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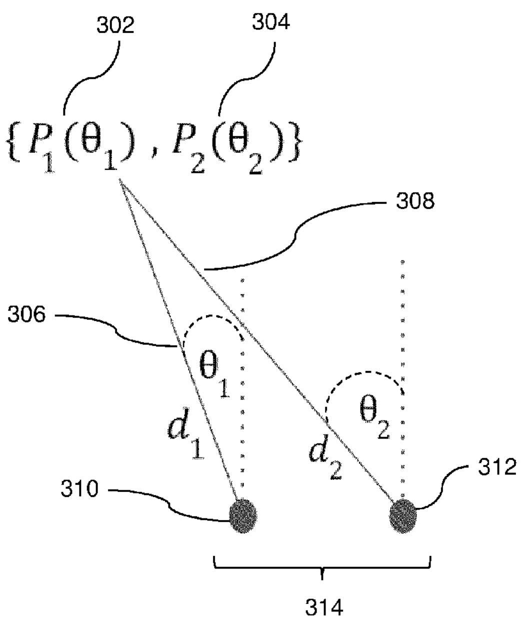

Fig. 2

(57) **Abstract:** Disclosed is a computer-implemented method for detecting one or more objects using at least two radar sensors (310; 312) of a stereo radar assembly (314) arranged spaced apart from each other. The method comprises receiving a first radar signal data and a second radar signal data determined using a first radar sensor (310) and a second radar sensor (312) respectively. Both radar signal data is descriptive of characteristics of the respective radar signals acquired using one of both the radar sensors (310; 312). One or more combinations of distance and radial velocity comprising an intensity peak are determined using the first and second radar signal data. For one or more of the respective combinations of distance and radial velocity, a first and second spectrum (302; 304) descriptive of intensities as a function of azimuth and elevation angle are determined using the first and the second radar signal data, respectively. By matching and comparing the first and second spectrum (302; 304), one or more positions of one or more objects in terms of the azimuth and elevation angle are determined.

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STEREO RADAR

FIELD OF THE INVENTION

[0001] The invention relates to the field of radar detection. More particularly, the invention relates to a computer-implemented method for detecting one or more objects using at least two radar sensors of a stereo radar assembly arranged spaced apart from each other.

BACKGROUND

[0002] Radar sensing is an integral solution, e.g., for autonomous driving as it may be used to yield locations and radial velocities of objects in the surroundings of a vehicle, e.g., a car. The ability of a radar in resolving two closely spaced objects depends, e.g., on the number of antennas, which may be limited by cost and dimension constraints. Multi-input-multi-output (MIMO) radars employ a virtual array idea to increase a radar aperture without increasing the number of physical antennas. However, MIMO radars compatible with automotive constraints still suffer, e.g., from low spatial resolution. In addition to low spatial resolution, a single radar may fail to detect objects with low signal-noise-ratio (SNR) as well as occluded targets. Therefore, there is a need for an approach for an improved object detection.

[0003] It is an objective to provide for a computer-implemented method, a computer program, and a computer device for detecting one or more objects using at least two radar sensors of a stereo radar assembly arranged spaced apart from each other. The objectives underlying the invention are solved by the features of the independent claims.

SUMMARY

[0004] In one aspect a computer-implemented method is disclosed for detecting one or more objects using at least two radar sensors of a stereo radar assembly arranged spaced apart from each other. The method comprises receiving first radar signal data determined using a first radar sensor of the at least two radar sensors. The first radar signal data is descriptive of characteristics of first radar signals acquired using the first radar sensor. Second radar signal data determined using a second radar sensor of the at least two radar sensors is received. The second radar signal data is descriptive of characteristics of second radar signals acquired using the second radar sensor. Using the first radar signal data one or more first combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the first radar signal data. Using the second radar signal data one or more second combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the second radar signal data. For one or more of the determined one or more first and second combinations of distance and radial velocity a first spectrum descriptive of intensities as a function of an azimuth and elevation angle is determined using the first radar signal data. Furthermore, a second spectrum descriptive of intensities as a function of the azimuth and elevation angle is determined using the second radar signal data. Furthermore, one or more positions of one or more objects in terms of the azimuth and elevation angle are determined using the first and second spectrum. The determining comprises a matching and a comparing of the first and second spectrum.

[0005] This method may enable an efficient implementation of a stereo radar approach in order to improve the performance of a radar system. This approach does not require the software of the radar system or the hardware to be extensively adapted. The at least two radar sensors in question may be two radar sensors arranged spaced apart from each other. In the following, such a combination of at least two radar sensors whose ranges of detection at least partially overlap is referred to as a stereo radar assembly. The at least two radar sensors may, e.g., be independent of one another, i.e., may not or only roughly be synchronized with one another

The individual radar sensors of the at least two radar sensors may, e.g., be operated in a monostatic mode and/or in a bistatic mode. The at least two radar sensors may, e.g., be operated in a multistatic mode. In the monostatic mode, a radar sensor is operated as a receiver for receiving reflected radar signals emitted by the same radar sensor, i.e., receiver and transmitter are co-located in form of the respective radar sensor. In the bistatic mode, a radar sensor is operated as a receiver for receiving reflected radar signals emitted by another radar sensors of the at least two radar sensors, i.e., receiver and emitter are arranged spaced apart from each other. In the multistatic mode, a radar sensor is operated as a receiver for receiving reflected radar signals emitted by multiple other radar sensors in case of an assembly of more than two radar sensors. In case of an assembly comprising a number of $n > 2$ sensors, a sensor of the assembly operated in the multistatic mode may, e.g., be used as a receiver for receiving radar signals emitted by up to $n - 1$ other radar sensor of the assembly.

[0006] Each radar sensor of the stereo radar assembly may, e.g., transmit radar signals. These radar signals may interact with objects, e.g., be reflected, scattered, and/or diffracted, and due to these interactions being received by the emitting radar sensor and/or one or more other radar sensors of the assembly.

[0007] In monostatic mode, a single radar sensor is used as both transmitter and receiver of a radar signal. The radar sensor emits radar signals and receives reflections of the emitted radar signals. Using the reflected radar signals acquired by the radar sensor, the distances, velocities, and/and other characteristics of the reflecting objects may be determined. When being operated in monostatic mode only, the first radar signal data may be descriptive of intensities of first radar signals received by the first radar sensor with the received first radar signals being emitted by the first radar sensor. When being operated in monostatic mode only, the second radar signal data may be descriptive of intensities of second radar signals received by the second radar sensor with the received second radar signals being emitted by the second radar sensor.

[0008] In bistatic mode, different radar sensors arranged spaced apart from each other are used as transmitter and receiver of a radar signal. The transmitter radar sensor emits radar signals which interact with objects, e.g., be reflected, scattered, and/or diffracted. The receiver radar sensor arranged spaced apart from the transmitter radar sensor receives the radar signals due to the interaction. When being operated in bistatic mode only, the first radar signal data may be descriptive of intensities of first radar signals received by the first radar sensor with the received first radar signals being emitted by the second radar sensor. When being operated in bistatic mode only, the second radar signal data may be descriptive of intensities of second radar signals received by the second radar sensor with the received second radar signals being emitted by the first radar sensor.

[0009] When being operated in monostatic and bistatic mode, the first radar signal data may be descriptive of a combination of intensities of first radar signals received by the first radar sensor with the received first radar signals comprising radar signals emitted by the first radar sensor as well as radar signals emitted by the second radar sensor. Thus, the first radar signal data may comprise a combination of radar signal data descriptive of received radar signals emitted by the first radar sensor and radar signal data descriptive of received radar signals emitted by the second radar sensor. When being operated in monostatic and bistatic mode, the second radar signal data may be descriptive of a combination of intensities of second radar signals received by the second radar sensor with the received second radar signals comprising radar signals emitted by the first radar sensor as well as radar signals emitted by the second radar sensor. Thus, the second radar signal data may comprise a combination of radar signal data descriptive of received radar signals emitted by the first radar sensor and radar signal data descriptive of received radar signals emitted by the second radar sensor.

