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(54) **ASSURED VEHICLE ABSOLUTE LOCALISATION**

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See application file for complete search history.

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(57) **ABSTRACT**

It is proposed to provide a system for localizing a vehicle in a marked environment, provided with a set of markers, e.g. on a road side, the markers emitting a position signal indicative of a respective marker's known geographical position. The system comprises a distance detection unit and a processing unit provided in the vehicle, the processing unit adapted to receive said position signal of a respective marker. The processing unit is adapted to receive said known

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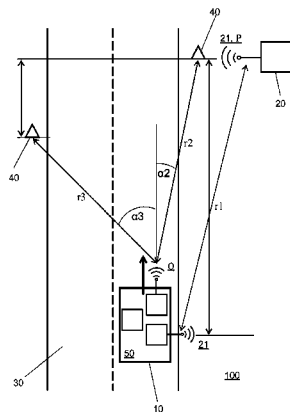
geographical position from the position signal of said respective marker; and to estimate a first distance measure of the vehicle relative to the respective marker based on a position signal measurement. The processing unit feeds said estimated first distance measure to the distance detection unit; the distance detection unit being adapted to detect said marker within the first distance measure by a second distance measure. The distance detection unit is further adapted to provide the processing unit with the second distance measure of the vehicle relative to the detected marker and with a detection angle of the detected marker; and the localization unit calculating an instantaneous geographical position of said vehicle from the second distance measure; the detection angle and the marker's known geographical position.

