of the present disclosure.

FIG. 4 is an illustration of an exemplary plurality of radar sensors having vertical sensing coverage.

FIG. 5 is an illustration of an exemplary plurality of radar sensors having horizontal sensing coverage.

FIG. 6 is flow chart showing examples of steps in the operation of a system for collision detection according to aspects of the present disclosure.

FIG. 7 is a flow chart showing examples of steps in the operation of a system according to aspects of the present disclosure.

FIG. 8 is flow chart showing examples of steps in the operation of a system for collision detection according to aspects of the present disclosure.

FIG. 9 is a flow chart showing examples of steps in the operation of a system according to aspects of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

In view of the foregoing, various embodiments and implementations are directed to a connected lighting system and methods thereof using radar sensors for collision and near miss detection. The connected lighting system for collision detection comprises one or more lighting fixtures, one or more radar sensors, and one or more controllers. The radar sensors are configured to collect data related to position and speed of a plurality of objects within an environment at a first time. The controllers are configured to receive data from the one or more sensors, predict position and speed of the first object at a second time, determine whether the first object is within a predetermined range for near miss or collision with a second object, and provide a signal to an alarm output if the first object is within the predetermined range for near miss or collision with the second object.

Referring to FIG. 1, a connected lighting system 10 for collision detection is illustrated. The system includes three lighting fixtures 14A, 14B, 14C, and each lighting fixture 14A, 14B, 14C has an adjacent radar sensor 18A, 18B, 18C. The connected lighting system 10 in this example has three controllers 22A, 22B, 22C. The controllers 22A, 22B, 22C are adjacent to the radar sensors and are interconnected in a manner to facilitate the transport of information with one or more of the radar sensors 18A, 18B, 18C.

The terms “lighting unit” and “lighting fixture” are interchangeably used herein to refer to an apparatus including one or more light sources of same or different types. A given lighting unit may have any one of a variety of mounting arrangements for the light source(s), enclosure/housing arrangements and shapes, and/or electrical and mechanical connection configurations. Additionally, a given lighting unit optionally may be associated with (e.g., include, be coupled to and/or packaged together with) various other components (e.g., control circuitry) relating to the operation of the light source(s). An “LED-based lighting unit” refers to a lighting unit that includes one or more LED-based light sources as discussed above, alone or in combination with other non LED-based light sources.

The term “light source” should be understood to refer to any one or more of a variety of radiation sources, including, but not limited to, LED-based sources (including one or more LEDs as defined above), incandescent sources (e.g., filament lamps, halogen lamps), fluorescent sources, phosphorescent sources, high-intensity discharge sources (e.g., sodium vapor, mercury vapor, and metal halide lamps), lasers, other types of electroluminescent sources, pyro-luminescent sources (e.g., flames), candle-luminescent sources (e.g., gas mantles, carbon arc radiation sources), photo-luminescent sources (e.g., gaseous discharge

sources), cathode luminescent sources using electronic satiation, galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources, sonoluminescent sources, radioluminescent sources, and luminescent polymers.

A given light source may be configured to generate electromagnetic radiation within the visible spectrum, outside the visible spectrum, or a combination of both. Additionally, a light source may include as an integral component one or more filters (e.g., color filters), lenses, or other optical components. Also, it should be understood that light sources may be configured for a variety of applications, including, but not limited to, indication, display, and/or illumination.

The term "network" as used herein refers to any interconnection of two or more devices (including controllers or processors) that facilitates the transport of information (e.g. for device control, data storage, data exchange, etc.) between any two or more devices and/or among multiple devices coupled to the network. As should be readily appreciated, various implementations of networks suitable for interconnecting multiple devices may include any of a variety of network topologies and employ any of a variety of communication protocols. Additionally, in various networks according to the present disclosure, any one connection between two devices may represent a dedicated connection between the two systems, or alternatively a non-dedicated connection. In addition to carrying information intended for the two devices, such a non-dedicated connection may carry information not necessarily intended for either of the two devices (e.g., an open network connection). Furthermore, it should be readily appreciated that various networks of devices as discussed herein may employ one or more wireless, wire/cable, and/or fiber optic links to facilitate information transport throughout the network.

In the example of FIG. 1, the controller 22A includes a memory 26, a processor 30, a network interface 34, and an alarm interface 38. The memory 26 and the processor 30 may take any suitable form known in their respective arts that is useful for controlling, monitoring, and/or otherwise assisting in the operation of the radar sensor 18, including analyzing data from the radar sensor 18. It is to be understood that the controller 22 is shown schematically in FIG. 1 and may include any other components useful for controlling, monitoring, and/or otherwise assisting in the operation of the radar sensor 18, including analyzing data related to detection of an object. The network interface 34 may be a wireless transceiver or any other device that enables the lighting fixtures 14 (A, B, C) to communicate wirelessly with each other as well as other devices utilizing the same wireless

protocol standard and/or to otherwise monitor network activity. The network interface 34 may also use wire/cable and/or fiber optic links. The alarm interface 38 provides a signal to a visual or auditory alarm output 40.

In some cases the alarm signal may go to a computer terminal where a person uses the signal to send an alert or alter the movement of people or things in the environment.

FIG. 2 provides an example of a connected network 50 having a plurality of lighting fixtures 14 for collision detection within an environment 54. The network includes three lighting fixtures 14 and each lighting fixture 14 has an adjacent radar sensor 18. The connected network 50 in this example has three controllers 22. The controllers 22 are adjacent to the radar sensors and are interconnected in a manner to facilitate the transport of information with one or more of the radar sensors 18. The radar sensors are positioned on neighboring lighting fixtures and oriented to sense objects in the environment below the light fixtures. As shown in FIG. 2, the radar sensors are positioned at a distance so that the radar sensors provide complete coverage of the environment 54 in a horizontal direction along the floor 68 of the environment 54. The radar sensors are oriented downwards towards the floor 68 and can detect the movement of object 58 and object 62.

Referring to FIG. 2, the position and speed of object 58 at a first time can be determined by one or more radar sensors 18 in the connected network 50. The controller 22 keeps, maintains, processes information about the position and speed of object 58 over time. The connected network 50 is used to make predictions about speed and position of object 58 at a second time. In another example, the connected network 50 predicts the position and speed of object 58 at a second time based on the detected position and speed of object 58 at a first time. The controllers 22 can store data relating to the position and speed of an object at one time, analyze the data, communicate the data to neighboring controllers, and implement prediction algorithms. The prediction algorithms can rely on the data accumulated from multiple radar sensors 18 gathering data within an environment 54 to predict the future speed and position of an object.

As shown in the FIG. 2, object 58 is predicted to be at position 60 at a second time. Position 60 is within a predetermined range 66 of the position of object 62 at a second time, position 64. The connected network 50 will send an alarm within the environment 54.

In the example, the connected network 50 is used to predict the position of object 62 at a second time, position 64, in the same manner that the position of object 58 at a second time, position 60, was predicted.

In a typical industrial environment where ceilings are about 40 feet (3.6 meters) high, a radar sensor can have a range greater than 60 feet (20 meters). Radar sensors can perform well even in conditions such as low light or poor weather.

Individual radar sensors can track all moving objects in their range in an environment, such as a warehouse or a manufacturing facility. An individual radar sensor can easily track up to one hundred objects. Due to the wide bandwidth (2 GHz or 4 GHz), radar sensors can have a resolution of a few centimeters. This resolution can help the connected network predict the position of the two or more objects and detect incidences of near miss or collision in an environment.

