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## Position tracking with multiple sensors


### Abstract

In an embodiment, a method of tracking includes predicting a predicted state, in a global coordinate space, of an object based on a state of the object; determining in local coordinates the predicted state; determining a plurality of measurements of the object, in the local coordinates, with first and/or second radar sensors; determining a matching of the predicted state and the plurality of measurements, in the local coordinates, for a matching result; and updating the state of the object based on the matching result. The first and second sensors are arranged along perpendicular lines which intersect at the origin of the global coordinate space.



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## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS
(1) This application claims the priority benefit of European Patent Application No. 21157944, filed on Feb. 18, 2021, which applications are hereby incorporated herein by reference.
TECHNICAL FIELD
(2) Examples relate to methods and devices for tracking an object.
BACKGROUND
(3) Tracking of objects is finding application across many fields for many purposes, such as for tracking a target, motion sensing, and gesture sensing.
SUMMARY
(4) Herein are disclosed methods of tracking and devices for tracking that may improve tracking accuracy in challenging conditions such as when measurement signals are weak, dropped, or sometimes spurious.
(5) A method of tracking an object is disclosed, including predicting a predicted state, in a global coordinate space, of an object based on a state of the object; determining in local coordinates the predicted state; determining a plurality of measurements of the object, in the local coordinates, with first and/or second radar sensors; determining a matching of the predicted state and the plurality of measurements, in the local coordinates, for a matching result; updating the state X of the object based on the matching result. The first and second sensors can be along perpendicular lines which intersect at the origin of the global coordinate space. Herein is disclosed a device including a processor that is configured to execute the method.

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## Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Some examples of apparatuses and/or methods will be described in the following by way of example only, and with reference to the accompanying figures, in which:
(2) FIG. **1** illustrates a method of tracking an object, according to an embodiment of the present disclosure;
(3) FIG. **2** illustrates a method of tracking, according to an embodiment of the present disclosure;
(4) FIG. **3** illustrates a device, according to an embodiment of the present disclosure;
(5) FIG. **4**A illustrates coordinate spaces, according to an embodiment of the present disclosure;
(6) FIG. **4**B illustrates a state, according to an embodiment of the present disclosure;
(7) FIG. **5** illustrates a block diagram of matching, according to an embodiment of the present disclosure;
(8) FIG. **6** illustrates a block diagram of a method of tracking, according to an embodiment of the present disclosure;
(9) FIG. **7** illustrates a cycle of a method of tracking an object, according to an embodiment of the present disclosure;
(10) FIG. **8** illustrates a cycle of a method of tracking an object, according to an embodiment of the present disclosure;
(11) FIG. **9** illustrates mathematical operations and definitions, according to an embodiment of the present disclosure;
(12) FIG. **10** illustrates data of an embodiment;
(13) FIG. **11** illustrates tracker output of an embodiment; and
(14) FIG. **12** illustrates a normalized innovation squared metric of an embodiment.
DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS
(15) Various examples will now be described more fully with reference to the accompanying drawings in which some examples are illustrated. In the figures, the thicknesses of lines, layers and/or regions may be exaggerated for clarity.
(16) Accordingly, while further examples are capable of various modifications and alternative forms, some particular examples thereof are shown in the figures and will subsequently be described in detail. However, this detailed description does not limit further examples to the particular forms described. Further examples may cover all modifications, equivalents, and alternatives falling within the scope of the disclosure. Same or like numbers refer to like or similar elements throughout the description of the figures, which may be implemented identically or in modified form when compared to one another while providing for the same or a similar functionality.
(17) FIG. **1** illustrates a method **100** of tracking an object. The method **100** of tracking an object can include predicting no a predicted state (e.g., a subsequent state) in a global coordinate space of an object, based on a state of the object, such as a previous state, of the object. The method **100** can also include determining **120**, in local coordinates (e.g., the coordinates used by the sensors), the predicted state (e.g., by transforming coordinates **120** from global coordinates used in predicting the state of the object into local coordinates). The method **100** can include determining **150** a plurality of measurements of the object in the local coordinates with a plurality of radar sensors, including first and second radar sensors. Having a plurality of sensors, particularly when optimized for placement, can aid in reducing blind spots and/or regions where the object is out of the field of view of the tracking device. Alternatively/additionally, multiple sensors may allow for continued data acquisition related to the object's state (e.g., position and/or velocity) when one of the sensors loses signal and/or produces spurious data.
(18) Having exactly two sensors is particularly contemplated, such as two radar sensors. Two

sensors may allow for redundancy and/or improved field of view coverage while keeping computational costs low. Redundancy, e.g., with multiple sensors, can aid in enabling tracking to continue when the object drops out of the field of view of one of the sensors. For example, the second sensor can be able to continue acquiring data for the determination of measurements of the object while the object is out of the field of view of the first sensor.

(19) A computer processor, for example, can be used to predict no the state of the object, such as the object's position and velocity. The prediction may be based on an unscented Kalman filter. The prediction can be done using global coordinates, which may aid in utilizing the parameterized state of the object for other applications and/or reduce computational costs, particularly when using multiple sensors for determining measurements of the object.

(20) The transform of variables can be performed **120**, such as to aid in comparison of the parameters used in the prediction no with measurements determinable from sensors. The predicted state of the object can be compared with measurements to determine matches and/or associations between the predicted state and the measurements **130**. The state of the object can be updated **140** based on the matching. The sensors can be configured to collect data from and/or determine **150** measurements from an object, from a scene that includes an object, and/or from an identifiable tag of an object.

(21) The method **100** can also include determining **130** a matching of the predicted state and the plurality of measurements from the sensors, in the local coordinates, for a matching result. The matching result can be a global cost, such as a global scalar value, which can determine an association between measurements and the predicted state, tracks of states, and/or active tracks. A global cost and/or global cost function may estimate a degree of association between measurements and the predicted state. Alternatively/additionally, the matching result, such as a global cost, can estimate a degree of association between measurements and a track of the object, e.g., a sequence of states of the objects which may have been determined before the measurements (e.g., current measurements) were made.

(22) The method **100** can include updating **140** the state of the object based on the matching result, e.g., the global cost and/or global cost function. The matching determination **130** and/or matching result can be based on a Hungarian bipartite matching algorithm.

(23) A Hungarian bipartite matching algorithm can determine assignments, associations, correlations, and/or similarities between the determined measurements **150** and the existing track(s) and/or predicted state(s). Existing track(s) may include a predicted state.

(24) The matching result can be based on a global cost and/or GCF, e.g., a maximum or minimum GCF. The global cost can be determined by the Hungarian bipartite matching algorithm, e.g., such that 1:1 matching between measurement(s) and existing track(s) and/or predicted state(s) are determined. Alternatively/additionally, Hungarian bipartite matching can determine matching of the measurements and tracks which include at least one state of the object which has been determined at a time preceding the measurements.

(25) FIG. **2** illustrates a method of tracking **200**. The method **200** illustrated in FIG. **2** can be comparable to that shown in FIG. **1**. FIG. **2** shows that the method **200** can include predicting **210** a state of an object, transforming **220** the state of the object (e.g., from global variables to local variables of the sensors), matching **230**, **232** and updating **230**, **240**. The method **200** can include determining **250** measurements from a plurality of sensors, such as a first measurement(s) from a first sensor and a second measurement(s) from a second sensor. Each sensor can determine **250** zero or a plurality of measurements before the matching **130**, **230**, **232**. The method **200** shown in FIG. **2** may be particularly advantageous when there are multiple sensors that each have independent noise. With the method illustrated in FIG. **2**, unsynchronized sensors may aid in accurate tracking, e.g., with measurements that are collected sequentially from sensors.