[0010] In case of more than two radar sensors, e.g., n radar sensors, the first radar signal data may comprise a combination data descriptive of received radar signals emitted by n or less radar sensors of the n radar sensors. In case of more than two radar sensors, e.g., n radar sensors, the second radar signal data may comprise a combination data descriptive of received radar signals emitted by n or less radar sensors of the n radar sensors.

[0011] For an assembly comprising n > 2 radar sensors arranged spaced apart from each other, the method may, e.g., comprise receiving first to n-th radar signal data determined using a first to n-th radar sensor of the n radar sensors. The first to n-th radar signal data being descriptive of characteristics of first to n-th radar signals acquired using the first to n-th radar sensor. Using the first to n-th radar signal data one or more first to n-th combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the first to n-th radar signal data. For one or more of the determined one or more first to n-th combinations of distance and radial velocity a first to n-th spectrum descriptive of intensities as a function of an azimuth and elevation angle is determined using the first to n-th radar signal data. Furthermore, one or more positions of one or more objects in terms of the azimuth and elevation angle are determined using the first to n-th spectrum. The determining comprises a matching and a comparing of the first to n-th spectrum.

[0012] For example, the radar signals emitted by the at least two radar sensors may have different waveforms in order to, e.g., reduce a likelihood of interference and improve coexistence of the different radar signals. For example, different frequency bands may be allocated to different radar sensors. By operating on different frequency bands, i.e., non-overlapping frequency ranges, the potential for interferences between radar signals emitted by different radar sensors may be reduced.

[0013] The stereo radar assembly may, e.g., be a stereo radar assembly of a vehicle, in particular a car. The radar sensors of the stereo radar assembly may, e.g., be installed in a vehicle, in particular a car, and may be configured to detect the surroundings of the vehicle, i.e., objects in the surroundings of the vehicle. For example, the stereo radar assembly may comprise radar sensors of a front radar, a corner radar, a side radar and/or a back radar of a vehicle, e.g., a car.

[0014] Such a stereo radar assembly may be used in a vehicle, e.g., for implementing functions of an assisted, automated and/or autonomous driving system. For example, such a stereo radar assembly may be used in car for an adaptive cruise control (ACC). An adaptive cruise control is a type of advanced driver-assistance system for road vehicles that is configured for automatically adjusting the vehicle's speed, e.g., to maintain a safe distance from vehicles ahead. For example, the adaptive cruise control may be part of a radar-based emergency braking assistant. Furthermore, such a stereo radar assembly may, e.g., be used for a cross traffic alert (CTA) in order to be able to detect cross traffic, e.g., behind the vehicle. Such a cross traffic alert may, e.g., work in conjunction with a blind spot monitoring system and be configured for warning the driver of approaching cross traffic when reversing out of a parking spot.

[0015] A stereo radar assembly, similar to a stereo camera system in the field of optical imaging, may allow for improving a performance of a radar system by combining radar signal data of at least two radar sensors arranged spaced apart from each other. Radar frequencies typically used for radars in vehicles may, e.g., be in the range of 76 to 77 GHz corresponding to a wavelength of about 4 mm.

[0016] Radar sensors are devices which are used to emit a radar signal and detect reflections of the emitted radar signal from objects within the ranges of detection of the radar sensors. The characteristics of these reflections and thus of the detected radar signal may depend on features of reflecting objects within the ranges of detection of the radar sensors. These features of the objects may, e.g., comprise position, size, shape, surface conditions, motion characteristics, and/or motion trajectory. The reflected radar signals acquired by the radar sensors may, e.g., comprise radar signals emitted by one or more radar sensors. For example, the first radar signal acquired using the first radar sensor may result from reflections of a radar signal emitted by the first radar sensor and/or the second radar sensor. The second radar signal acquired using the second radar sensor may, e.g., result from reflections of a radar signal emitted by the second radar sensor and/or the first radar sensor. The reflected radar signals acquired by the radar sensors may, e.g., be descriptive of positions of one or more objects being detected, e.g., defined by a distance, an azimuth angle, and an elevation angle, as well as of radial velocities relative to radar sensors. Thus, radar signal data descriptive of such a radar signal may comprise four-dimensional information about objects within a range of detection of a radar sensor. This four-dimensional information may comprise distance, azimuth angle, elevation angle, and radial velocity of the detected object relative to the detecting radar sensor. A presence of an object within the range of detection of a radar sensor may, e.g., be indicated by an intensity peak of the acquired radar signal and thus of the radar signal data descriptive of the respective radar signal. By determining dependences of intensity peaks comprised by the radar signal data on distance, azimuth angle, elevation angle, and/or radial velocity distances, azimuth angles, elevation angles, and/or radial velocities of objects within the range of detection of the radar sensor may be determined.

[0017] Radar signal data may, e.g., be provided in form of an acquired radar signal or radar signal data may, e.g., be provided in form of a processed radar signal acquired using a radar sensor.

[0018] For example, a range-Doppler profile may be determined using the radar signal data descriptive of the radar signal, i.e., the detected radar reflections. A range-Doppler profile may be provided in form of a graphical two-dimensional representation of intensities of radar reflections received from objects in the range of detection of a radar sensor as a function of range, i.e., distance, and Doppler frequency shift, i.e., radial velocity of the respective objects relative to the radar sensor.

[0019] For example, frequency modulated continuous wave (FMCW) radar sensors may be used. In case of a FMCW radar sensor, the transmitted radar signal is frequency modulated. This frequency modulation enables a distance measurement using an indirect time-of-flight measurement by comparing the frequency of the received radar signal with a reference, e.g., the emitted radar signal. Furthermore, radial velocities may be measured Doppler shifts of the received radar signal. Depending upon an object relative distance and radial velocity to the radar sensor, the acquired reflected radar signal may comprise frequency variations. These frequency variations may be processed using suitable techniques, like Fast Fourier Transform (FFT), to extract characteristics of objects, like distances and/or radial velocities. Thus, by performing an FFT on the acquired reflected radar signals or the radar signal data descriptive of the radar signals positions of detected objects, defined in terms of distance, azimuth angle and/or elevation angle, and/or radial velocities may be determined. This analysis may, e.g., aid in target detection, target identification, target tracking, and other applications in autonomous driving systems.

[0020] Range-Doppler profiles of an object determined by two radar sensors spaced apart from each may differ from each other. The range-Doppler profiles may be descriptive of intensity spectra or power spectra of the radar signals acquired by the radar sensors. In the monostatic mode, i.e., with radar sensor data determined using radar sensors operated in monostatic mode, the range-Doppler profiles may be descriptive of intensity spectra or power spectra of radar signals emitted and received by the same radar sensor. In the bistatic mode, i.e., with radar sensor data determined using radar sensors operated in bistatic mode, the range-Doppler profiles may be descriptive of intensity spectra or power spectra of radar signals emitted and received by different radar sensors arranged spaced apart from each other. In a combined monostatic and bistatic mode, i.e., with radar sensor data determined using radar sensors operated in combined monostatic and bistatic mode, the range-Doppler profiles may be descriptive of intensity spectra or power spectra of a combination of radar signals emitted and received by the same radar sensor with radar signals emitted and received by different radar sensors arranged spaced apart from each other.