FIG. 3 provides an example of a lighting network 70 having a plurality of lighting fixtures 14 for collision detection within an environment 54. The network includes three lighting fixtures 14 and each lighting fixture 14 has an adjacent radar sensor 18. The lighting network 50 in this example also has three controllers 22. The controllers 22 are adjacent to the radar sensors 14 and are interconnected in a manner to facilitate the transport of information with one or more of the radar sensors 18. The controllers 22 are also interconnected in a manner to facilitate the transport of information between two or more radar sensors 18 and/or controllers 22. The radar sensors 18 are positioned to detect the movement of object 72 and object 74 within the environment 54.

In the example illustrated in FIG. 3, object 74 is stationary and does not move with respect to the environment 54. The position and speed of object 72 are detected at a first time and a prediction is made about the speed and position of object 72 at a second time, position 73. The lighting network 70 is used to determine whether object 72 will be, at the second time, within a predetermined range 78 for collision or near miss with object 74. If object 72 is predicted to be at a position within the predetermined range 78 from the position of object 74, the lighting network 70 will provide for an alarm output 40 (show in FIG. 1) to be generated within the environment 54.

The predetermined distance for providing an alarm output 40 can be a distance that does not vary based on the type of objects or the speed of the objects predicted to be within the range for near miss or collision. Alternatively, the predetermined distance for providing an alarm output 40 may vary based on the type of objects or the speed of the objects predicted to be within the range for near miss or collision. Objects may be classified according to size, speed, or types based on identifiers, for example, identifiers such as Doppler shift object signatures. For example, as shown in FIG. 8, one example method of collision detection involves the step (520) of classifying objects in the environment that may

have a near miss or collision to determine the severity or priority level of the near miss or collision.

One example of a connected network 50 in which two radar sensors 18 are positioned on the lighting fixtures 14 of a warehouse is illustrated in FIG. 4. The radar sensors 18 are facing downwards towards the floor 68 of the environment 54, and they can sense objects moving across the floor 68 of the environment 54. The radar sensors have vertical sensing coverage, meaning that they can sense object in a vertical cone 86 from the lighting fixtures 14 on or near the ceiling and the floor 68. In the example illustrated in FIG. 5, additional radar sensors 18B are positioned on vertical structure or surface 82 of the environment and face to the side of the warehouse. These radar sensors 18 have horizontal sensing coverage and can detect objects in a horizontal cone 84 away from the radar sensor. The vertical cones 86 and horizontal cones 84 may be overlapping to provide complete coverage of a surface.

To better understand the various embodiments described herein, FIG. 6 is provided which includes a flowchart that depicts a method 100 for collision or near miss detection according to one example. At step 110, data about a first object in the environment is collected, and this data includes the position and speed of the first object at a first time. At step 120, the connected network 50 is used to predict the position and speed of the object at a second time. At step 130, the connected network 50 is used to determine whether the first object is within a predetermined range for near miss or collision with a second object. If the first object is within the predetermined range, the connected network provides for an alarm at step 150.

At optional step 150, a report is generated which identified zones within the environment having one or more instances of near miss or collision. This report may identify zones where the first and the second objects were predicted to be within the predetermined range for near miss or collisions. This report may aggregate and sort information about near miss and collision predictions relating to additional objects when identifying near miss and collision zones. At optional step 160, data relating to instances of near miss or collision between a first object and a second object is provided to the first object and/or the second object. This may be done to prevent present or future instances of near miss or collision. This data may also be provided to one or more additional objects so that the one or more additional objects can prevent future instances of near miss or collision by identifying hazards, planning routes, etc.

In an example, data regarding objects that are detected or tracked within the environment 54 is uploaded to a controller 22, which may not be local to the environment 54, and the accumulated information is used to generate a report that identifies incidences of near miss or collision. This report may be specific to a certain time window. This report can be used to improve the safety of the environment, for example, by individuals or objects operating within the environment to avoid collisions and near misses. In another example, information about objects that are detected or tracked in the environment can be fed to individuals or objects operating within the environment, for example forklift drivers or autonomous robots, to improve their route planning and improve overall efficiency in the environment. Additionally, individuals or objects outside the environment can use the report to plan routes and manage activities within the environment, such as optimizing moving paths or the layout in the environment.

An example of another optional step is shown in FIG. 7. In this example, multiple objects are within the environment, and the position and speed of each object at a first time is obtained. The system can prioritize certain objects over other objects in predicting their speed and position at a second time or in determining whether the prioritized objects are within a predetermined range for near miss or collision, as shown at step 170.

To better understand the various embodiments disclosed herein, FIG. 8 is provided which includes a flowchart that depicts a method 500 of collision or near miss detection according to one example. At step 510, data about two or more object in the environment is collected, and this data includes the position and speed of the each object at a first time. At step 520, each of the objects is classified by the connected network.

As an example, each of the plurality of objects may be classified by a distributed object classification method. For example, data obtained from radar sensors 18 from adjacent lighting fixtures 14 can be used to obtain a signature for the objects being classified, and machine learning algorithms can be used to classify the objects. Also, the radar sensors 18 can obtain Doppler shift object signatures to help classify an object. The lighting fixtures 14 transmit the Doppler shifts noticed locally by their radar sensors 18 to a central controller 22. The central controller 22 collects all the Doppler shift data streams and synchronizes them if needed. The central controller 22 has spatial-temporal patterns of different Doppler shifts observed by various lighting fixtures 14 in an environment 54. The spatial-temporal patterns of Doppler shifts are then used as input to a controller 22 which classifies objects. This controller 22 is trained using labelled signatures of different objects.

As an example, a forklift will produce a certain pattern of Doppler shifts, and this pattern of Doppler shifts is distinct from the pattern produced by a human being.

Referring to FIG. 8, at step 530, the connected network 50 is used to predict the position and speed of each of the objects at a second time. At step 540, the connected network 50 is used to determine whether a first object is within a predetermined range for near miss or collision with a second object. If the first object is within the predetermined range, the connected network is used to determine the severity or priority level of the determined near miss or collision at step 550. At step 560 the connected network 50 provides for an alarm based on the determined severity or priority level. At optional step 570, a report is generated which identified zones within the environment having one or more instances of near miss or collision. This report may identify zones where the first and the second objects were predicted to be within the predetermined range for near miss or collisions. This report may, alternatively, aggregate and sort information about near miss and collision determinations relating to additional/many other objects when identifying zones. In another example, the report identifies zones and also determines a severity of priority level for the zones. At optional step 580, data relating to instances of near miss or collision between a first object and a second object is provided to the first object and/or the second object. This may be done to prevent present or future instances of near miss or collision from happening. This data may also be provided to one or more additional objects so that the one or more additional objects can prevent future instances of near miss or collision by identifying hazards, planning routes, etc.

An example of another optional step is shown in FIG. 9. In this example, multiple objects are within the environment, and the position and speed of each object at a first time is obtained. The system can prioritize certain objects over other objects in predicting their speed and position at a second time or in determining whether the prioritized objects are within a predetermined range for near miss or collision, as shown at step 590.

In another example, collision and near miss detection using a connected network 50 may involve local tracking, global tracking, and cloud data analytics. In an example, information about the position and speed of an object is uploaded to a controller 22, a local edge device for networked global tracking. The local edge device receives data regarding the position and speed of all objects detected by each individual radar sensor 18. The local edge device then performs global tracking. For example, two objects are moving towards each other, and the two objects are tracked by two different radar sensors 18 that are adjacent to each other. The local edge device passes a tracked object from one radar sensor to

a second radar sensor when the object moves into the tracking area of the second radar sensor. The local edge device has the computational power to perform real-time processing of the data from hundreds or thousands of radar sensors.