(26) In an example, at least one sensor is used to determine **250** a plurality of measurements before the matching steps **230**, **232**. It is possible that only one of the sensors provide data to determine

**150**, **250** of any measurements **250** before the matching steps **230**, **232**. Each sensor may be capable of being used to determine multiple measurements, for example. The measurements determinable **150**, **250** from each sensor **310**, **320** may be at least one of: a range (e.g., a distance), an azimuthal angle, an elevation angle, a polar angle, and a radial velocity. Angular velocities may alternatively/additionally be determinable.
(27) For example, in an asynchronous method, the determination of a measurement **150**, **250** with any of the sensors **310**, **320** (such as at least one of the sensors) can trigger a cycle of the method **100**, **200** as explained herein with reference to FIG. **1** and/or FIG. **2**. The determination of a measurement **150**, **250**, such as a measurement based on a radar pulse reflection received by sensor **310**, **320**, can provide data for updating **140**, **240**, **242** the state of the object (e.g., the object position and/or velocity). The measurement **150**, **250** can trigger at least a matching **130**, **230**, **232**, for example, and can also trigger at least indirectly at least one of the prediction(s) **110**, **210** transform(s) **120**, **220**, and updating **140**, **240**.
(28) For example, determination **150**, **250** of the plurality of measurements can trigger the matching **130**, **230**, **232**, which is followed by the updating **140**, **240** (possibly before a further predicting and/or subsequent measurement of a subsequent cycle of the method).
(29) As illustrated in each of FIGS. **1** and **2**, the matching **130**, **230**, **232** and updating **140**, **240**, **242** can be performed sequentially (such as in the order shown in FIGS. **1** and/or **2**). Referring to FIG. **2**, for example, a first matching **230** of the predicted state and the first measurement(s) is determined, and a second matching **232** of the predicted state and the second measurement(s) is determined. The updating can include a first update **240** and a second update **242**. The first update **240** can occur between the first matching **230** and the second matching **232**. The second update **242** can be determined after the second matching (**232**). Such a sequence can allow asynchronous tracking; alternatively/additionally, such a sequence can aid in accurately updating the object position when the measurements from one of the sensors is spurious or missing.
(30) For example, it is possible that a match between the measurement and the state can be excluded (e.g., when the measurement(s) is an outlier and/or the measurement(s) is undetermined). Taking an illustrative example in which there are exactly two sensors, with reference to FIG. **2**: a measurement is determined **250** by the second sensor **320**; the first matching **230** has no first measurement with which to determine a match; the first updating **240** can set the state of the object to be equal to the predicted state (which may be unchanged from the last updated state); the method continues, as shown in FIG. **2**, by determining **232** a second match between the measurement from the second sensor **320** and the predicted state as determined **210**; the second update **242** can then occur, based on the match result determined **232** from the second sensor **320** and the predicted state. In such a case, the first updating **240** can set the state of the object to be to the predicted state and/or the previous state (e.g., the state as previously updated in the immediately preceding cycle of the method **200**).
(31) As suggested, FIGS. **1** and **2** may each illustrate a single cycle of respective methods **100**, **200** of tracking in which multiple cycles of the method are performed. For example, with each successive determination of measurements **150**, **250** of at least one sensor, the state of the object is updated based on the prediction **110**, **210**, transformation **120**, **220**, and match(es) **130**, **230**, **232**. For example, after a duration in which measurements **150**, **250** are determined from at least one sensor (possibly from multiple sensors), the state of the object is updated based on the prediction **110**, **210**, transformation **120**, **220**, and match(es) **130**, **230**, **232**. After updating **140**, **240**, **242**, subsequent measurements can be determined **150**, **250**, and the cycle can begin anew, using the last updated state as the state to be updated in the subsequent cycle.
(32) It is possible that the method is based on a clock, and/or repeating regularly with time. Each cycle of the method **100**, **200** can be repeated at regular intervals. For example, the sensors can collect data for a duration, after which the predicting **110**, **220** transforming **120**, **220** matching **130**, **230**, **232** and updating **140**, **240** **242** is done. The duration can be constant or be varied. The

duration may be varied, e.g., by a processor **390** of the device **300**, in such a way that depends on the state of the object, such as a velocity thereof (e.g., a linear velocity and/or an angular velocity). For example, when there is N sensors, over a duration, M sensors (M≤N) may acquire data from which measurements are determined **250**; in such a scenario, there may be M matching determinations **230**, **232** and M updates **240**, **242**.

(33) It is possible that the methods **100**, **200** described herein can be used with a plurality of N sensors. The measurement(s) can be determined **150**, **250** from at least one of the N sensors. The determination **130** of matching can be done with the entire plurality of measurements, or any part thereof. As illustrated in FIG. **1**, a single update can be determined **130** after the matching. As illustrated in FIG. **2**, for N=2, there can be a sequence of matching determinations **230**, **232** and updates **240**, **242** such that after matches are determined for the N.sup.th sensor, an N.sup.th update is determined. It is also possible that, with each data acquisition, measurement determination, and/or transmission of data to the processor from one of the N sensors, the matching process is triggered. As in FIG. **1**, there can be one update **140** which is based on the measurement(s) from one of the N sensors.

(34) After each update, the method of tracking **100**, **200** may continue in cyclic form (see FIGS. **1** and **2**), such as when new measurement(s) are determined, or after a duration of time in which measurements are acquired or determined; and/or using measurement(s) that were determined since the previous measurement(s). Each cycle of the method **100**, **200** may contribute to the determination of a track (e.g., a sequence of states) of at least one object. It is also possible that the methods **100**, **200** determine more than one track, e.g., when multiple objects are tracked and each object has one track, and when features of an object are tracked and each feature has one track.

(35) FIG. **3** illustrates a device **300**, such as a personal electronic device and/or component thereof, such as a printed circuit board assembly (PCB assembly). The device **300** is configured to track an object according to the methods **100**, **200** described herein. The device **300** includes a processor **390** which can be communicatively coupled to a plurality of sensors **310**, **320**, such as radar sensors. It is particularly contemplated to have exactly two sensors. The plurality of sensors includes a first sensor **310** and a second sensor **320**. The first and second sensors **310**, **320** can be arranged along perpendicular lines **330**, **340** (imaginary lines) that intersect at an origin **350**. The origin **350** can be used as the origin of a global coordinate space, for example in the predicting **110**, **120** of a predicted state of the object based on its current and/or previous state.

(36) FIG. **4**A illustrates coordinate spaces. The global coordinate space **450** (GCS **450**) can have an origin **350** and orientation such that the x-y plane of the GCS corresponds to a plane of reference, such as the plane **335** of the device **300**, such as a PCB assembly, or personal electronic device, such as a tablet and/or smartphone. For example, the device **300** of FIG. **3** has the sensors **310**, **320** at a reference plane **335** that includes the perpendicular lines **330**, **340**. The first device **310** can be at a point of the first line **330**. The second sensor **320** can be at a point of the second line **340**. The intersection of the perpendicular lines **330**, **340** may correspond to the origin **350** of the global coordinate system **450**; and the lines **330**, **340** may define the reference plane, e.g., the reference plane **335** of the device. The lines **330**, **340** can be correspond to x and y axes, respectively, of the GCS.

(37) The first sensor **310**, as illustrated in FIG. **3**, may be at a first edge **311** of the device **300**. The second sensor **320**, as illustrated in FIG. **3**, may be at a second edge **322** of the device **300**. The first and second edges **311**, **322** may meet at a corner **333** of the device.