[0021] The intensity spectra or power spectra may be descriptive of intensity or power distributions over distance and radial velocity. An intensity or power spectrum determined using the first radar sensor of the at least two-radar system is referred to as a first spectrum and an intensity or power spectrum determined by the second radar sensor of the at least two-radar system is referred to as a second spectrum. Depending on the mode used to determine the first radar signal data, the first spectrum may, e.g., be a spectrum of radar signals received and emitted by the first radar sensor and/or radar signals received by the first radar sensor, but emitted by another radar sensor of the assembly arranged spaced apart from the first radar sensor, e.g., the second radar sensor. Depending on the mode used to determine the second radar signal data, the second spectrum may, e.g., be a spectrum of radar signals received and emitted by the second radar sensor and/or radar signals received by the second radar sensor, but emitted by another radar sensor of the assembly arranged spaced apart from the second radar sensor, e.g., the first radar sensor.

[0022] Intensity I and power P are proportional to each other with an area A as a proportionality constant, i.e. $I = P/A$. Thus, an intensity spectrum and a power spectrum are proportional to each other.

[0023] For the purpose of determine a range-Doppler profile, a parameter space spanned by distance and radial velocity may, e.g., be discretized by dividing it into intervals or bins. The bins may be specified as consecutive, non-overlapping intervals of the variables distance and radial velocity. The bins may be adjacent and of equal size. Each bin may be assigned with an accumulation of the radar signal data assigned to a distance and a velocity comprised by the respective bin. Based on intensity peaks, bins may be identified with radar signal data descriptive of one or more objects being present or detected. For these bins, e.g., intensity or power spectra may be determined as a function of azimuth angle and elevation angle, which corresponds to a two-dimensional image from which a position of the corresponding object or objects within the area spanned by azimuth and elevation angle may be determined. Such an intensity or power spectrum may describe a two-dimensional distribution of intensity or power of a radar signal depending on the azimuth and elevation angle for radar signal data assigned to a distance and a velocity comprised by the respective bin. Thus, a spatial arrangement of objects in terms of azimuth and elevation angle at distances within the same interval of distances and with radial velocities within the same interval of radial velocities may be determined.

[0024] For example, a presence of the one or more objects is determined in response to determining intensity peaks within the first and second spectrum at matching positions in terms of the azimuth and elevation angle. By using radar signal data of two radar sensors, higher SNR and/or precision may be achievable and consequently false positives and/or false negatives may be avoided. For example, a presence of an object may be positively detected, in case it is detectible at matching positions in terms of the azimuth and elevation angle within the radar signal data of both radar sensors. This may even be the case for comparatively low intensity peaks enabling a detection of low SNR objects and/or occluded objects. On the other hand, without a matching, intensity peaks may be discarded in order to avoid false positives.

[0025] The azimuth and elevation angle may when matching the first and second spectrum be coordinates of a global coordinate system used to locate the position of the objects relative to the stereo radar assembly and consequently, e.g., relative to a car. For each individual radar sensors azimuth and elevation angle may be defined in a local coordinate system relative to the respective radar sensors. These local coordinate systems may differ from one another as they are arranged spaced apart to each other. By transforming these local coordinates to the global coordinate system positions may be commonly defined relative to the stereo radar assembly comprising both radar sensors.

[0026] For example, the first and second combinations of distance and radial velocity comprise combinations of intervals of distances and intervals of radial velocities according to a predefined distribution of intervals. These intervals are designated as bins which may be specified as consecutive, non-overlapping ranges of values. The range of parameter values, i.e., distance and radial velocity, may be divided into a series of intervals. Different combinations of distance and radial velocity may fall in different intervals. Thus, range of parameter values may be discretized.

[0027] The parameter space of distance and radial velocity may, e.g., be discretized by dividing it into intervals or bins. Based on intensity peaks, bins may be identified within which one or more objects are present or detected. For these bins, e.g., an intensity or power spectrum may be determined as a function of azimuth angle and elevation angle. Such an intensity or power spectrum for a specific bin corresponds to a two-dimensional image, from which a position of the corresponding object or objects within the area spanned by azimuth and elevation angle may be determined.

[0028] For example, a first distribution of intervals used for the determining of the first combinations of distance and radial velocity is shifted relative to a second distribution of intervals used for the determining the second combinations of distance and radial velocity. Thus, bins defined for the analysis of the first radar signal data may, e.g., be shifted relative to bins defined for the analysis of the second radar signal data. Thus, a border between two bins defined for the first radar sensor may, due to the shifting, correspond to a combination of parameter values within a bin defined for the second radar sensor. It may, e.g., correspond to the middle of the bin defined for the second radar sensor, in case the bins are shifted by half a bin’s width. This shift may result in a slightly different assignment of radar signal data to bins for the different radar sensors. For example, radar signal data assigned to two different adjacent bins defined for the first radar sensor may be assigned to the same bin in case of the second radar sensor. This may further improve a detection of objects, since effects only resulting from the selection of the borders of the bins may be compensated and thus avoided.

[0029] For example, a global coordinate system descriptive of the azimuth and elevation angle is used for determining the first and second spectrum. The using of the global coordinate system comprises transforming first local coordinates of a first local coordinate system assigned to the first radar sensor and second local coordinates of a second local coordinate system assigned to the second radar sensor into global coordinates of the global coordinate system.

[0030] Transforming the local coordinates to a global coordinate system may enable a definition of a common volume sensed by the two radar sensors. This volume may, e.g., be a 3D space spanned using a common distance, azimuth angle and elevation angle as coordinates. Intensity or power of the radar signals detected by the two radar sensors may be assigned to positions within this volume and describe a strength of radar signal reflections of objects arranged at these positions. The acquired radar signals may be analyzed using different interval, i.e., bins, defined based on a discretization of the respective common volume. For example, bins may be defined using distance and radial velocity. Each interval or bin in this volume may, e.g., have two channels namely a power or intensity spectrum determined using first radar signal data of the first radar sensor and a power or intensity spectrum determined using second radar signal data of the second radar sensor. For example, a machine learning module comprising, e.g., an architecture of a neural network, may be trained and used to regularize the power spectra. The neural network may, e.g., comprise convolutional neural network (CNN) layers used for the regularization.

[0031] For example, a machine learning module is used for the determining of the one or more positions of the one or more objects. The machine learning module is trained for providing the one or more positions of the one or more objects in response to receiving the first and second spectrum as an input. The matching and comparing of the first and second spectrum may, e.g., be executed by the machine learning module. In case of $n > 2$ radar sensors, machine learning module may, e.g., be trained for providing the one or more positions of the one or more objects in response to receiving the first to n-th spectrum as an input.

[0032] For example, the machine learning module comprises one or more neural networks. The one of more neural networks may, e.g., comprise one or more of the following: a feed-forward neural network, a convolutional neural network. A feed-forward neural network is also known as a multilayer perceptron (MLP) where the flow of information through the network occurs in a single direction, from the input layer through one or more hidden layers to the output layer, without any loops or feedback connections. A convolutional neural network is a type of deep learning model designed specifically for image classification, object detection, and image segmentation. Its ability to automatically learn hierarchical representations from raw input data makes it well-suited for analyzing images and other grid-like data structures. A convolutional neural network consists of an input layer, hidden layers, and an output layer. The hidden layers comprise one or more layers that perform convolutions, i.e., convolutional layers. As the convolution kernel slides along an input matrix for a layer, the convolution operation may generate a feature map, which in turn contributes to the input of a next layer. The one or more convolutional layers may be followed by other layers such as pooling layers, fully connected layers, and/or normalization layers.