An illustration of the use of radar sensors 18 within a connected lighting network 50 is shown in FIG. 2. Each individual lighting fixture 14 with a radar sensor 18 detects and tracks objects in its covered area. In an example, data about the objects tracked, including data referring to the position and speed of the objects at a time, is uploaded to a local edge device for real-time global tracking. The information is then uploaded from a local edge device to the cloud to generate a near miss report. In another example, the controller and local edge device are used to prioritize which of multiple objects should be further evaluated for collision detection. The controller and local edge device can be used to send data regarding prioritized objects to the cloud for determination of whether the objects are within the predetermined range for near miss or collision detection. In an example, detection of near miss and collision does not happen in real time.

In an example, tracking algorithms known in the art can be used to predict the future position and speed of multiple objects in an environment. The tracking algorithm can be performed in the connected network, at the controllers that are adjacent and interconnected in a manner to facilitate the transport of information with the radar sensors.

For example, position and speed of an object at a future time can be modeled based on information about the position and speed of the object at a previous time. In the below equations, the relationship between the position and speed of an object at an index for time, k, and the position and speed of an object at an index for an earlier time, k-1, is shown.

$$\mathrm{X} = \begin{bmatrix} x \\ y \\ \dot{x} \\ \dot{y} \end{bmatrix}$$

$$\mathrm{X}_k = \mathrm{F}_{k,k-1}\mathrm{X}_{k-1} + v_{k-1}$$

$$\mathrm{Z}_k = \mathrm{H}_k\mathrm{X}_{k-1} + w_k$$

$\mathrm{F}_{k,k\text{-}1}$ is the state transition matrix, and $\mathrm{v}_{k\text{-}1}$ is the processing noise. Z_k is the observation from the radar sensor, H_k is the observation matrix, and W_k is the sensor noise. For all the elements in the above equations, the subscript k represents the index for the time. For a typical Kalman filter, it is assumed that $\mathrm{v}_{k\text{-}1}$ and w_k follow/have a Gaussian distribution. If the system cannot be modelled linearly with normal distribution for the noise, a different method may be used, such as Gaussian-sum filter or particle filter.

One generally known method in the art for tracking multiple objects in modern multiple target tracking systems is the use of multiple hypothesis tracking (MHT) algorithms. Observations from individual sensors, including, for example, information relating to the position and speed of objects, are received at regular intervals of time. These observations are considered for inclusion in existing tracks and for new tracks, which are used to track individual or groups of objects. As shown in Figure 2, the input from individual sensors will be assigned to existing tracks if the observations fall within a threshold or amount captured by the track gate, and the existing tracks will be considered updated. The global nearest neighbor (GNN) approach is a conventional method for assignment of input observations to existing tracks. If observations are not assigned to existing tracks, they will be used to initiate new tracks. As a next step in the algorithm, all of the tracks, whether newly updated existing track, existing tracks that were not updated, or new tracks, will be confirmed or deleted based on a low probability determination.

At another step, all remaining tracks will be checked to determine if any two or more tracks are already within a predetermined range for near miss or collision. The position and speed of each track for a next time will also be determined: $\mathbf{X}_k = f_{K|K-1}(\mathbf{X}_{k-1})$.

In one embodiment, if the predicted positions are within the predetermined range for near miss or collision, an alarm will be triggered. Alternatively, if two objects are within a predetermined range for near miss or collision, a pre-alarm may be triggered. This pre-alarm indicates that the objects should be examined with higher priority over the next time period being observed/tracked.

While several inventive embodiments have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or structures for performing the function and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the inventive embodiments described herein. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the inventive teachings is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific inventive embodiments described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, inventive embodiments may

be practiced otherwise than as specifically described and claimed. Inventive embodiments of the present disclosure are directed to each individual feature, system, article, material, kit, and/or method described herein. In addition, any combination of two or more such features, systems, articles, materials, kits, and/or methods, if such features, systems, articles, materials, kits, and/or methods are not mutually inconsistent, is included within the inventive scope of the present disclosure.

The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified. As used herein in the specification and in the claims, "or" should be understood to have the same meaning as "and/or" as defined above.

It should also be understood that, unless clearly indicated to the contrary, in any methods claimed herein that include more than one step or act, the order of the steps or acts of the method is not necessarily limited to the order in which the steps or acts of the method are recited.

CLAIMS:

1. A method (100) for collision detection within an environment (54) using a connected lighting network (50) having a plurality of radar sensors (18), the method comprising the steps of:

obtaining (110), via at least one of the plurality of radar sensors, information about a first object (58) within the environment (54) including speed and position of the first object (54) at a first time, the plurality of sensors comprising: a first set of radar sensors positioned to provide vertical sensing coverage of objects within the environment, and a second set of radar sensors positioned to provide horizontal sensing coverage of objects within the environment;

predicting (120), by the connected lighting network (50), speed and position of the first object at a second time (60);

determining (130) by the connected lighting network whether the first object (58) is within a predetermined range (66) for near miss or collision with a second object (62); and

providing an alarm within the environment (140) if the first object is within the predetermined range (66) for near miss or collision with the second object (62).

2. The method of claim 1, wherein the lighting network comprises a plurality of lighting fixtures (14).

3. The method of claim 1, further comprising tracking multiple objects within the environment and prioritizing which objects in the environment should be monitored to determine if they are within a predetermined range for near miss or collision (170).

4. The method of claim 1, further comprising the step of generating a report (150) identifying zones within the environment having one or more instances of near miss or collision between the first object and the second object.

5. The method of claim 1, further comprising the step of providing data relating to one or more instances of near miss or collision between the first object and the second object to the first object or second object (160).

6. The method of claim 1, wherein the first object (60) and the second object (64) are both movable within the environment (54).

7. The method of claim 1, wherein the first object (72) is movable within the environment (54) and the second object (74) is fixed within the environment (54).

8. A method (500) for collision detection within an environment (54) using a connected lighting network (50) having a plurality of radar sensors (18), the method comprising the steps of:

obtaining (510) via the plurality of sensors information about a plurality of objects (60,64) within the environment, including position and speed of each object, at a first time, the plurality of sensors comprising: a first set of radar sensors positioned to provide vertical sensing coverage of objects within the environment, and a second set of radar sensors positioned to provide horizontal sensing coverage of objects within the environment;

classifying, by the connected lighting network, each of the plurality of objects within the environment (520);

predicting by the connected lighting network the positon and speed of each object of the plurality of objects at a second time (530);

determining by the connected lighting network whether a first object is within a predetermined range for a near miss or collision with a second object of the plurality of objects (540);

determining a severity level or priority level (550) of the determined near miss or collision; and

providing an alarm (560) within the environment based on the determined severity or priority level if the first object is within the predetermined range for near miss or collision with the second object.

9. The method of claim 8, wherein the lighting network comprises a plurality of lighting fixtures (14).

10. The method of claim 8, further comprising the step of tracking multiple objects within the environment and prioritizing which objects in the environment should be monitored to determine if they are within a predetermined range for near miss or collision (590).

11. The method of claim 8, further comprising the step of generating a report identifying zones within the environment having one or more instances of near miss or collision between the first object and the second object (570).

12. The method of claim 8, further comprising the step of providing data relating to one or more instances of near miss or collision between a first object and a second object to the first object or second object (580).