(38) The sensors **310**, **320** may have a field of view that projects away from device, such as along a z axis which extends away from the intersection of the perpendicular lines **330**, **340**, which may be regarded as directions x **330** and y **340**, respectively.

(39) The sensors **310**, **320** may be oriented, such as to complement each sensor's field of view to optimize, e.g., maximize, the field of view of the device **300**. The sensors can use a local coordinate system, e.g., each sensor uses a local coordinate system. The sensors can measure, for

example, an azimuth and elevation, each in a respective local coordinate system. The sensors **310**, **320** can be placed such that the global coordinate space **450** is centered (e.g., has the origin **350**) at the center of the reference plane (which may correspond to the plane **335** of the device). Perpendicular lines **330** and **340** may correspond, respectively to the x and y axes of the global coordinate space **450**.

(40) Having the sensors arranged so that the origin **350** is centered may aid in tracking the object, such as by providing a field of view that is defined relative to the device. Other applications of the device may utilize the state of the object as determined by the tracking method **100**, **200**. It can be useful to have the state of the object expressed in a coordinate space, such as the GCS **450**, that is intuitively aligned and/or oriented with the device. Alternatively/additionally, the positions of the sensors **310**, **320** along the perpendicular axes **330**, **340** can work synergistically with the placement of the origin **350** in the center to simplify coordinate transformation(s) that can be done in order to efficiently match measurements based on sensor data with predicted states.

(41) It is optional to synchronize the sensors. An advantage of the methods **100**, **200** described herein is that tracking errors (such as loss of tracking) are reduced in challenging circumstances, such as when there is timing jitter, such as timing mismatch between sensors, system jitter, jitter within individual sensors, and/or unsynchronized measurements. Corrupted phase and/or measurements, such as when the object falls in the blind-spot of a particular sensor may also be challenging (measurement drops).

(42) There may be a set of x, y, z (and/or r, θ, φ) local coordinates for each sensor. As illustrated in FIG. **4**A, a first local space **410** can originate at the first sensor **310**, and the second local space **420** can originate at the second sensor **320**. The orientations of the local coordinates, **410**, **420**, and **450** may be different. For example, the second local space **420** can be rotated at an angle, such as 90°, from the global coordinate space **450**, e.g., about a z-axis which extends away from the x-y plane (the x-y plane can includes radar receivers **310**, **320** and the origin **350** of the global coordinate space **450**). The orientation of the second sensor **320** can be rotated at the angle along z-axis from alignment with the global coordinate space **450**. At least one of the sensors **310**, **320** can be in at least partial alignment with the global coordinate space **450**.

(43) As in FIG. **4**A, the orientation of the first local space **410** and global coordinate space **450** may be aligned (e.g., each of the axes of the two spaces are parallel, e.g., x axis of **410** is along that of **450**, y axis of **410** is along that of **450**, and z axis of **410** is along that of **450**). For example, a transformation from the global coordinate space **450** to the first local space **410** (e.g., a determination **120** in the first local space **410**, of a predicted a state which is predicted **110** already in the global coordinate space **450**) can be done by a translation of the x component of the predicted state. As seen in FIG. **4**, the first local space **410** and the global coordinate space **450** can be identical except for an offset along the x direction.

(44) It is noted that the sensors may have orientation. For example, sensor output can include azimuthal data, which may be expressed relative to an orientation of the sensor. A transformation **120**, **220** from GCS **450** to a local coordinate space (e.g., second local space **420**) may include a translation and a rotation.

(45) As seen for example in FIG. **4**A for the second local space **420**, a local space **420** may be rotated with respect to the global coordinate space **450**. For example, a determination **120**, **220**, in the second local coordinates **420**, of a state of an object—the state being initially expressed (e.g., as a vector) in the global coordinate space **450**—may be done by a translation and a rotation. For example, for determining **120**, **220** in the second local space **420**, a state that was predicted **110**, **210** in the global coordinate space **450**: they component of the state in the global space **450** can be translated (e.g., in y by the distance between the GCS origin **350** and the second sensor **320**); and the state can be rotated (e.g., about the z axis by 90° counterclockwise).

(46) For example, the state can be a vector and the transform **120**, **220** of the state from the global coordinate space **450** to the local space(s) **410**, **420** can be done by a matrix and/or matrices, e.g.,

by matrix manipulations.
(47) The sensor(s) **310**, **320** can have orientations. For example, the sensors each use respective local coordinate spaces **410**, **420** that are oriented. The sensors **310**, **320** may be radar sensors, for example, and/or may have an orientation for determining azimuthal angle and/or a reference direction (e.g., an x, y, and/or z direction, and/or a direction corresponding to an azimuthal angle of 0° and/or an elevation angle of 0°). For example, the sensors **310**, **320** can be oriented in the device **300**. For example, the sensors are in the XY plane. Alternatively/additionally, the first sensor **310** is aligned so that its 0° azimuthal angle is oriented at a known angle relative to the 0° azimuthal angle of the second sensor **320**. The known angle may be 90°, e.g., such that the first sensor **310** is aligned along the x direction **330** and the second sensor **320** is aligned along the y direction **340**. It is practical that the device **300** can be rectangular as this can be a preferred shape for consumer devices and can provide an intuitive interface.
(48) The effectiveness and/or efficiency of the sensor may be direction dependent. The effectiveness and/or efficiency may be related to the accuracy of radar measurements and/or an increased field of view, for example. The sensor may be most sensitive to detecting objects and/or small changes in the position of objects within a part of the sensor's entire field of view. For example, the sensor has a maximum sensitivity and/or effectiveness at 0° azimuthal angle, and the azimuthal angle is defined with respect to the orientation of the sensor itself. The sensor's orientation can be adjusted on the device to maximize the sensor sensitivity and/or the effectiveness and/or sensitivity of the device **300**. It is contemplated to have the sensors **310**, **320** oriented to maximize effectiveness and/or efficiency in the region of space directly in front of the device, e.g., toward the center of the device, while allowing for the field of view to extend off-center of the device in all directions, at least in the region of space in front of the reference plane **335** of the device.
(49) It can be advantageous to have the first sensor **310** at an edge **311** of the device **300** which is perpendicular to the x axis **330**, and oriented for maximum efficiency along the x axis **330** facing the GCS origin **350**, and the second sensor **320** on another edge **322** of the device **300** which is perpendicular to the y axis **330**, and oriented for maximum efficiency along the y axis **340** facing the GCS origin **350**, such that the edges **311**, **322** meet at a corner **333** of the device **300**.
(50) Alternatively/additionally, a sensor(s) can be calibrated so as to determine the orientation of the sensor(s). For example, after the sensor(s) is attached to the device, PCB board, or the like, a calibration can be formed to define the azimuthal angle of 0°. As illustrated by comparison of FIGS. **3** and **4**, it is particularly contemplated that the first and second sensors **310**, **320** can be centered at respective adjacent edges **311**, **322** of a rectangular device **300**, and oriented so that the local coordinates are rotated at 90° about the z axis from each other.
(51) It can be convenient to use the global coordinate space **450** to predict **110**, **210** the state of the object being tracked, and to transform **110**, **120** the predicted state into local coordinates **410**, **450** before matching **130**, **230**, **232**. The global coordinate space **450** can be used for the predicting and storing of the determined state of the object. The state of the object, in the global coordinate space **450**, can be accessed by other processes and/or utilized for other device functionalities (e.g., for tracing object motion for determining input signals, and/or providing warnings when the tracked object may reach a limit of the field of view of the device). The state of the object, in the global coordinate space **450**, can be used for other purposes for which the global coordinate space **450** is convenient. Use of the global coordinate space **450** to describe a tracked object's state is particularly convenient when the origin of the space **450** is near the center of the device.
(52) FIG. **4**B illustrates a state X. A state X may be a vector such as a vector that includes at least one position element (x, y, z) and/or at least one velocity component element (x′, y′, z′). Polar coordinates (r, θ, φ) and/or Cartesian coordinates (x, y, z) may be used, for example. The state X may include radial velocity, e.g., in θ and/or φ. The state X may be in any space, such as a local space **410**, **420** or the global coordinate space **450**, for example. Transformations, such as by linear

methods, may be used to change coordinates, e.g., to change the representation of the state from one space to another and/or from one coordinate system to another.