[0033] For example, Fast-ABC may be used as a neural network, such as described in Xiaoru Xie et al., "Fast-ABC: A Fast Architecture for Bottleneck-Like Based Convolutional Neural Networks," in 2019 IEEE Computer Society Annual Symposium on VLSI (ISVLSI), pages 1 to 6. Fast-ABC provides an accelerator for BLO(Bottleneck-Like Operations)-based convolutional networks.

[0034] Neural networks may be able to efficiently learn the matching between the spectra at positions with and without objects. These neural networks are trained to fuse the power spectra at different locations in the global coordinate system. Since the idea of stereo radar matching is not yet explored in previous studies, concepts used in stereo algorithms for optical images may be utilized to design the neural network architecture. The stereo algorithms for optical images may be used to extract depth information from pairs of stereo images by matching corresponding points between the images in pair, thereby inferring the 3D structure of the object with improved accuracy.

[0035] For example, the machine learning module comprises one or more encoder-decoder blocks with residual layers trained for determining similarities between the first and second spectrum as an output in response to receiving the first and second spectrum as an input.

[0036] Due to the presence of noise in the radar signal data, the power spectra of the two radar sensors may not exactly match and display some deviations from each other. Thus, the data may be passed to one or more encoder-decoder blocks, i.e., hourglass blocks, with residual layers to regularize the data, find similarities between channels, and mitigate the noise effect. These encoder-decoder blocks may further be able to extract information at various levels of detail, from fine-grained details to more global details, which contributes to enhancing the resolution. The output of the neural network may indicate positions, at which objects are present. Since the results of two radars are used, by matching and comparing the first and second spectrum of the respective first and second radar sensor, one or more positions of one or more objects in terms of the azimuth and elevation angle may be determined with improved accuracy. To decrease the processing time and avoid unnecessary computations, the calculations may be limited to the detection areas of the radar sensors from where intensity peaks are acquired. Thus, the calculations may be limited to areas with potential objects.

[0037] For example, a machine learning module to be trained may be provided. A set of training datasets may be provided for training the machine learning module to be trained. For example, each training dataset may comprise a first training spectrum and a second training spectrum as well as a training specification of one or more positions of one or more objects. The first training spectrum is descriptive of intensities of a first training radar signal as a function of an azimuth and elevation angle. The second training spectrum is descriptive of intensities of a second training radar signal as a function of an azimuth and elevation angle. The machine learning module to be trained may be trained to provide the one or more positions of one or more objects defined by the training specifications of the training datasets as an output in response to receiving the first and second training spectra of the respective training datasets as an input.

[0038] For n > 2 radar sensors, the training datasets may, e.g., comprise a first to n-th training spectrum as well as a training specification of one or more positions of one or more objects. The first to n-th training spectrum is descriptive of intensities of a first to n-th training radar signal as a function of an azimuth and elevation angle. The machine learning module to be trained may be trained to provide the one or more positions of one or more objects defined by the training specifications of the training datasets as an output in response to receiving the first to n-th training spectra of the respective training datasets as an input.

[0039] For example, one or more vectorial velocities of the one or more objects are determined. The determining of the one or more vectorial velocities comprises using the determined one or more positions of the one or more objects and the one or more radial velocities of the one or more objects determined using the first and second radar signal data. A vectorial velocity of an object refers to the changes in both the position and radial velocity over time, providing a comprehensive description of the objects motion. It may particularly be useful for example in autonomous driving system to obtain the total velocity of the detected object including its magnitude and direction.

[0040] In another aspect, a computer program is disclosed for detecting one or more objects using at least two radar sensors of a stereo radar assembly arranged spaced apart from each other. The computer program comprises program instructions, which are executable by a processor of a computer device to cause the computer device to receive first radar signal data determined using a first radar sensor of the at least two radar sensors. The first radar signal data is descriptive of characteristics of first radar signals acquired using the first radar sensor. Second radar signal data determined using a second radar sensor of the at least two radar sensors is received. The second radar signal data is descriptive of characteristics of second radar signals acquired using the second radar sensor. Using the first radar signal data one or more first combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the first radar signal data. Using the second radar signal data one or more second combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the second radar signal data. For one or more of the determined one or more first and second combinations of distance and radial velocity a first spectrum descriptive of intensities as a function of an azimuth and elevation angle is determined using the first radar signal data. Furthermore, a second spectrum descriptive of intensities as a function of the azimuth and elevation angle is determined using the second radar signal data. Furthermore, one or more positions of one or more objects in terms of the azimuth and elevation angle are determined using the first and second spectrum. The determining comprises a matching and a comparing of the first and second spectrum.

[0041] The program instructions comprised by the computer program may further be executable by the processor of the computer device to cause the computer device to execute any of the aforementioned examples of the computer-implemented method for detecting the one or more one or more objects using the at least two radar sensors of the stereo radar assembly arranged spaced apart from each other.

[0042] For example, a computer program product for detecting one or more objects using at least two radar sensors of a stereo radar assembly arranged spaced apart from each other comprises a computer readable storage medium having program instructions embodied therewith. The program instructions are executable by a processor of a computer device to cause the computer device to receive first radar signal data determined using a first radar sensor of the at least two radar sensors. The first radar signal data is descriptive of characteristics of first radar signals acquired using the first radar sensor. Second radar signal data determined using a second radar sensor of the at least two radar sensors is received. The second radar signal data is descriptive of characteristics of second radar signals acquired using the second radar sensor. Using the first radar signal data one or more first combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the first radar signal data. Using the second radar signal data one or more second combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the second radar signal data. For one or more of the determined one or more first and second combinations of distance and radial velocity a first spectrum descriptive of intensities as a function of an azimuth and elevation angle is determined using the first radar signal data. Furthermore, a second spectrum descriptive of intensities as a function of the azimuth and elevation angle is determined using the second radar signal data. Furthermore, one or more positions of one or more objects in terms of the azimuth and elevation angle are determined using the first and second spectrum. The determining comprises a matching and a comparing of the first and second spectrum.

[0043] The program instructions provided by the computer program product may further be executable by the processor of the computer device to cause the computer device to execute any of the aforementioned examples of the computer-implemented method for detecting the one or more objects using the at least two radar sensors of the stereo radar assembly arranged spaced apart from each other.

[0044] In another aspect a computer device is disclosed for detecting one or more objects using at least two radar sensors of a stereo radar assembly arranged spaced apart from each other. The computer device comprises a processor and a memory storing program instructions executable by the processor. Execution of the program instructions by the processor causes the computer device to receive first radar signal data determined using a first radar sensor of the at least two radar sensors. The first radar signal data is descriptive of characteristics of first radar signals acquired using the first radar sensor. Second radar signal data determined using a second radar sensor of the at least two radar sensors is received. The second radar signal data is descriptive of characteristics of second radar signals acquired using the second radar sensor. Using the first radar signal data one or more first combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the first radar signal data. Using the second radar signal data one or more second combinations of distance and radial velocity are determined, for which an intensity peak is comprised by the second radar signal data. For one or more of the determined one or more first and second combinations of distance and radial velocity a first spectrum descriptive of intensities as a function of an azimuth and elevation angle is determined using the first radar signal data. Furthermore, a second spectrum descriptive of intensities as a function of the azimuth and elevation angle is determined using the second radar signal data. Furthermore, one or more positions of one or more objects in terms of the azimuth and elevation angle are determined using the first and second spectrum. The determining comprises a matching and a comparing of the first and second spectrum.

[0045] Execution of the program instructions stored in the memory by the processor may further cause the computer device to execute any of the aforementioned examples of the computer-implemented method for detecting the one or more one or more objects using the at least two radar sensors of the stereo radar assembly arranged spaced apart from each other.