13. A connected lighting system (10) for collision detection, comprising:
one or more lighting fixtures (14);
one or more radar sensors (18) configured to collect data related to position and speed of a plurality of objects within an environment at a first time, the one or more radar sensors comprising: a first set of radar sensors positioned to provide vertical sensing coverage of objects within the environment, and a second set of radar sensors positioned to provide horizontal sensing coverage of objects within the environment;
one or more controllers (22) configured to:
receive data from the one or more sensors (110);
predict position and speed of the first object at a second time (120);
determine whether the first object is within a predetermined range (66) for near miss or collision with a second object (130); and
provide a signal to an alarm output if the first object is within the predetermined range for near miss or collision with the second object (140).

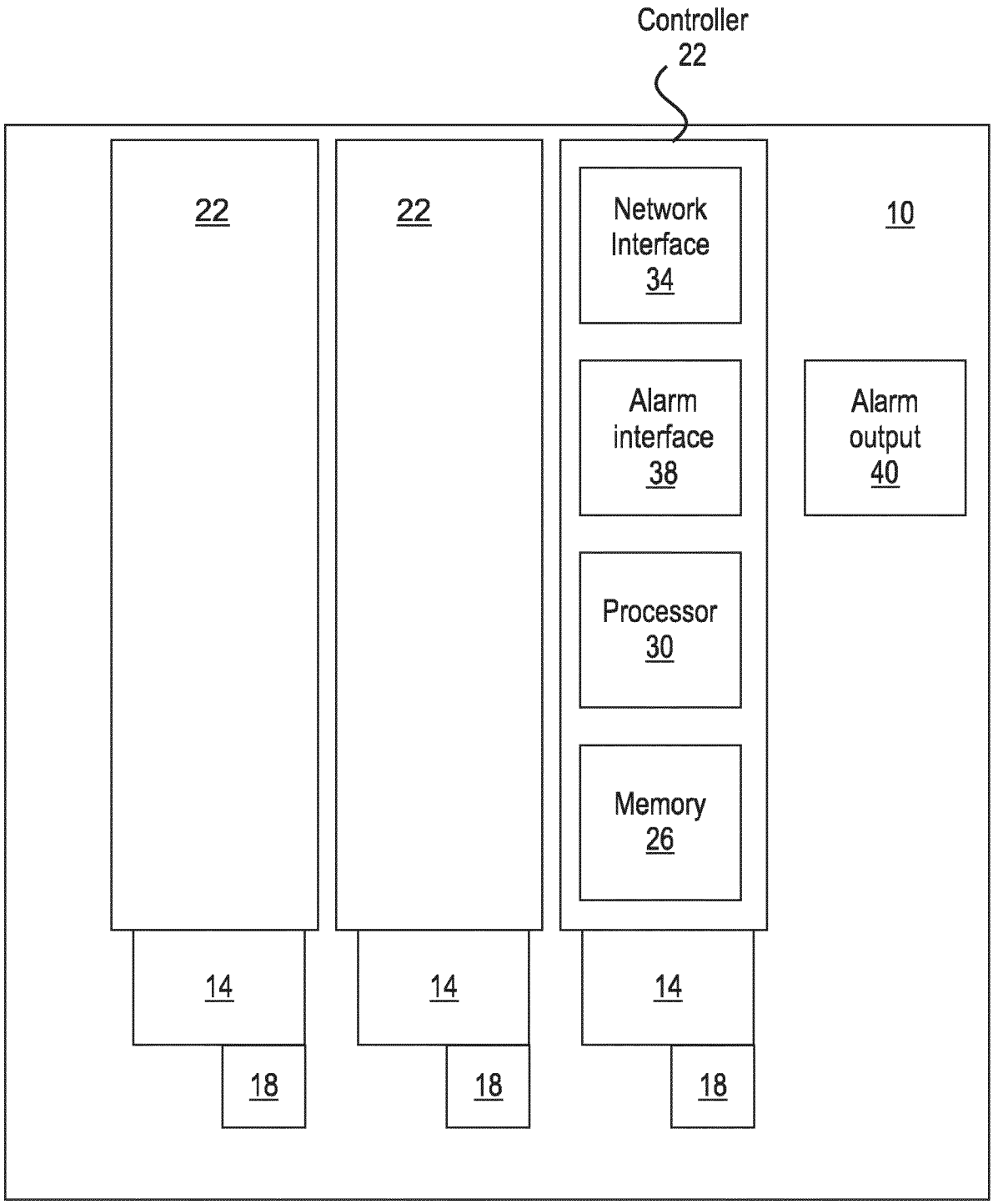

Controller
22
22
22
Network
Interface
34
10
Alarm
interface
38
Alarm
output
40
Processor
30
Memory
26
14
14
14
18
18
18