(53) For example, in the methods of tracking **100**, **200** described herein, determining **120**, **220**, in local coordinates **410**, **420**, the predicted state can include: coordinate-transforming the predicted state of the object into a first local space **410** of the first sensor **310**, and coordinate-transforming the predicted state of the object into a second local space **420** of the second sensor **320**. For example, some of the steps of the method **100**, **200** of tracking may utilize comparisons (e.g., determination **130**, **230** of matching) between the measurements as determined from the sensors **310**, **320** and the predicted state X. The measurements may each be determined in the local spaces **410**, **420** of the respective sensors **310**, **320**. Transforming coordinates from global space can enable matching and updating the state vectors of the object.

(54) As can be represented in FIG. **1**, for example, the method **100** of tracking can determine **130** the matching after the coordinate transformation **120**. The coordinate-transforms can be done after the determining **120** in global coordinates **450** the predicted state X. For example, each of the coordinate-transforming of the predicted state of the object into the first local space **410**, and the coordinate-transforming of the predicted state into the second local space **420** can be done after predicting no the predicted state in the global coordinate space **450** and before determining **130** the matching.

(55) It is also possible that the predicting **110**, **210** of a predicted state of an object based on a (previous) state of the object and the determining **120**, in local coordinates **410**, **420** the predicted state can be combined. The predicted state may be determined in the same coordinate space and/or system as the (previous) state such as in global coordinate system/space. For example, appropriately modified matrix forms of the prediction operations can be used. For example, predicted states can be computed based on a motion model of the tracker. Also, an observation and/or measurement model of a Kalman filter (e.g., in matrix form H) can include a coordinate transformation. A predicted state can be determined in an arbitrary coordinate system, such as a global coordinate space.

(56) FIG. **5** illustrates a block diagram of matching **500**. The matching **500** described with reference to FIG. **5** can be utilized in the methods **100**, **200** of tracking an object described herein, such as in a process of matching **130**, **230**, **232** a predicted state and a plurality of measurements. The matching **500** of FIG. **5** can be Hungarian bipartite matching. Hungarian bipartite matching can include an algorithm for optimal matching of nodes, such as a first group of nodes **511**, **512**, **513** and a second group of nodes **521**, **522**, **523**.

(57) FIG. **5** can illustrate an example with multiple tracks **511**, **512**, **513** which may be regarded as the first group of nodes **511**, **512**, **513**. The measurements **521**, **522**, **523** can be regarded as a second group of nodes **521**, **522**, **523**. The matching **500** can determine the association and/or correspondence of tracks **511**, **512**, **513** with measurements **521**, **522**, **523**. Global matching, which may help in association between active tracks and current measurements, may be represented in FIG. **5**.

(58) It is also possible to implement the tracking method, particularly the matching **500** thereof, to a single track. An object may have more than one tracked feature. For example, multiple features of an object can be identified and tracked. FIG. **5** illustrates a case with multiple tracks, which may be representative of tracking multiple objects. Alternatively/additionally, tracks **511**, **512**, **513** may correspond to a plurality of features of an object for which the respective features are tracked.

(59) The first group of nodes **511**, **512**, **513** (e.g., states, tracks, and/or components of a state) may be in a first frame **510** (e.g., of a given time). The nodes **511**, **512**, **513** can correspond to a predicted state(s) and/or tracks of a tracked object(s) for which a state is predicted **110**, **210** and/or previously known. FIG. **5** shows nodes **521**, **522**, **523** of a second frame **520** (e.g., a subsequent frame to the first frame **510**). The nodes **521**, **522**, **523** of the second frame **520** can correspond to measurements, such as measurements as determined from the sensor(s) **310**, **320**. The

determination **130**, **230**, **232** of matching, in the methods **100**, **200** described herein, may determine the matching of nodes **521**, **522**, **523** of the second frame **520** to nodes and/or tracks **511**, **512**, **513** of the first frame **510**. For example, the determination **130**, **230**, **232** may assess the association and/or correspondence of measurements (e.g., in the form of nodes **521**, **522**, **523**) to the nodes **511**, **512**, **513** (e.g., states, tracks, and/or components of a state).
(60) The determination **130**, **230**, **232** of the matching **500**, such as is illustrated in FIG. **5**, may match the predicted state of the object and the plurality of measurements, in the local coordinates **410**, **420**. Alternatively/additionally, the determination **130**, **230**, **232** of the matching **500** may determine a matching result, such as a global cost minimum and/or global cost function GCF. GCF can solve for an association problem between the plurality of measurements and the existing active tracks (e.g., multiple targets tracked in a given frame). A GCF can determine a global cost and/or global cost minimum, for example.
(61) The matching result may include information about a similarity measure (e.g., increased certainty) between the measurements and current active state vectors, for example/based on a global minimum Mahalanobis distance between the nodes in **510** and **520**.
(62) FIG. **5** shows intermediate results **511-21**, **511-22**, **511-23**, which are represented as lines connecting the first node **511** of the first frame **510** to the first, second, and third nodes **521**, **522**, **523** of the second frame **520**. The intermediate results **511-21**, **511-22**, **511-23** are depicted as solid or dotted lines.
(63) FIG. **5** also shows intermediate results that connect the second node **512** of the first frame **510** to the first, second and third nodes (**512-21**, **512-22**, **512-23**) of the second frame **520**; and the third track **513** of the first frame **510** to the first, second and third nodes (**513-21**, **513-22**, **513-23**) of the second frame **520**.
(64) Each of the intermediate results **511-21**, **511-22**, **511-23**, **512-21**, **512-22**, **512-23**, **513-21**, **513-22**, **513-23** can each be determined based on assessing the association, similarity and/or correlation between each node **511**, **512**, **513** of the first frame **510** and each node **521**, **522**, **523** of the second frame **520**.
(65) In FIG. **5**, the determined and/or optimal matching is illustrated by the solid lines **511-22**, **512-23**, **513-21**. The solid lines solid lines **511-22**, **512-23**, **513-21** may indicate intermediate results which are indicative of greater certainty of these matches being accurate. The remaining dotted lines can be indicative of relatively poorer certainty of matches in comparison to those of solid lines **511-22**, **512-23**, **513-21**. The matching result, global cost, and/or GCF, may be determined such that it is shown, for the example of FIG. **5** that, when all possible matches are taken into account, it is more likely that track **511** matches node **522** than any other node; similarly, it is more likely that track **512** matches node **523**; and it is more likely that track **513** matches node **521**.
(66) The matching result can be determined by the assessment of the association of each node **521**, **522**, **523** of the first frame **510** with each node **521**, **522**, **523** of the second frame **520**.
(67) In FIG. **5**, the determined matches between each node **511**, **512**, **513** and each node **521**, **522**, **523** are depicted as solid lines **511-22**, **512-23**, **513-21**. As illustrated in FIG. **5**, dotted lines indicate a lower assessment of association, correlation, and/or similarity. The example of FIG. **5** can represent a matching **500** which determines a 1:1 match between each of nodes **521**, **522**, **523** and respective nodes **511**, **512**, **513**. In the example of FIG. **5**, a relatively high score for the intermediate results **511-22**, **512-23**, and **513-21** and relatively low score for the remaining intermediate results can lead to a matching result which determines the matching of nodes **521**, **522**, **523** and respective nodes **511**, **512**, **513**.
(68) The method **100**, **200** of tracking may include updating **140**, **240**, **242** a state X of an object based on the matching result. The matching result may, for example, be compared to a threshold and/or acceptable range, to determine how the state of the object is updated **140**, **240**, **242**. For example, if the matching result is high (e.g., there is relatively high association between the measurement(s) and the predicted state, such as an acceptable range of association), the update **140**,