[0046] It is understood that one or more of the aforementioned examples may be combined as long as the combined embodiments are not mutually exclusive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0047] In the following, examples are described in greater detail making reference to the drawings in which:

[0048] Fig. 1 shows a flowchart illustrating an exemplary method for detecting one or more objects using at least two radar sensors arranged spaced apart from each other;

[0049] Fig. 2 shows a diagram illustrating an exemplary detecting of an object using radial distance and angle relative to two radar sensors arranged spaced apart from each other; and

[0050] Fig. 3 shows block diagram of an exemplary computer device for detecting one or more objects using at least two radar sensors arranged spaced apart from each other.

DETAILED DESCRIPTION

[0051] In the following, similar elements are denoted by the same reference numerals.

[0052] Fig. 1 shows an exemplary method for detecting one or more objects using at least two radar sensors arranged spaced apart from each other.

[0053] In block 200, first radar signal data is received using a first radar sensor. In block 202, second radar signal data is received using a second radar sensor respectively. The first and second signal data may, e.g., be received in form of separated datasets. The first and second signal data may, e.g., be received together. These received radar signal data are descriptive of characteristics, e.g., intensities, of the radar signals. For example, an intensity peak in received radar signal data signifies an object detection. The radar signal data may be descriptive of a position, in particular distance, and radial velocity of an object, with which it is associated. Therefore, a signal intensity indicative of an object detection may be used to determine the position, where an object may be present, as well as a radial velocity of the object by analyzing the received radar signal data. The first and second radar sensor may, e.g., be operated in monostatic and/or bistatic mode. In case of $n > 2$ radar sensors, the first and second radar sensor may, e.g., be operated in multistatic mode.

[0054] In block 204, one or more first combinations of distance and radial velocity using the first radar signal data may be determined. In block 206, one or more second combinations of distance and radial velocity using the second radial signal data respectively may be determined. The first and second combinations of distance and radial velocity each may, e.g., be a combination of an interval of distances and an interval of radial velocities according to a predefined distribution of intervals forming a two-dimensional bin. A first distribution of intervals used for the determining the first combinations of distance and radial velocity may be shifted relative to a second distribution of intervals used for the determining the second combinations of distance and radial velocity.

[0055] In block 208, for the first and second combinations of distance and radial velocity determined in block 204 and 206 one or more first spectra using the first radar signal data may be determined. In block 210, for the first and second combinations of distance and radial velocity determined in block 204 and 206 one or more second spectra using the second radar signal data may be determined. A global coordinate system descriptive of the azimuth and elevation angle may be used for determining first and second spectra. The using of the global coordinate system may comprise transforming first local coordinates of a first local coordinate system assigned to the first radar sensor and second local coordinates of a second local coordinate system assigned to the second radar sensor into the global coordinates of the global coordinate system.

[0056] In block 212, determined first and second spectra are matched and compared to determine one or more positions of one or more objects in terms of the azimuth and elevation angle. For example, the method further comprises using a machine learning module for the determining of the one or more positions of the one or more objects. The machine learning module may be trained for providing the one or more positions of the one or more objects in response to receiving the first and second spectrum as an input. The machine learning module may, e.g., comprise one or more neural networks. The one of more neural networks may, e.g., comprise one or more of the following: a feed-forward neural network and/or a convolutional neural network. When determining the one or more positions of the one or more objects, furthermore vectorial velocities of the detected objects may be determined. Such a determination of vectorial velocities of detected objects may be an important component in autonomous driving systems, which are required to guide a vehicles motion and to help making decisions related to path planning, obstacle avoidance, speed control, and overall safety.

[0057] Fig. 2 illustrates an exemplary detection of an object using two radar sensors arranged spaced apart from each other, i.e., a first radar sensor 310 and a second radar sensor 312. Here, an exemplary detection using a monostatic mode of operation is illustrated. For the object a first power P_1 spectrum 302 is determined using first radar signal data acquired with the first radar sensor 310 as well as second P_2 spectrum 304 using second radar signal data acquired with the second radar sensor 312. The power spectra 302, 304 may, e.g., be descriptive of radar signal intensities as a function of an azimuth and elevation angle. The azimuth angles θ_1, θ_2 shown in Fig. 2 may, e.g., be determined in local coordinate systems assigned to the individual radar sensors 310, 312. Using a coordinate transformation, the power spectra 302, 304 may be described in a global coordinate system descriptive of azimuth and elevation angle defined relative to the radar sensor assembly 314. Using the global coordinate system may comprise transforming first local coordinates of a first local coordinate system assigned to the first radar sensor 310 and a second local coordinates of a second local coordinate system assigned to the second radar sensor 314 into the global coordinates of the global coordinate system.

[0058] Fig. 3 illustrates an exemplary computer device 102 for detecting one or more objects using at least two radar sensors arranged spaced apart from each other. The computer device 102 may be integrated in a vehicle, e.g., a car. For example, the computer device 102 is intended to represent one or more computer devices, which may be distributed. The computer device 102 is shown as comprising a computational system 104. The computational system 104 is intended to represent one or more computational systems. The computer device 102 is further shown as containing an optional hardware interface 106. The hardware interface may enable the computational system 104 to control other components such as a sensor, like a radar sensor for acquiring signal data of objects, if such other components are present. The computational system 104 is further shown as being in communication with an optional user interface 108. The user interface 108 may for example also include a display device, e.g., a display device in a car. A display could include such things as a two-dimensional computer display, a touchscreen, a virtual reality system, and an augmented reality system.

[0059] The computational system 104 is further shown as being in communication with a memory 110. The memory 110 is intended to represent various types of memory which the computational system 104 may have access to. In one example the memory 110 is a non-transitory storage medium.

[0060] The memory 110 is shown as containing machine-executable instructions 120. The machine-executable instructions 120 may enable the computational system 104 to perform various numerical, stereo processing, and computational tasks. The machine-executable instructions 120 may also enable the computational system 104 to control and operate other components via the hardware interface 106, like a radar sensor. Execution of the machine-executable instructions 120 by the computational system 104 may cause the computational system 104 to control the computer device 102 to execute the method for detecting one or more objects, e.g., as illustrated in Fig. 1. The memory 110 is further shown as containing a first spectrum module 122. The memory 110 is further shown as containing a second spectrum module 124. The first spectrum module 122 and the second spectrum module 124 are configured to determine the characteristics, e.g., intensities, of received radar signal data acquired using the first and second radar sensors. Alternatively, a single spectrum module may be used for determining the characteristics of the received radar signal data. The memory 110 is further shown as containing a machine learning module 130. The machine learning module 130 may, e.g., comprise two architectures of neural network referred as stereo processing module 126 and encoder-decoder module 128. The stereo processing module 126 may be configured for extracting depth information by matching the pairs of stereo images. It may involve stereo algorithms for images that matches corresponding points between the images in pair to estimate disparity, which represents the pixel-level depth or 3D position differences between the images. For example, first and second spectra determined using the spectrum modules 122, 124 may, e.g., be provided as input in form of two-dimensional images to the stereo processing module 126. The encoder-decoder module 128 may be trained to find similarities between spectra and mitigate noise effects that may be comprised in the received radar signal data. The stereo process module 126, the encoder-decoder module 128 of the machine learning module 130 may work together to learn and model complex input-output relationships. The machine learning module 130 may further provide complementary functions to the stereo processing module 126 and the encoder-decoder module 128, where the stereo processing module 126 and the encoder-decoder module 128 provide a structured framework for generating outputs, which may be postprocessed by the machine learning module 130, e.g., for optimizing and/or improving an overall output. Overall, the machine learning module 130 may be trained for providing the one or more positions of the one or more objects with an improved accuracy in response to receiving the first and second spectrum as an input.