Fig. 1

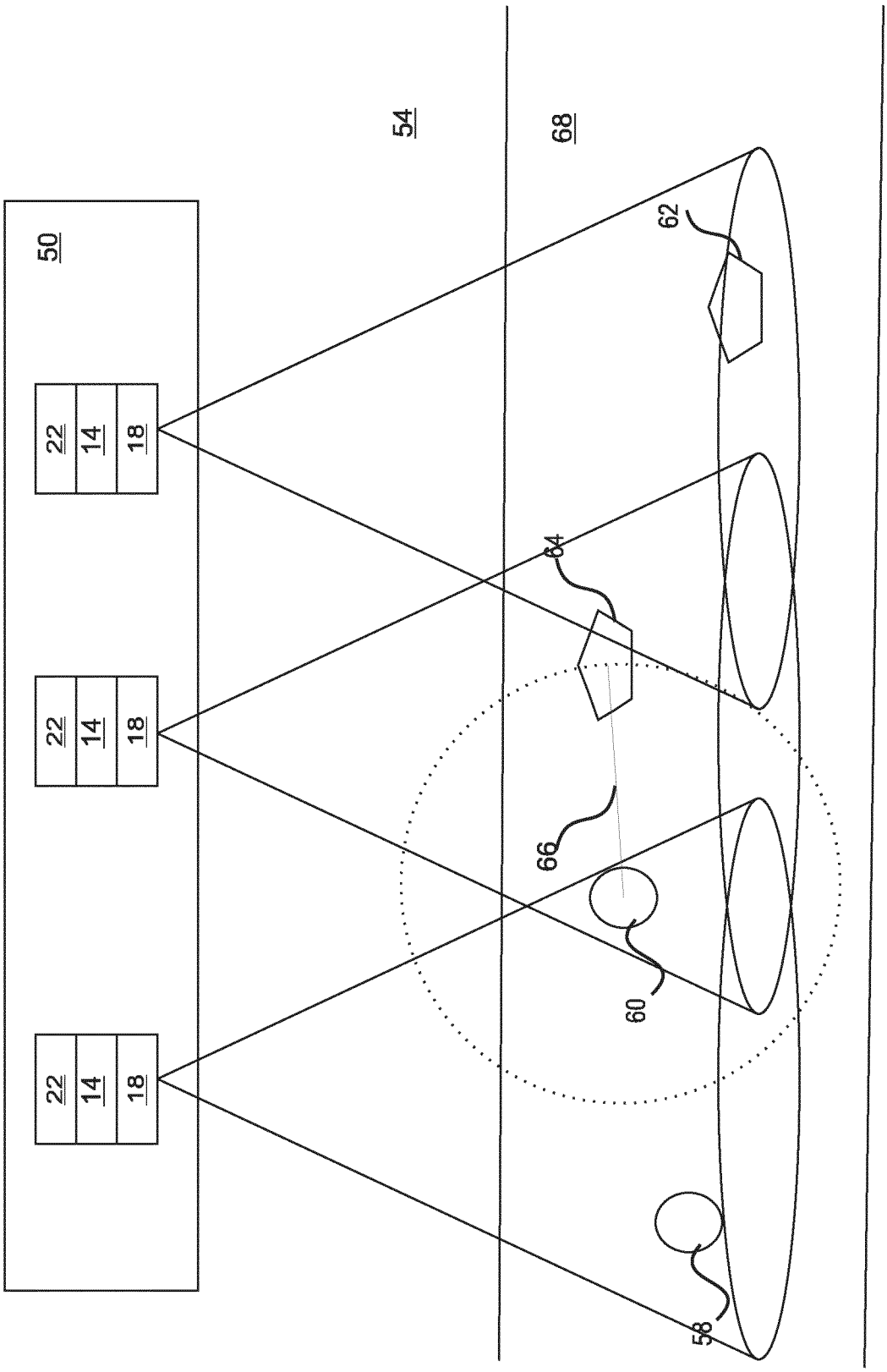


Fig. 2

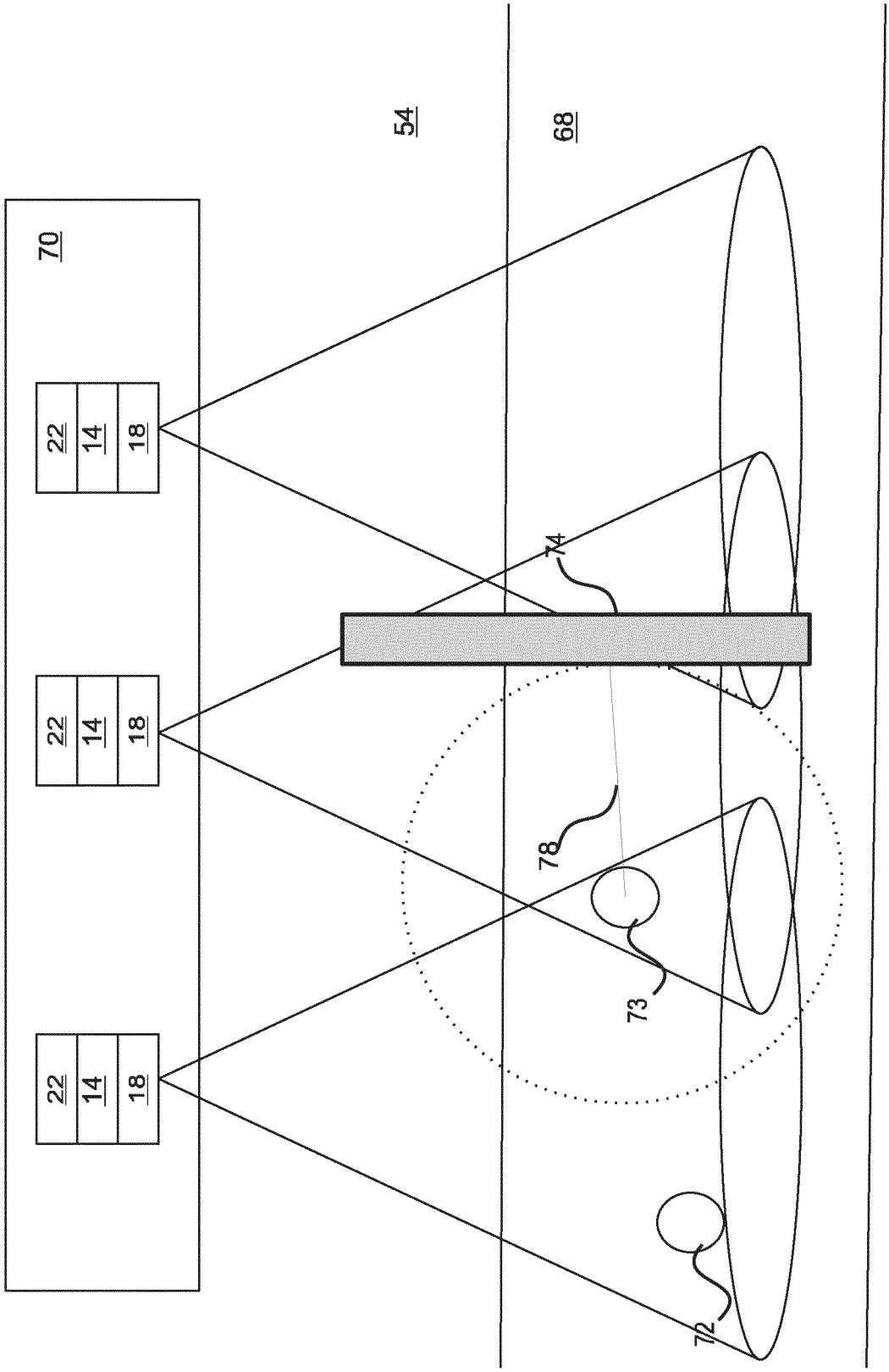