**240**, **242** may be to accept an update to the state directly from the measurement. If the matching result is relatively poor (e.g., there is relatively low association between the measurement(s) and the predicted state, such as out of an acceptable range of association), the update **140**, **240**, **242** may be to use the predicted state for the update (e.g., to discard the measurement and to determine the state based solely on the prediction).

(69) As mentioned herein, a plurality of measurements can be determined by a plurality of sensors, such as first and second sensors **310**, **320**. The determination of the matching **130**, **230**, **232**, such as in a manner illustrated the block diagram of matching **500** of FIG. **5**, may utilize a group of first measurements from the first sensor **310** and/or a group of second measurements from the second sensor **320**.

(70) For example, the method **100** of tracking can be an asynchronous method. The determination **150** of any measurement from any sensor **310**, **320** can trigger an update **140**. For example, a transmission of sensor data **310**, **320** to the processor **390** can initiate a cycle of the method **100** of tracking **100**, including when the transmission comes from only one sensor. The method of tracking **100** can include repeating the algorithm with each data transmission from any of the sensors **310**, **320**. For example, the state X is updated with each determination of a measurement iso. The updates **140** can happen as sensor data is available and/or transmitted (e.g., to the processor **390** of the device **300**). An update **140** can occur when a measurement(s) based on at least one of the sensors **310**, **320** is determined.

(71) Updating **140** can include changing the state X based on the method **100** as described herein, and can alternatively include leaving the state unchanged, e.g., when spurious data is determined. For example, the object may be static, and the predicted state may be identical to the initial state (e.g., no change in state is predicted); a spurious detection event may trigger a measurement, and the tracking method as illustrated in FIG. **1** is performed; and the updating **140** may set the state X of the object to be identical to the predicted state and/or previous state.

(72) In another example, the matching determination **130**, **230**, **232** can include: determining **230** a first matching result of the predicted state and a plurality of first measurements of the first sensor **310**; and determining **232** a second matching result of the predicted state and a plurality of second measurements of the second sensor **320**. For example, each update occurs at a regular interval, and the sensor data that is generated over each successive interval is used to track the object.

(73) With reference to FIG. **2**, the determination of matching can include a first matching **230** of the predicted state and the first plurality of first measurements of the first sensor, and a second matching **232** of the predicted state and a second plurality of second measurements of the second sensor **320**. The updating can include a first update **240** to the state X which is done between the first matching **230** and the second matching **232**. A second update **242** can be done following the second matching **232**, such as immediately following the second matching **232**.

(74) FIG. **6** illustrates a block diagram of a method **600** of tracking. The device for implementation of the method can have more than one radar sensor, such as exactly two radar sensors **610**, **620**. Multiple radar sensors can aid in reducing the loss of signal; for example, when one sensor loses signal, the other(s) can continue providing data for tracking the object. Two radar sensors **610** can reduce the computational load in comparison to more, and/or can significantly cover the desired field of view. Two or more monostatic radar sensors, such as millimeter-wave (mmWave) radar sensors, are particularly contemplated, which can be useful in short-range applications.

(75) As illustrated in FIG. **6**, the tracking method **600** can includes a measurement cycle (e.g., for determining measurements), a fusion stage (e.g., for predicting **110**, **210** the object state and/or coordinate transformations **120**, **220**), and adaptive changes (e.g., for matching **130**, updating the object state **140**, statistical determinations, and/or adjustment of algorithmic parameters). The measurement cycle (which can correspond to the determination of measurements **150**, **250**) can pass and/or communicate sensor data from the sensor(s) to the processor. Alternatively/additionally, the sensor measurements may be taken sequentially and fused with the unscented Kalman filter.

The processor can determine the state, e.g., the state vector(s) in global coordinate space (e.g., determination of global state vectors).

(76) In the fusion stage depicted in FIG. **6**, determinations of coordinate transformations can be done, such as rotation and/or translation of the state vector, and prediction(s) of state(s). The prediction of the state of the object may utilize an extended Kalman filter and/or an unscented Kalman filter, for example. Adaptive changes can update the state of the object as well as the models/parameters of the Kalman filter. With each adaptive change (or determination of no change of state), a normalized innovation squared (NIS) metric can be determined. The NIS metric can be used to determine how the update occurs. A NIS metric can be calculated to check for lower and/or upper bounds, such as based on confidence levels, e.g., required confidence levels, to modify process noise, Q and measurement noise, R accordingly that can be used in prediction and/or measurement steps of the tracker. A NIS metric can be used for smooth updating of tracker parameters.

(77) The algorithm can be tweaked, particularly the parameters utilized in the fusion stage, such as the process noise Q, and measurements noise R. The process noise Q and measurements noise R parameters can be computed at the end of a cycle, based on the NIS metric and a confidence bound (e.g., a 95% confidence bound). The updated state X, process noise Q, and measurements noise R parameters can be used in the next cycle. Alternatively/additionally, Q and R can be calibrated before the device **300** is used. Q and R can be tweaked, for example, to bring the NIS and/or measurements within confidence bounds.

(78) The methods and devices described herein may operate using assumptions and/or features such as at least one of: measurement noise for each sensor is independent of measurement noise of other sensors; the estimation of states of each target from each sensor corresponds to the true target state with negligible error; measurements, including unsynchronized measurements that are sequentially processed.

(79) FIG. **7** illustrates a cycle of a method **700** of tracking an object. The method can include a determination **710** of the predicted state X_pred and covariance P_pred using an unscented Kalman filter (UKF). After the prediction **710**, there can be a transformation **720** of the predicted state X_pred from the global coordinate system to the local coordinates for a first sensor. Predicted measurements Z_1 for the first sensor and a corresponding innovation matrix S_1 can be determined **720**.

(80) It is possible that the prediction **710** and coordinate transformation **720** are combined in a single determination. For example, when an unscented Kalman filter is used to determine **710** the prediction, a motion model can be used. The observation model H can be combined with the coordinate transformation during the measurement step, so that the actual measurements and predicted measurements are compared before the state update.

(81) After predicted measurements Z_1 are determined, determining **730** a matching with a probabilistic data association filter can be performed, or using a Hungarian bipartite filter. The matching determination **730** can be applied to determine matching of the tracks, e.g., the predicted measurements Z_1, and the measurements of the first sensor. Next, there can be a first update **740**, which can determine the state X1 and the state covariance P1, e.g., by updating the state and covariance.