[0061] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments.

[0062] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

[0063] A single processor or other unit may fulfill the functions of several items recited in the claims. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

[0064] As will be appreciated by one skilled in the art, aspects of the present invention may be embodied as an apparatus, method, or computer program product. Accordingly, aspects of the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a “circuit,” “module” or “system.” Furthermore, aspects of the present invention may take the form of a computer program product embodied in one or more computer readable medium(s) having computer executable code embodied thereon.

[0065] Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A “computer-readable storage medium” as used herein encompasses any tangible storage medium which may store instructions which are executable by a processor or computational system of a computing device. The computer-readable storage medium may be referred to as a computer-readable non-transitory storage medium. The computer-readable storage medium may also be referred to as a tangible computer readable medium. In some embodiments, a computer-readable storage medium may also be able to store data which is able to be accessed by the computational system of the computing device. Examples of computer-readable storage media include, but are not limited to: a floppy disk, a magnetic hard disk drive, a solid-state hard disk, flash memory, a USB thumb drive, Random Access Memory (RAM), Read Only Memory (ROM), an optical disk, a magneto-optical disk, and the register file of the computational system. Examples of optical disks include Compact Disks (CD) and Digital Versatile Disks (DVD), for example CD-ROM, CD-RW, CD-R, DVD-ROM, DVD-RW, or DVD-R disks. The term computer readable-storage medium also refers to various types of recording media capable of being accessed by the computer device via a network or communication link. For example, data may be retrieved over a modem, over the internet, or over a local area network. Computer executable code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wire line, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

[0066] A computer readable signal medium may include a propagated data signal with computer executable code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device.

[0067] “Computer memory” or “memory” is an example of a computer-readable storage medium. Computer memory is any memory which is directly accessible to a computational system. “Computer storage” or “storage” is a further example of a computer-readable storage medium. Computer storage is any non-volatile computer-readable storage medium. In some embodiments computer storage may also be computer memory or vice versa.

[0068] A “computational system” as used herein encompasses an electronic component which is able to execute a program or machine executable instruction or computer executable code. References to the computational system comprising the example of “a computational system” should be interpreted as possibly containing more than one computational system or processing core. The computational system may for instance be a multi-core processor. A computational system may also refer to a collection of computational systems within a single computer system or distributed amongst multiple computer systems. The term computational system should also be interpreted to possibly refer to a collection or network of computing devices each comprising a processor or computational system. The machine executable code or instructions may be executed by multiple computational systems or processors that may be within the same computing device or which may even be distributed across multiple computing devices.

[0069] Machine executable instructions or computer executable code may comprise instructions or a program which causes a processor or other computational system to perform an aspect of the present invention. Computer executable code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object-oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages and compiled into machine executable instructions. In some instances, the computer executable code may be in the form of a high-level language or in a pre-compiled form and be used in conjunction with an interpreter which generates the machine executable instructions on the fly. In other instances, the machine executable instructions or computer executable code may be in the form of programming for programmable logic gate arrays.

[0070] The computer executable code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

[0071] Aspects of the present invention are described with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the invention. It is understood that each block or a portion of the blocks of the flowchart, illustrations, and/or block diagrams, can be implemented by computer program instructions in form of computer executable code when applicable. It is further understood that, when not mutually exclusive, combinations of blocks in different flowcharts, illustrations, and/or block diagrams may be combined. These computer program instructions may be provided to a computational system of a general-purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the computational system of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0072] These machine executable instructions or computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the flowchart and/or block diagram block or blocks.

[0073] The machine executable instructions or computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0074] A “user interface” as used herein is an interface which allows a user or operator to interact with a computer or computer system. A “user interface” may also be referred to as a “human interface device”. A user interface may provide information or data to the operator and/or receive information or data from the operator. A user interface may enable input from an operator to be received by the computer and may provide output to the user from the computer. In other words, the user interface may allow an operator to control or manipulate a computer and the interface may allow the computer to indicate the effects of the operator's control or manipulation. The display of data or information on a display or a graphical user interface is an example of providing information to an operator. The receiving of data through a keyboard, mouse, trackball, touchpad, pointing stick, graphics tablet, joystick, gamepad, webcam, headset, pedals, wired glove, remote control, and accelerometer are all examples of user interface components which enable the receiving of information or data from an operator.

[0075] A “hardware interface” as used herein encompasses an interface which enables the computational system of a computer system to interact with and/or control an external computing device and/or apparatus. A hardware interface may allow a computational system to send control signals or instructions to an external computing device and/or apparatus. A hardware interface may also enable a computational system to exchange data with an external computing device and/or apparatus. Examples of a hardware interface include but are not limited to: a universal serial bus, IEEE 1394 port, parallel port, IEEE 1284 port, serial port, RS-232 port, IEEE-488 port, Bluetooth connection, Wireless local area network connection, TCP/IP connection, Ethernet connection, control voltage interface, MIDI interface, analog input interface, and digital input interface.

[0076] A “display” or “display device” as used herein encompasses an output device or a user interface adapted for displaying images or data. A display may output visual, audio, and or tactile data. Examples of a display include, but are not limited to: a computer monitor, a television screen, a touch screen, tactile electronic display, Braille screen,

[0077] Cathode ray tube (CRT), Storage tube, Bi-stable display, electronic paper, Vector display, Flat panel display, Vacuum fluorescent display (VF), Light-emitting diode (LED) displays, Electroluminescent display (ELD), Plasma display panels (PDP), Liquid crystal display (LCD), Organic light-emitting diode display (OLED), a projector, and Head-mounted display.

[0078] The term “machine learning” (ML) refers to a computer algorithm used to extract useful information from training datasets by building probabilistic models, which are referred to as machine learning modules or models, in an automated way. A machine learning module may also be referred to as a predictive model. machine learning algorithms build a mathematical model based on sample data, known as “training data”, in order to make predictions or decisions without being explicitly programmed to perform the task. The machine learning module may be performed using a learning algorithm such as supervised or unsupervised learning. The machine learning module may be based on various techniques such as clustering, classification, linear regression, reinforcement, self-learning, support vector machines, neural networks, etc. A machine learning module may, e.g., be a data structure or program such as a neural network, in particular a convolutional neural network, a support vector machine, a decision tree, a Bayesian network etc. The machine learning module may be adapted, i.e., trained to predict an unmeasured value. The trained machine learning module may thus be enabled to predict the unmeasured value as output from other known values as input.

[0079] A machine learning module to be trained may, e.g., be an untrained machine learning module, a pre-trained machine learning module or a partially trained machine learning module. The machine learning module being trained may be an untrained machine learning module, which is trained from scratch. Alternatively, the machine learning module being trained may be a pre-trained or partially trained machine learning module. In general, it may not be necessary to start with an untrained machine learning module, e.g., in deep learning. For example, one may start with a pre-trained or partially trained machine learning module. The pre-trained or partially trained machine learning module may have been pre-trained or partially trained for the same or a similar task. Using a pre-trained or partially trained machine learning may, e.g., enable a faster training of the trained machine learning module to be trained, i.e., the training may converge faster. For example, transfer learning may be used for training a pre-trained or partially trained machine learning module. Transfer learning refers to a machine learning process, which rather than starting the learning process from scratch starts from patterns that have been previously learned, when solving a different problem. This way previous learnings may, e.g., be leveraged, avoiding to start from scratch. A pre-trained machine learning module is a machine learning module that was trained previously, e.g., on a large benchmark dataset to solve a problem similar to the one to be solved by the additional learning. In case of a pre-trained machine learning module a previous learning process has been completed successfully. A partially trained machine learning module is a machine learning module, which has been partially trained, i.e., the training process may not have been completed yet. A pre-trained or partially machine learning module may, e.g., be import and trained to be used for the purposes disclosed herein.