Fig. 3

Fig. 4

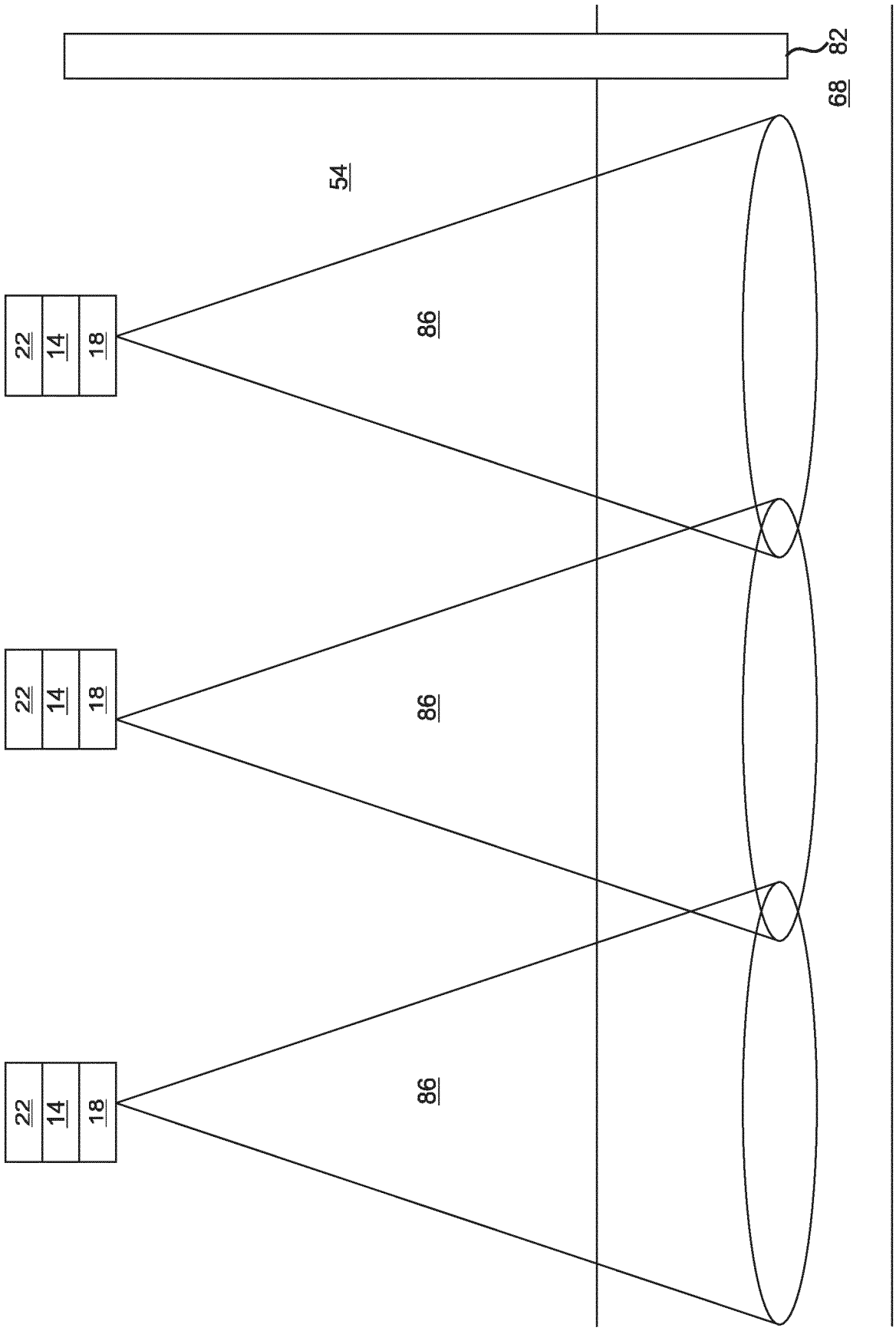
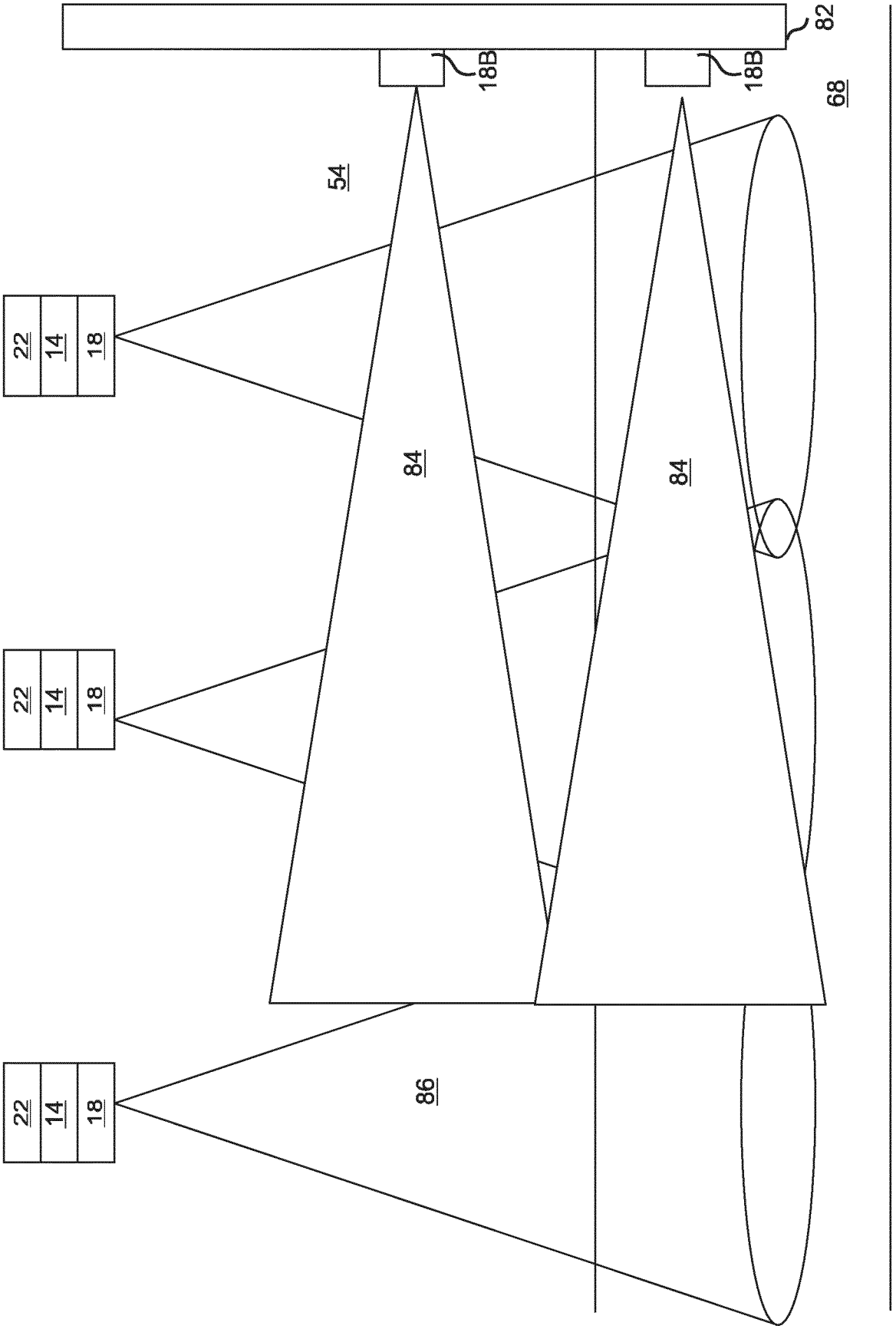