(82) The update can be based on selecting the predicted state X_Pred as the updated state X1 (e.g., a first determined updated state, such as based on the first measurements form the first sensor **320**), such as when the association of the first sensor measurement and the predicted state is relatively poor (e.g., out of an acceptable range for the first update determination). In another scenario, the update can be the associated measurement from the first sensor Z_associated, such as when the association of the first sensor measurement and the predicted state is in high agreement. In another scenario, the updated state X1 can be a state based on combining the predicted state X_Pred and the first sensor measurements. The combination, e.g., the relative weights of the predicted state X_Pred

and first sensor measurements that go into the updated state X1 may be determined based on the unscented Kalman filter, such as the observation model H_1 and/or the covariance R_1, particularly that of the measurement noise.
(83) The process (e.g., as described directly above for FIG. **7** and the first sensor measurements) can be modified for the second sensor measurements. The process can use the updated state determined from the first sensor as the initial state X, transforming coordinates if appropriate, determining matching **750**, and updating **760** the state of the object. As illustrated in FIG. **7**, the prediction **710** can be done once per cycle, for example, e.g., whether there is data from no sensor, one sensor, or multiple sensors.
(84) Referring again to FIG. **7**, it is possible to determine that there is not a valid association from the second sensor (e.g., based on a matching result which is out of an acceptable range. In such a case, the updated state X2 (e.g., determined from a second update to the state) can be set to the previously updated state X1. Alternatively, as with the description above directed at determinations related to the first sensor's measurement, the state of the object can be updated according to a match, e.g., a match determined to be within an acceptable range (such as based on a second match result). There may be an acceptable match between (i) the predicted state X_Pred and/or the previously updated state X1 and (ii) the measurements from the second sensor. The updated state X2 can be a state based on combining (i) the previously updated state X1 and/or predicted state X_Pred and (ii) the measurements from the second sensor. The combination, e.g., the relative weights of the second sensor measurements and the predicted state X_Pred (and/or first updated state X1) that go into the updated state X2 may be determined based on the unscented Kalman filter, such as the observation model H_2 and/or the covariance R_2, particularly that of the measurement noise of the second sensor.
(85) A cycle of the method may also include a determination of the measurements from at least one sensor. The cycle may be repeated in order to track the object over time.
(86) FIG. **8** illustrates a cycle of a method **800** of tracking an object. The cycle may also include a determination of the measurements from at least one sensor. The method can include a determination **810** of the predicted state X_pred and covariance P_pred using an unscented Kalman filter. After the prediction **710**, there can be a transformation(s) **820***a*, **820***b* of the predicted state X_pred from the global coordinate system to the local coordinates of the sensors. FIG. **8** can illustrate a scenario with exactly two sensors. More sensors are possible. The transformation(s) **820***a*, **820***b* can determine the predicted measurements X_m1, X_m2 of each sensor, and, optionally, predicted covariance(s) P_m1, P_m2. The transformations **820***a*, **820***b* can utilize the predicted measurement Z_m1, an observation model H1 and noise covariance R1 of the first sensor, and of the other sensors, such as the second sensor, Z_m2, H2, R2.
(87) The predicted measurements X_m1 for the first sensor and other sensors, such as the second sensor X_m2, can be determined **830** for matching, e.g., associated using Hungarian bipartite association. The determination **830** of matching can be done using the measurements determined from at least one sensor, such as from two sensors, as shown in FIG. **8**. The determination **830** of matching can determine a matching result, such as to determine the association between actual measurements and predicted measurements.
(88) The state of the object can be updated **840**, **842** in the local coordinate space, e.g., there can be a first update **840** to the state as expressed in the local space of the first sensor, and there can be a second update **842** to the state, such as an update expressed in the local space of the second sensor. There can be at least as many updates **840**, **842** during one cycle of the tracking method **800** as there are sensors for which there are measurements, for that particular cycle. (The tracking method **800** can include more than one cycle).
(89) The first update **840** can be based on at least one of: the relevant measurements determined by the matching **830** for the relevant sensor(s) (e.g., Z_associated, such as for the first sensor), the innovation matrix (such as S1 for the first sensor) relevant to the first sensor measurements and the

prediction, the predicted state X_Pred, the predicted covariance P_Pred, the observation model relevant for the first sensor H_1, and the noise covariance of the first sensor R_1.

(90) The second update **842** can be based on at least one of: the relevant measurements determined by the matching for the relevant sensor (e.g., Z_associated, such as for the second sensor), the innovation matrix relevant to the sensor measurements and the prediction (e.g., S2 for the second sensor), the previous update to the state (e.g., X1, for when there has already been an update from a previous sensor, in this case the first sensor), the predicted state, the predicted covariance (e.g., P1, for when there has already been an update from a previous sensor, in this case the first sensor), the observation model relevant for the sensor (e.g., H_2 for the second sensor), and the noise covariance of the sensor (e.g., R_2 for the second sensor).

(91) The methods of tracking described herein can aid in reducing loss of tracking particularly when there are spurious and/or missing tracking signals and/or measurements. For example, when one sensor provides outlier data and/or the object leaves the field of view of the one sensor, the measurements from the other sensor(s) may continue to be adequate for accurate tracking. The matching determined herein may allow for determining and/or neglecting outlier measurements.

(92) An example algorithm flow is provided, in which the lines of pseudocode are enumerated and parameters azi and ele refer to azimuthal angle and elevation angle respectively: 1. If (no_measurements) 2. (X,P)=UKFPredict (X,P) 3. Elseif (azi=present, ele=absent) 4. (Xpred,Ppred)=UKFPredict (X,P) 5. (X,P)=UKFUpdate1(Xpred, Ppred) 6. Elseif (azi=absent, ele=present) 7. (Xpred,Ppred)=UKFPredict (X,P) 8. (X,P)=UKFUpdate2(Xpred, Ppred) 9. Else 10. (Xpred,Ppred)=UKFPredict (X,P) 11. (X1,P1)=UKFUpdate1(Xpred, Ppred) 12. (X,P)=UKFUpdate2(X1, P1) 13. end

(93) In the methods of tracking described herein, as exemplified above, the sensor(s) can each provide azimuthal data and/or elevation data (or no data), e.g., for each cycle of the tracking method. As in the example pseudocode above, the method may possibly make no change to the state of the object, for example when there is no data (lines 1-2); the prediction can be based on an unscented Kalman filter, for example; the method can update the state in a way that depends on whether there is only azimuthal data (lines 3-5), only elevation data (lines 6-8), or both azimuthal and elevation data (lines 9-12).

(94) FIG. **9** illustrates mathematical operations and definitions. The operations and/or definition of FIG. **9** can be used in the methods described herein. In the left column, there are matrices defined for an unscented Kalman filter, which can be used in the prediction of a state. The top matrix, P, of the left column can represent the initially predicted covariance. The middle matrix Q can be the process noise covariance, as initially predicted. F can be a state transition matrix, and/or the motion model used for the prediction.

(95) The middle column of FIG. **9** illustrates operations pertaining to coordinate transformation, such as for a sensor that is 0.6 distance units from the global origin along a y direction and otherwise in alignment with the global coordinates (e.g., no rotation is necessary). A transformation matrix R is defined at the top of the middle column, for this scenario. The middle column illustrates that it is possible to convert from global to local coordinates, e.g., to convert to measurement space (which may be equivalent to converting to local coordinates), and to convert between Cartesian and polar coordinates (bottom of middle column of FIG. **9**). Herein, coordinate and/or spatial transformations of the state of an object are particularly envisioned.

(96) The right column of FIG. **9** illustrates operations pertaining to coordinate transformation, such as for a sensor that is 0.4 units from the global origin along an x direction, and also orientationally rotated 90° about the z axis from the global coordinates. The transformation matrix R is defined at the top of the right column, for this scenario. Otherwise, the third column is similar to that of the middle column at least in the sense that it is possible to convert from global to local coordinates, e.g., to convert to measurement space (which may be equivalent to converting to local coordinates), and to convert between Cartesian and polar coordinates.