REFERENCE SIGNS LIST

102	computer device
104	computational system
106	hardware interface
108	user interface
110	memory
120	machine-executable instructions
122	first spectrum module
124	second spectrum module
126	stereo processing module
128	encoder-decoder module
130	machine learning module
302	first spectrum
304	second spectrum
306	first radar signal data
308	second radar signal data
310	first radar sensor
312	second radar sensor
314	stereo radar assembly
d_1	distance between first radar sensor and detected object
d_2	distance between second radar sensor and detected object
θ_1	azimuth angle measured from first radar sensor
θ_2	azimuth angle measured from second radar sensor to
P_1	power determined for first radar sensor
P_2	power determined for second radar sensor

CLAIMS

1. A computer-implemented method for detecting one or more objects using at least two radar sensors (310; 312) of a stereo radar assembly (314) arranged spaced apart from each other, the method comprising:

- receiving first radar signal data determined using a first radar sensor (310) of the at least two radar sensors (310; 312), the first radar signal data being descriptive of characteristics of first radar signals acquired using the first radar sensor (310);
- receiving second radar signal data determined using a second radar sensor (312) of the at least two radar sensors (310; 312), the second radar signal data being descriptive of characteristics of second radar signals acquired using the second radar sensor (312);
- determining using the first radar signal data one or more first combinations of distance and radial velocity, for which an intensity peak is comprised by the first radar signal data;
- determining using the second radar signal data one or more second combinations of distance and radial velocity, for which an intensity peak is comprised by the second radar signal data;
- for one or more of the determined one or more first and second combinations of distance and radial velocity:
  - determining for the respective combination of distance and radial velocity a first spectrum (302) descriptive of intensities as a function of an azimuth and elevation angle using the first radar signal data and a second spectrum (304) descriptive of intensities as a function of the azimuth and elevation angle using the second radar signal data; and
  - determining one or more positions of one or more objects in terms of the azimuth and elevation angle using the first and second spectrum (302; 304), the determining comprising a matching and a comparing of the first and second spectrum (302; 304).

2. The method of claim 1, a presence of the one or more objects being determined in response to determining intensity peaks within the first and second spectrum (302; 304) at matching positions in terms of the azimuth and elevation angle.

3. The method of any of the preceding claims, the first and second combinations of distance and radial velocity comprising combinations of intervals of distances and intervals of radial

velocities according to a predefined distribution of intervals, wherein a first distribution of intervals used for the determining of the first combinations of distance and radial velocity is shifted relative to a second distribution of intervals used for the determining the second combinations of distance and radial velocity.

4. The method of any of the preceding claims, further comprising using a global coordinate system descriptive of the azimuth and elevation angle for determining the first and second spectrum (302; 304), the using of the global coordinate system comprising transforming first local coordinates of a first local coordinate system assigned to the first radar sensor (310) and second local coordinates of a second local coordinate system assigned to the second radar sensor (312) into global coordinates of the global coordinate system.

5. The method of any of the preceding claims, further comprising using a machine learning module (130) for the determining of the one or more positions of the one or more objects, the machine learning module (130) being trained for providing the one or more positions of the one or more objects in response to receiving the first and second spectrum (302; 304) as an input.

6. The method of claim 5, the machine learning module (130) comprising one or more neural networks, the one of more neural networks for example comprising one or more of the following: a feed-forward neural network, a convolutional neural network.

7. The method of claim 6, the machine learning module (130) comprising one or more encoder-decoder blocks (128) with residual layers trained for determining similarities between the first and second spectrum as an output in response to receiving the first and second spectrum (302; 304) as an input.

8. The method of any of the preceding claims, further comprising determining one or more vectorial velocities of the one or more objects, the determining of the one or more vectorial velocities comprising using the determined one or more positions of the one or more objects and the one or more radial velocities of the one or more objects determined using the first and second radar signal data.

9. A computer program for detecting one or more objects using at least two radar sensors (310; 312) of a stereo radar assembly (314) arranged spaced apart from each other, the

computer program comprising program instructions, the program instructions being executable by a processor of a computer device (102) to cause the computer device (102) to:

- receive first radar signal data determined using a first radar sensor (310) of the at least two radar sensors (310; 312), the first radar signal data being descriptive of characteristics of first radar signals acquired using the first radar sensor (310);
- receive second radar signal data determined using a second radar sensor (312) of the at least two radar sensors (310; 312), the second radar signal data being descriptive of characteristics of second radar signals acquired using the second radar sensor (312);
- determine using the first radar signal data one or more first combinations of distance and radial velocity, for which an intensity peak is comprised by the first radar signal data;
- determine using the second radar signal data one or more second combinations of distance and radial velocity, for which an intensity peak is comprised by the second radar signal data;
- for one or more of the determined one or more first and second combinations of distance and radial velocity:
    - determining for the respective combination of distance and radial velocity a first spectrum (302) descriptive of intensities as a function of an azimuth and elevation angle using the first radar signal data and a second spectrum (304) descriptive of intensities as a function of the azimuth and elevation angle using the second radar signal data; and
    - determining one or more positions of one or more objects in terms of the azimuth and elevation angle using the first and second spectrum (302; 304), the determining comprising a matching and a comparing of the first and second spectrum (302; 304).

10. A computer device (102) for detecting one or more objects using at least two radar sensors (310; 312) of a stereo radar assembly (314) arranged spaced apart from each other, the computer device comprising a processor and a memory storing program instructions executable by the processor, execution of the program instructions by the processor causing the computer device (102) to:

- receive first radar signal data determined using a first radar sensor (310) of the at least two radar sensors (310; 312), the first radar signal data being descriptive of characteristics of first radar signals acquired using the first radar sensor (310);

- receive second radar signal data determined using a second radar sensor (312) of the at least two radar sensors (310; 312), the second radar signal data being descriptive of characteristics of second radar signals acquired using the second radar sensor (312);
- determine using the first radar signal data one or more first combinations of distance and radial velocity, for which an intensity peak is comprised by the first radar signal data;
- determine using the second radar signal data one or more second combinations of distance and radial velocity, for which an intensity peak is comprised by the second radar signal data;
- for one or more of the determined one or more first and second combinations of distance and radial velocity:
    - determining for the respective combination of distance and radial velocity a first spectrum (302) descriptive of intensities as a function of an azimuth and elevation angle using the first radar signal data and a second spectrum (304) descriptive of intensities as a function of the azimuth and elevation angle using the second radar signal data; and
    - determining one or more positions of one or more objects in terms of the azimuth and elevation angle using the first and second spectrum (302; 304), the determining comprising a matching and a comparing of the first and second spectrum (302; 304).