Fig. 5



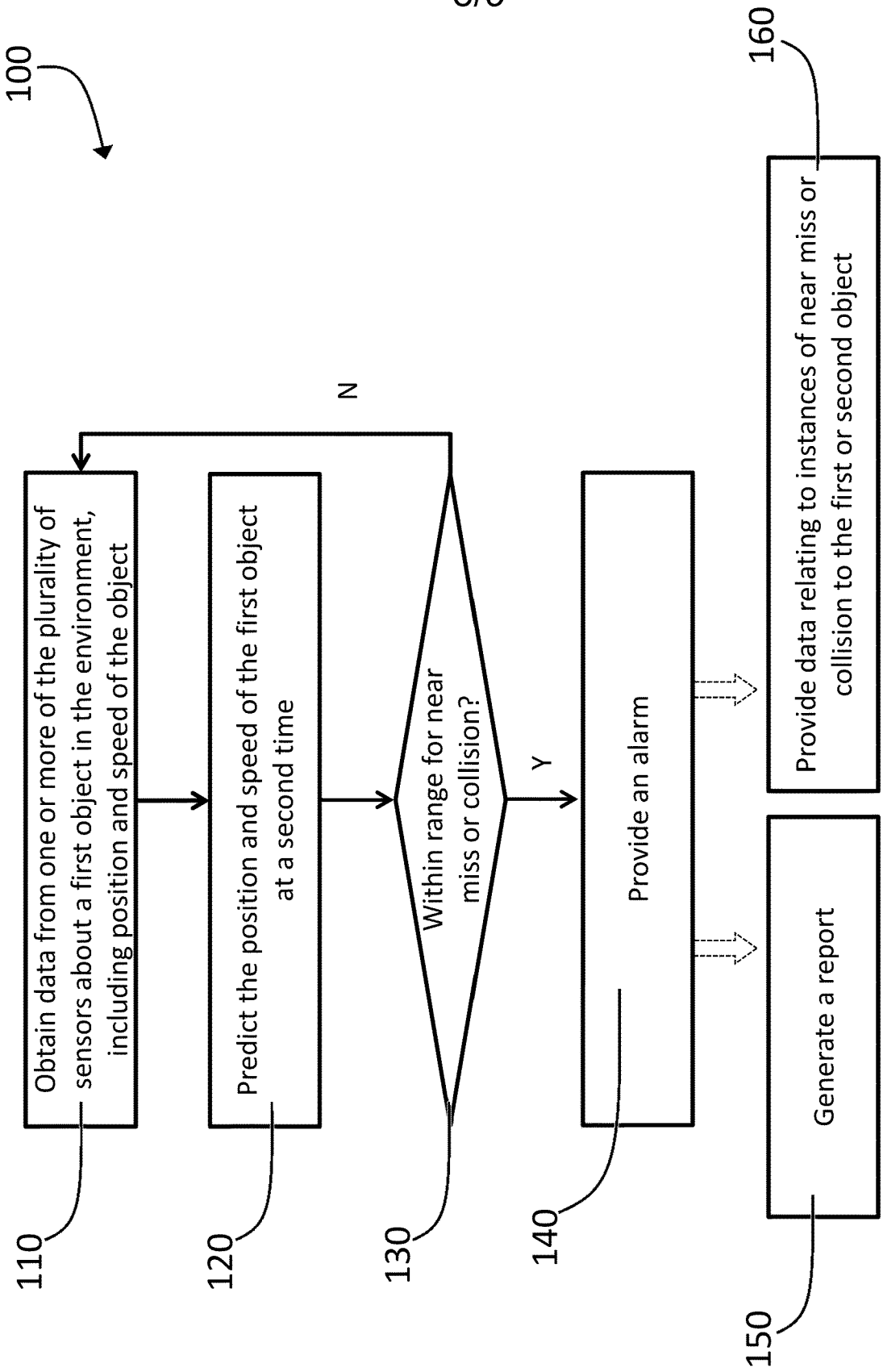

100
Obtain data from one or more of the plurality of sensors about a first object in the environment, including position and speed of the object
110
Predict the position and speed of the first object at a second time
120
Within range for near miss or collision?
130
N
Y
Provide an alarm
140
Generate a report
150
Provide data relating to instances of near miss or collision to the first or second object
160

FIG. 6

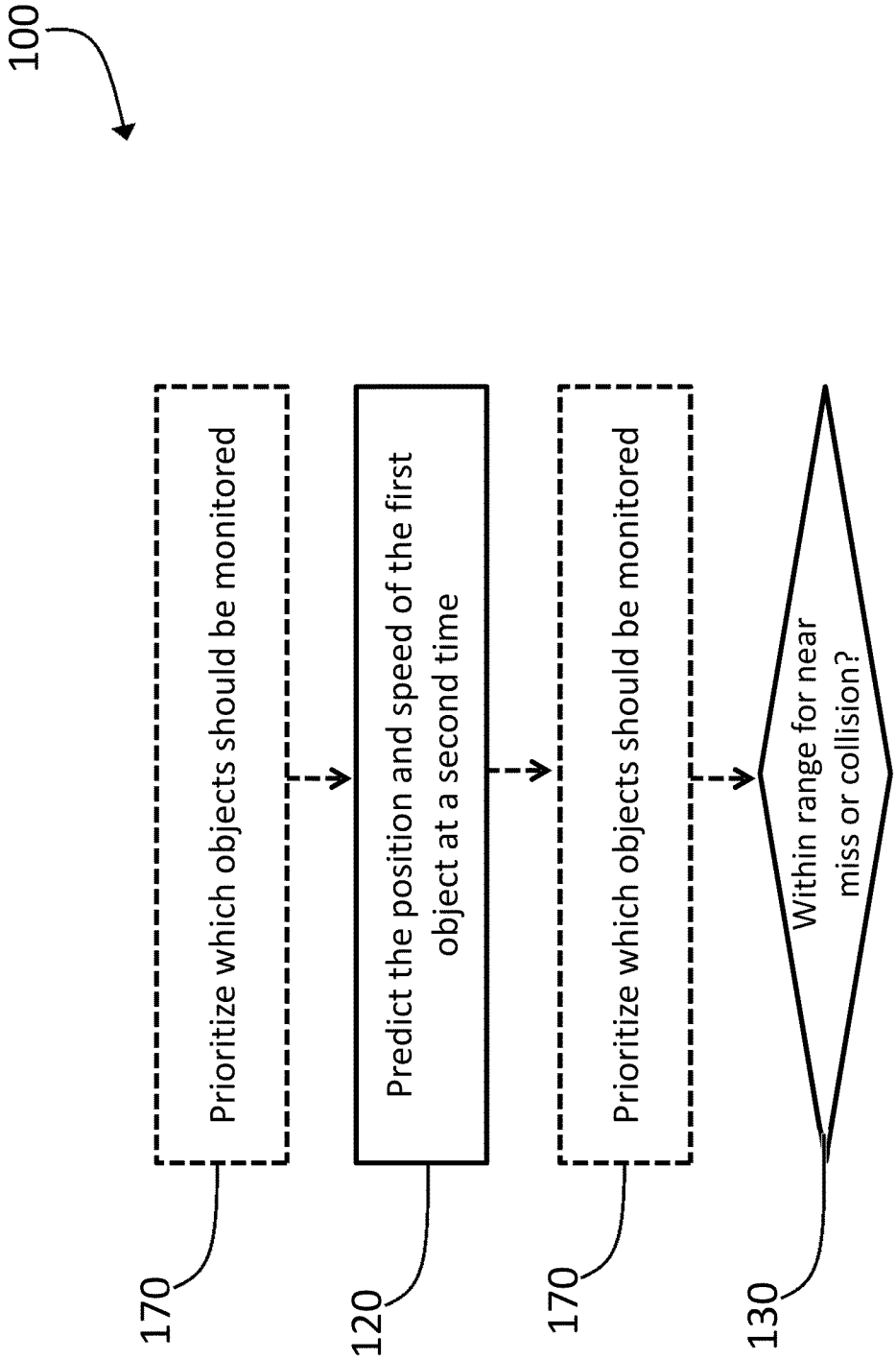

100
Prioritize which objects should be monitored
Predict the position and speed of the first object at a second time
Prioritize which objects should be monitored
Within range for near miss or collision?
170
120
170
130