(97) FIGS. **10-12** illustrates an example, including data collected by the sensors (FIG. **10**), tracker output (FIG. **11**) which may be regarded as the states predicted and/or determined by the method of tracking, and the normalized innovation squared for azimuth and elevation (FIG. **12**). Frames of FIGS. **10-12** may be regarded as corresponding to successive cycles of the tracking method.
(98) The example shown in FIGS. **10-12** may highlight some features of the methods described herein. The example is one for which it is challenging to track the object, in order to aid in the explanation of the methods described herein, and advantages thereof.
(99) For the example illustrated in FIGS. **10-12**, an object was rotated in a plane substantially parallel with the reference plane of the device, which has two sensors in the reference plane. The object was rotated at about 1 meter from the reference plane. The left column of FIG. **10** shows the data from a first sensor, and the right column that of a second sensor. The range and speed data from the sensors (FIG. **10**) is more difficult to interpret than the angle data (FIG. **10**). From the azimuthal data and the elevation data (FIG. **10**), the periodic motion of the object can be more easily inferred.
(100) Superimposed on each of the periodic signals of the azimuth data and elevation data is noise, dropped signals (zeros). Furthermore, each of the azimuthal and elevation measurements of the object also appears to be periodically out of range of the sensors, particularly for the second sensor's elevation data. Comparing the azimuthal and elevation data, it is inferred that the periodic motion of the object of this example is more often out of range of the second sensor than the first sensor (e.g., the crests of the elevation angle seem to be chopped off more than the troughs of the azimuth, which also appear to be chopped). It is also inferred from the data of FIG. **10** that there is loss of signal at approximately frame number **800**.
(101) FIG. **11** illustrates the tracker output. In comparison to the measurements of FIG. **10**, there are fewer spurious data points for each of the range, azimuth, and elevation for the tracker output (FIG. **11**) than the measurements (FIG. **10**). For example, the state variable of range (as determined and/or cyclically updated by the tracking method) is on average approximately 1 meter and does not show the jumps that are seen in the range measurements of FIG. **10**. The comparison of the tracker's determination range and the data from the sensor(s) may particularly highlight the capability of the tracking methods described herein, e.g., due to the comparatively smoother tracker output of range (FIG. **11**) than raw measurement of range (FIG. **10**).
(102) The state variable of azimuth (as determined and/or cyclically updated by the tracking method) seen in FIG. **11** lacks the measurement drops (the zeros) seen in FIG. **10**. The state variable of elevation (as determined and/or cyclically updated by the tracking method) seen in FIG. **11** lacks the measurement drops (the zeros) seen in FIG. **10**. Also, the crests and troughs of the state variables azimuth and elevation (FIG. **11**) do not appear as chopped as the sensor measurements of azimuth and elevation (FIG. **10**).
(103) FIG. **12** illustrates the normalized innovation squared (NIS) for azimuth and elevation. The NIS can be regarded as a test for biasedness, for example. The unscented Kalman filter has parameters and/or matrices that can be tweaked, tuned, and/or adjusted to optimize results. The NIS can be used to determine how to adjust the Kalman filter. The Kalman filter parameters may be adjusted after any frame and/or cycle of the method. According to one of several ways of interpreting the NIS metric as shown in FIG. **12**, the NIS can (in some scenarios) sharply increase over a few frames when there is a relatively large increase in the difference in the predicted state and the measurement. For example, at approximately frame **400**, the NIS of the azimuth shows a spike (left side of FIG. **12**). This spike can be interpreted to correspond to the comparatively rapid change of angle seen in the azimuthal measurement (see FIG. **10**) from the first sensor at frame **400**.
(104) A few spikes in NIS are also noted from approximately frame **500** to fame **600** of the NIS azimuth (FIG. **12**). Comparing to frames **500-600** of the azimuth angle measurement (FIG. **10**), this corresponds to where the trough of the generally sinusoidal measurement data is chopped (e.g., for

being at the edge or beyond of the field of view of the first sensor). It can be appreciated that the elevation angle measurement (FIG. **10** lower right) is smoother than the azimuthal measurement (FIG. **10** lower left); this can account for how, in FIG. **12**, the NIS elevation metric is smoother than the NIS azimuthal metric.

(105) In view of the above example pertaining to FIGS. **10-12**, particularly in combination with the description of the methods herein such as with reference to FIGS. **1-9**, it is apparent that the methods described herein can aid in tracking an object in situations in which there are challenging circumstances such as signal drops from at least one sensor, spurious signals, and/or the object passing for a duration out of the field of view of a sensor.

(106) Herein, sensors may be radar sensors and which may include at least one of a radar receiver and radar transmitter. The methods of tracking described herein may involve repeated cycles of the processes and/or steps described. Herein, the state of a tracked object may be repeatedly updated, such as in accordance with new measurements and other procedures and/or steps. For example, a sequence of updates to the state of the object may be regarded as tracking and/or part of a tracking process.

(107) Herein, the term "global coordinate space" may be used interchangeably with "global coordinates." Herein a trailing "(s)" of a term, such as appears in "track(s)" is used to indicate at least one of the terms, such as "at least one track;" the trailing (s) may be regarded as indicating a possible plurality.

(108) Herein, the term "fusion" can refer to a determination of a predicted state based on at least one of a previous state, a measurement (such as from a sensor, particularly a radar sensor); for example fusion can refer to determining, using an unscented Kalman filter, a predicted state based on a previous state and plurality of measurements.

(109) Herein the term "Hungarian bipartite matching" may be used interchangeably with "Hungarian bipartite association." The tracking described herein may be done in three dimensional space.

(110) Herein, a "node" may refer to, for example: a measurement; a plurality of measurements; a state; a component or substate of a state such as a position and/or velocity; and a track. A track may be a sequence of states of an object. A state may be a previous state, a determined state, a current state, or future state; for example a state may be updated by a process that includes predicting a predicted state based on the state (e.g., the current or previous state) and matching the state to measurements. Herein an "existing track" may be a type of track that includes at least one previous state, e.g., a state determined at a time previous to a plurality of measurements being used as nodes in a Hungarian bipartite matching process, and may optionally include a predicted state.

(111) Herein a velocity can be an angular velocity or linear velocity. Herein "transform" and "transformation" can be used interchangeably, particularly to refer to a coordinate transformation.

(112) Herein, the term "measurement" may refer to, for example, data directly obtained by a sensor, data transmitted from a sensor (such as to a processor), data used by a processor; for example, a measurement may be at least one of a range, azimuthal angle, elevation, angular velocity, radial velocity, linear velocity, velocity component, position, position component. A measurement may be determined based on acquired data. In an example, a measurement of position may be determined from a range and angles.

(113) Herein, when an element is "connected" or "coupled" to another element, the elements may be directly connected or coupled via one or more intervening elements. Herein, when two elements A and B are combined using an "or", all possible combinations are disclosed unless otherwise described. "A and B" can mean only A, only B as well as A and B. The same applies, mutatis mutandis, for combinations of more than two elements.

(114) The aspects and features described in relation to a particular one of the previous examples may also be combined with one or more of the further examples to replace an identical or similar feature of that further example or to additionally introduce the features into the further example.