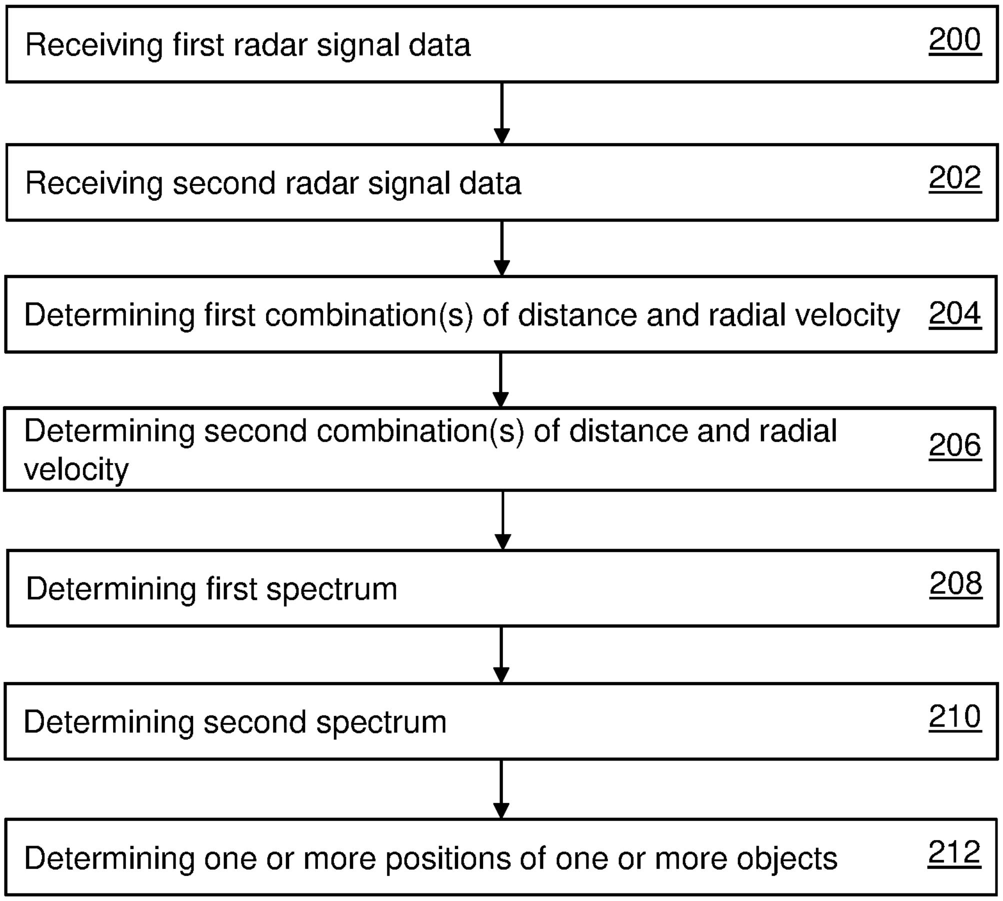
Receiving first radar signal data
200
Receiving second radar signal data
202
Determining first combination(s) of distance and radial velocity
204
Determining second combination(s) of distance and radial velocity
206
Determining first spectrum
208
Determining second spectrum
210
Determining one or more positions of one or more objects
212

Fig. 1

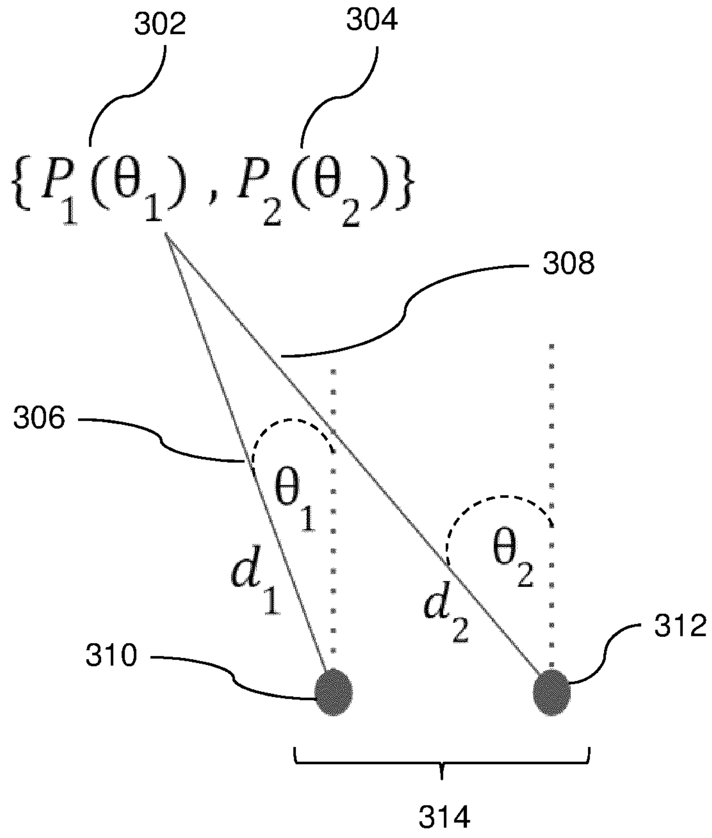

Fig. 2

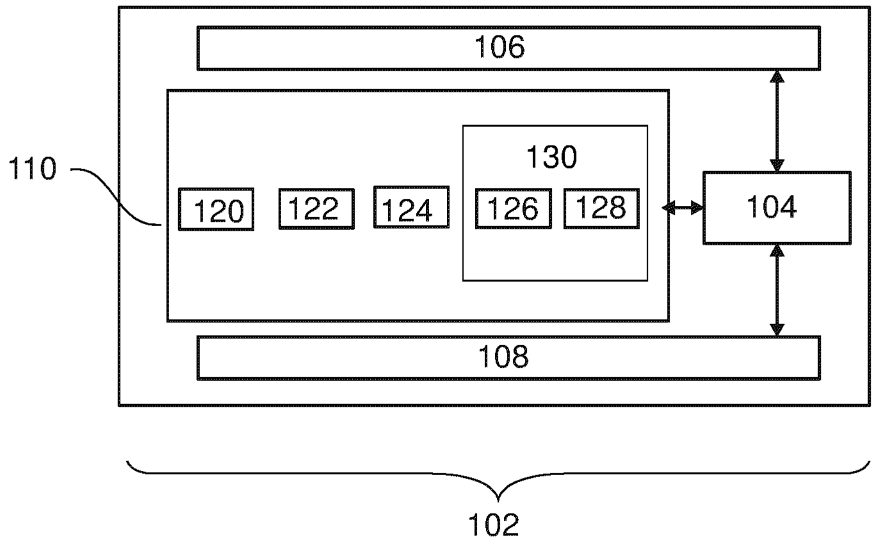

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/075712

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S13/87 G01S13/42 G01S13/58 G01S13/931
ADD. G01S13/34 G01S7/35

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2020 123293 A1 (UNIV FRIEDRICH ALEXANDER ER [DE]; SYMEO GMBH [DE]) 10 March 2022 (2022-03-10) paragraphs [0002], [0006] - [0008], [0010], [0018], [0045] - [0049], [0057], [0058], [0061], [0074], [0084], [0097] - [0099], [0113]; figures 1-6 paragraphs [0126] - [0131]; figure 13 paragraphs [0134] - [0141], [0147] - [0156]; figure 14 paragraphs [0181] - [0198], [0215]; figures 15,16 -----	1-10

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[x] Further documents are listed in the continuation of Box C.

[x] 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
"E" earlier application or patent but published on or after the international filing date
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"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
23 October 2024	05/11/2024

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	Schmelz, Christian

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2019 219649 A1 (BOSCH GMBH ROBERT [DE]) 17 June 2021 (2021-06-17) paragraphs [0026], [0027], [0040], [0042], [0044], [0047], [0049], [0050], [0051], [0060]; figure 1 -----	1-10
X	EP 3 470 874 A1 (SYMEO GMBH [DE]) 17 April 2019 (2019-04-17) paragraphs [0002], [0012], [0019], [0022], [0023], [0056], [0062], [0082], [0084]; figures 1-4 -----	1-10

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/075712

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102020123293 A1	10-03-2022	CN 116507940 A	28-07-2023
		DE 102020123293 A1	10-03-2022
		EP 4211490 A1	19-07-2023
		US 2023314588 A1	05-10-2023
		WO 2022049241 A1	10-03-2022
DE 102019219649 A1	17-06-2021	NONE	
EP 3470874 A1	17-04-2019	NONE	