FIG. 7

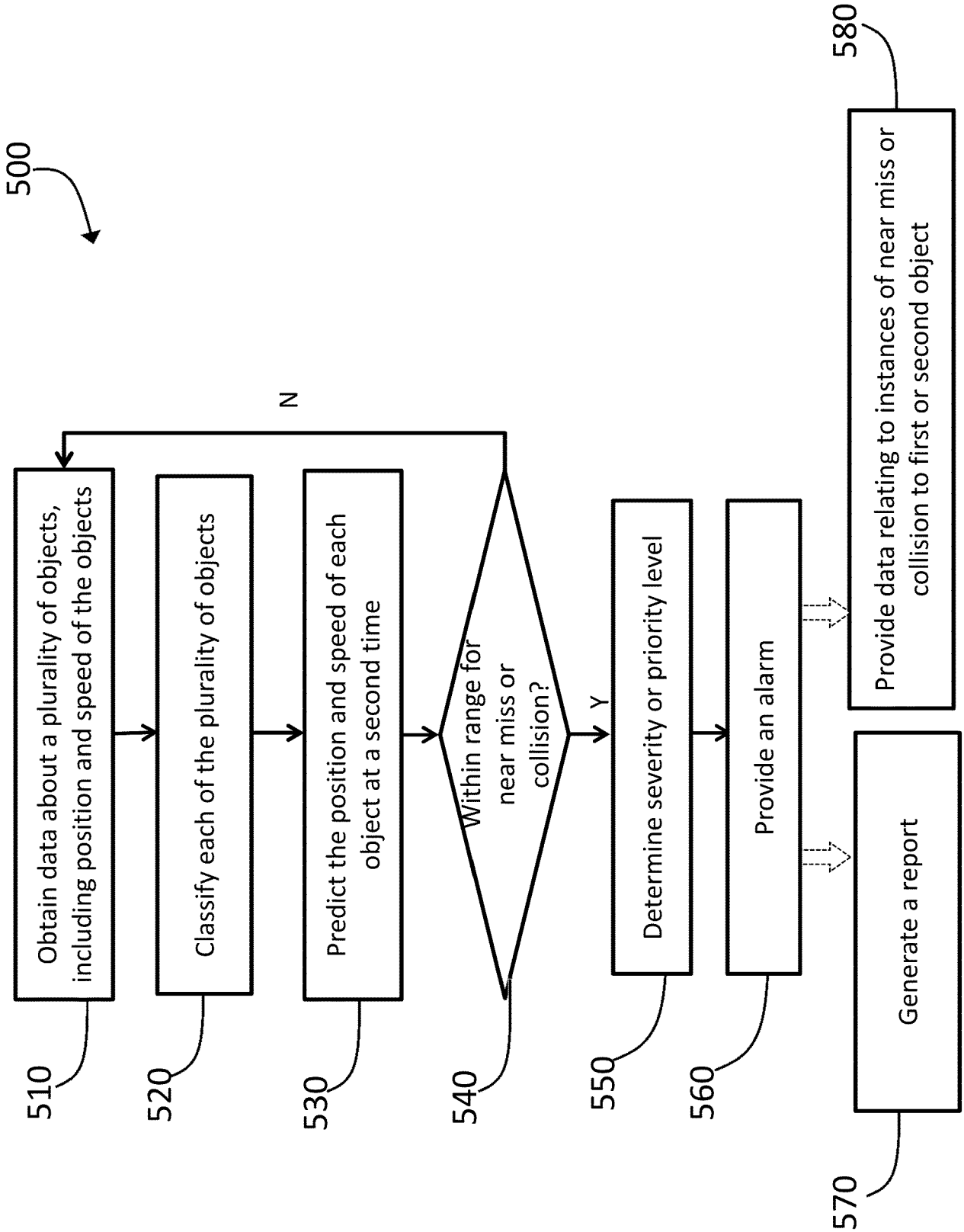

500
Obtain data about a plurality of objects, including position and speed of the objects
510
Classify each of the plurality of objects
520
Predict the position and speed of each object at a second time
530
Within range for near miss or collision?
540
N
Y
Determine severity or priority level
550
Provide an alarm
560
Generate a report
570
Provide data relating to instances of near miss or collision to first or second object
580

FIG. 8

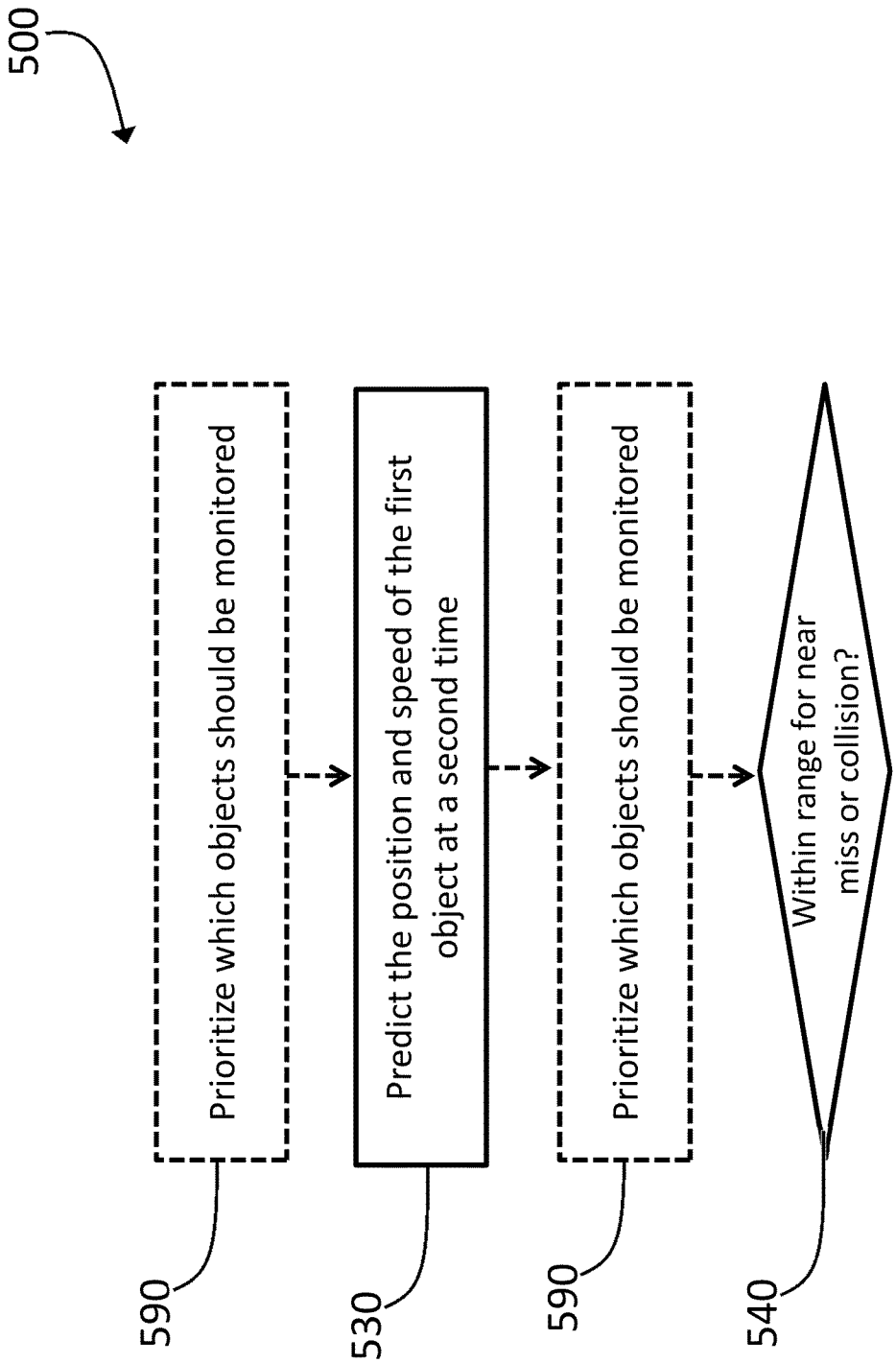

500
Prioritize which objects should be monitored
Predict the position and speed of the first object at a second time
Prioritize which objects should be monitored
Within range for near miss or collision?
590
530
590
540

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/085558

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S13/66 G01S13/87
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/012487 A1 (RUENZ JOHANNES [DE] ET AL) 11 January 2018 (2018-01-11) paragraphs [0003], [0024], [0034], [0039], [0040], [0046], [0050] - [0053]; figures 2-4	1-13
A	US 2013/229116 A1 (VAN ZEIJL PAULUS THOMAS MARIA [NL] ET AL) 5 September 2013 (2013-09-05) paragraphs [0018], [0028]; figure 1	1-13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 April 2020	29/04/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Metz, Carsten

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/085558

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