(115) Examples may further be or relate to a (computer) program including a program code to execute one or more of the above methods when the program is executed on a computer, processor or other programmable hardware component. Thus, steps, operations or processes of different ones of the methods described above may also be executed by programmed computers, processors or other programmable hardware components. Examples may also cover program storage devices, such as digital data storage media, which are machine-, processor- or computer-readable and encode and/or contain machine-executable, processor-executable or computer-executable programs and instructions. Program storage devices may include or be digital storage devices, magnetic storage media such as magnetic disks and magnetic tapes, hard disk drives, or optically readable digital data storage media, for example. Other examples may also include computers, processors, control units, (field) programmable logic arrays ((F)PLAs), (field) programmable gate arrays ((F)PGAs), graphics processor units (GPU), application-specific integrated circuits (ASICs), integrated circuits (ICs) or system-on-a-chip (SoCs) systems programmed to execute the steps of the methods described above.
(116) It is further understood that the disclosure of several steps, processes, operations or functions disclosed in the description or claims shall not be construed to imply that these operations are necessarily dependent on the order described, unless explicitly stated in the individual case or necessary for technical reasons. Therefore, the previous description does not limit the execution of several steps or functions to a certain order. Furthermore, in further examples, a single step, function, process or operation may include and/or be broken up into several sub-steps, -functions, -processes or -operations.
(117) If some aspects have been described in relation to a device or system, these aspects should also be understood as a description of the corresponding method. For example, a block, device or functional aspect of the device or system may correspond to a feature, such as a method step, of the corresponding method. Accordingly, aspects described in relation to a method shall also be understood as a description of a corresponding block, a corresponding element, a property or a functional feature of a corresponding device or a corresponding system.
(118) The following claims are hereby incorporated in the detailed description, wherein each claim may stand on its own as a separate example. It should also be noted that although in the claims a dependent claim refers to a particular combination with one or more other claims, other examples may also include a combination of the dependent claim with the subject matter of any other dependent or independent claim. Such combinations are hereby explicitly proposed, unless it is stated in the individual case that a particular combination is not intended. Furthermore, features of a claim should also be included for any other independent claim, even if that claim is not directly defined as dependent on that other independent claim.

## Claims

1. A method of tracking an object, the method comprising: predicting a predicted state, in a global coordinate space, of the object based on a state of the object; determining in local coordinates the predicted state; determining a plurality of measurements of the object, in the local coordinates, with a first radar sensor and/or a second radar sensor; determining a matching of the predicted state and the plurality of measurements, in the local coordinates, to generate a matching result; and updating the state of the object based on the matching result, wherein the first radar sensor and the second radar sensor are arranged along perpendicular lines which intersect at an origin of the global coordinate space.
2. The method of claim 1, wherein determining the matching comprises: determining a first matching result of the predicted state and a plurality of first measurements of the first radar sensor; and determining a second matching result of the predicted state and a plurality of second measurements of the second radar sensor.

3. The method of claim 1, wherein determining in the local coordinates the predicted state comprises: coordinate-transforming the predicted state of the object into a first local space of the first radar sensor; and coordinate-transforming the predicted state of the object into a second local space of the second radar sensor.
4. The method of claim 3, wherein: the first local space originates at the first radar sensor; the second local space originates at the second radar sensor; the second local space is rotated at an angle from the global coordinate space along a z-axis which extends away from an x-y plane which includes the first radar sensor, the second radar sensor and the origin of the global coordinate space, the z-axis being orthogonal to the x-y plane; and an orientation of the second radar sensor is rotated at the angle along the z-axis from alignment with the global coordinate space.
5. The method of claim 4, wherein determining the matching comprises: determining a first matching of the predicted state and a first plurality of first measurements of the first radar sensor; and determining a second matching of the predicted state and a second plurality of second measurements of the second radar sensor.
6. The method of claim 5, wherein the updating comprises: performing a first update to the state between determining the first matching and determining the second matching; and performing a second update to the state after determining the second matching.
7. The method of claim 5, wherein: coordinate-transforming the predicted state into the first and second local spaces comprises coordinate-transforming the predicted state into the first and second local spaces before determining the matching and after determining in global coordinates the predicted state; determining the matching is based on the first plurality of first measurements and the second plurality of second measurements; and updating the state of the object comprises updating the state of the object after determining the matching.
8. The method of claim 1, wherein the first radar sensor and the second radar sensor are separated by a first distance, the first distance being between 3 cm and 30 cm, and wherein the origin of the global coordinate space is at a center of a device.
9. The method of claim 8, wherein the first distance is between 5 cm and 10 cm.
10. The method of claim 1, wherein the first radar sensor is at a first edge of a device and the second radar sensor is at a second edge of the device.
11. The method of claim 1, wherein the state comprises a position and velocity of the object.
12. The method of claim 1, wherein predicting the predicted state comprises predicting the predicted state based on an unscented Kalman filter.
13. The method of claim 1, wherein determining the matching comprises determining the matching based on a Hungarian bipartite matching which determines the matching of the plurality of measurements and an existing track which includes at least one state determined at a time preceding the determining of the plurality of measurements.
14. The method of claim 1, wherein determining the plurality of measurements triggers the determining the matching, and wherein updating the state of the object follows the determining the matching.
15. A non-transitory computer readable medium with instructions stored thereon, wherein the instructions, when executed by a processor, enable the processor to perform the method of claim 1.
16. A device comprising: a plurality of sensors arranged along perpendicular lines which intersect at an origin of a global coordinate space, the plurality of sensors comprising a first radar sensor and a second radar sensor; and a processor configured to: predict a predicted state, in the global coordinate space, of an object based on a state of the object, determine in local coordinates the predicted state, determine a plurality of measurements of the object, in the local coordinates, with the first radar sensor and/or the second radar sensor, determine a matching of the predicted state and the plurality of measurements, in the local coordinates, to generate a matching result, and update the state of the object based on the matching result.
17. The device of claim 16, wherein the processor is configured to determine in the local

coordinates the predicted state by coordinate-transforming the predicted state of the object into a first local space of the first radar sensor, and coordinate-transforming the predicted state of the object into a second local space of the second radar sensor, wherein the first local space originates at the first radar sensor, wherein the second local space originates at the second radar sensor, wherein the second local space is rotated at an angle from the global coordinate space along a z-axis which extends away from an x-y plane which includes the first radar sensor, the second radar sensor and the origin of the global coordinate space, the z-axis being orthogonal to the x-y plane, and wherein an orientation of the second radar sensor is rotated at the angle along the z-axis from alignment with the global coordinate space.

18. The device of claim 17, wherein the processor is configured to determine the matching by determining a first matching of the predicted state and a first plurality of first measurements of the first radar sensor, and determining a second matching of the predicted state and a second plurality of second measurements of the second radar sensor, and wherein the processor is configured to update the state of the object by performing a first update to the state between determining the first matching and determining the second matching, and performing a second update to the state after determining the second matching.

19. The device of claim 16, wherein the first radar sensor is disposed at a first edge of the device and the second radar sensor is at a second edge of the device.

20. A device comprising: A first millimeter-wave radar sensor and a second millimeter-wave radar sensor respectively arranged along perpendicular lines which intersect at an origin of a global coordinate space, wherein the first millimeter-wave radar sensor is disposed at a first edge of the device and the second millimeter-wave radar sensor is at a second edge of the device, and wherein the origin of the global coordinate space is at a center of the device; and a processor configured to: predict a predicted state, in the global coordinate space, of an object based on a state of the object, determine in local coordinates the predicted state, determine a plurality of measurements of the object, in the local coordinates, with the first millimeter-wave radar sensor and/or the second millimeter-wave radar sensor, determine a matching of the predicted state and the plurality of measurements, in the local coordinates, to generate a matching result, and update the state of the object based on the matching result.