14 Claims, 6 Drawing Sheets

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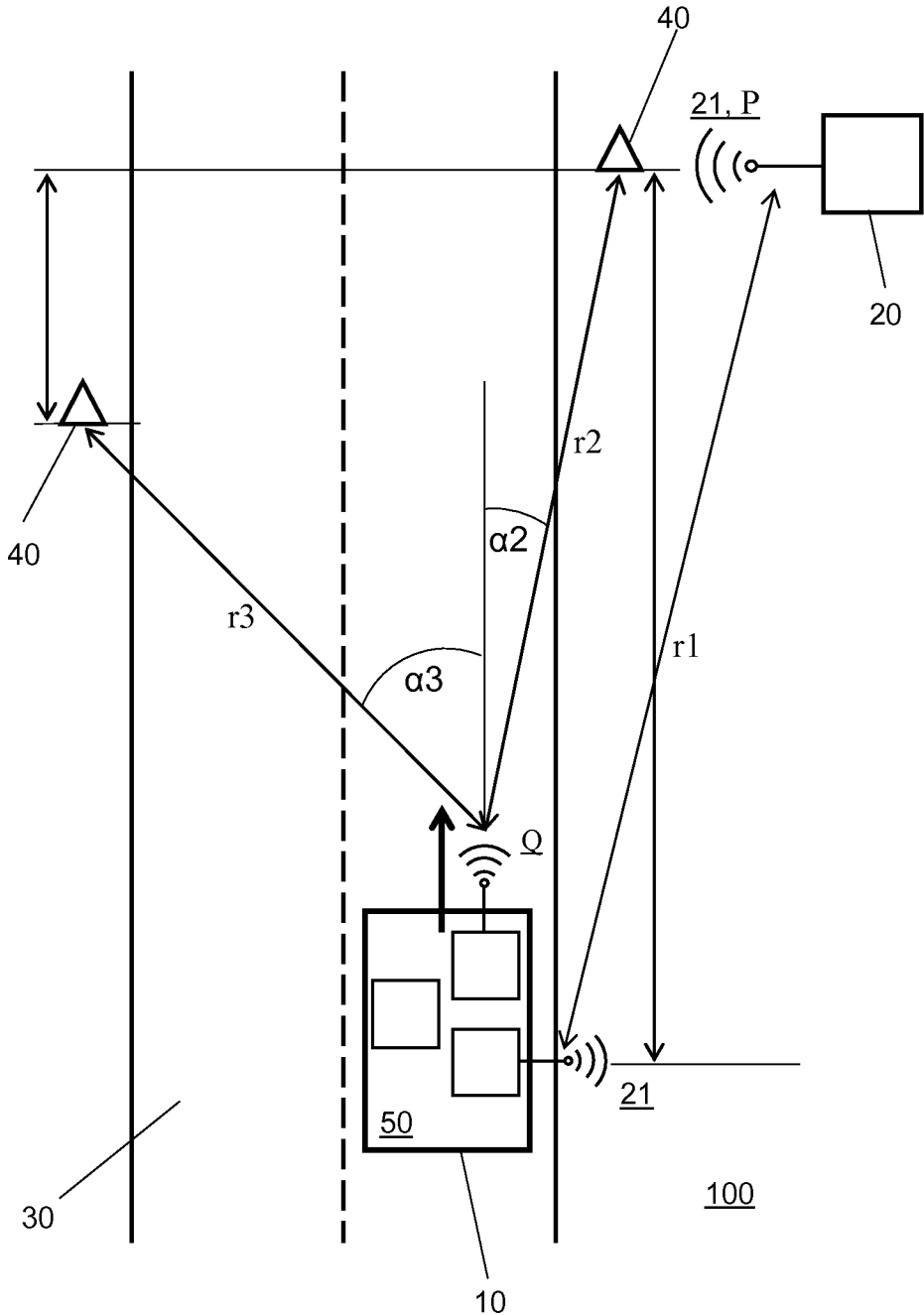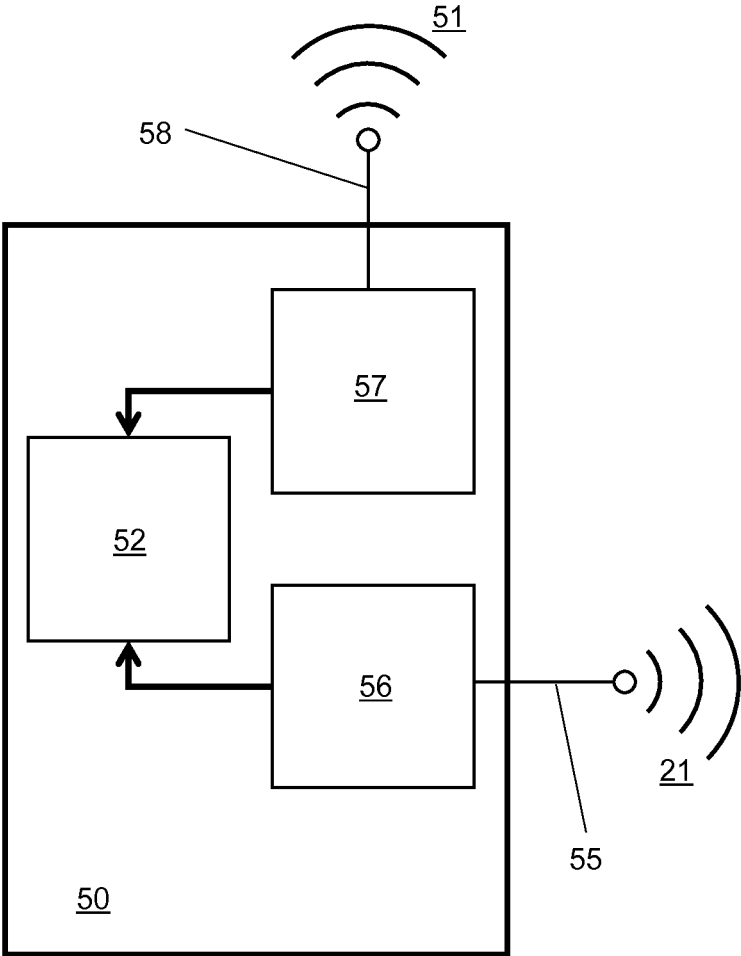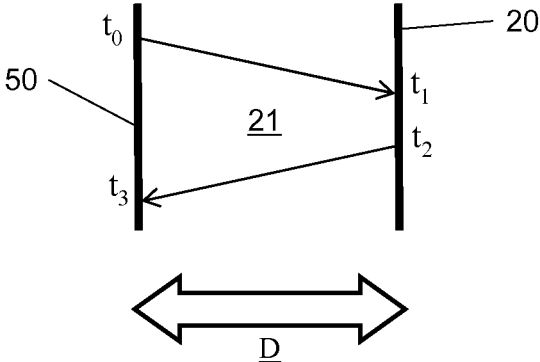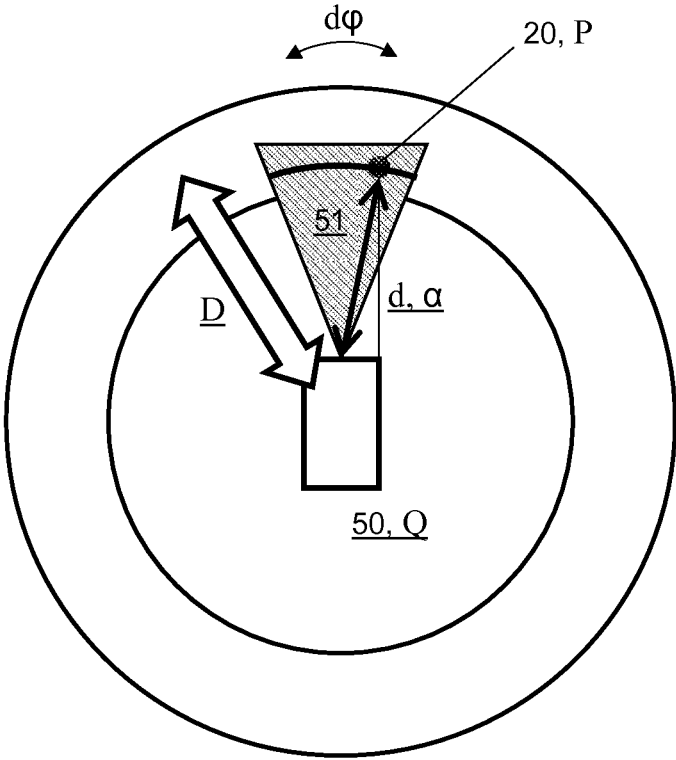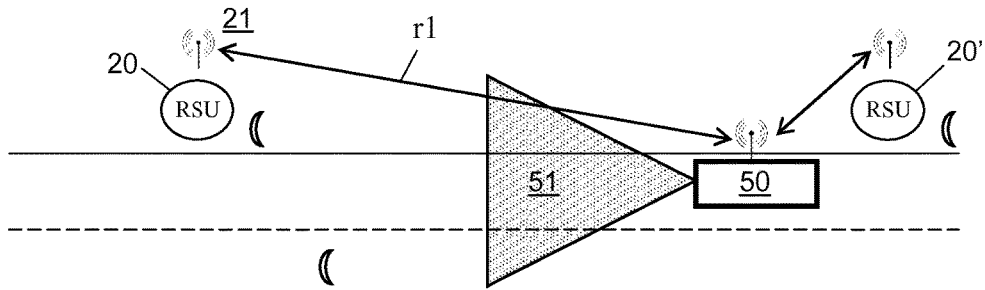|		
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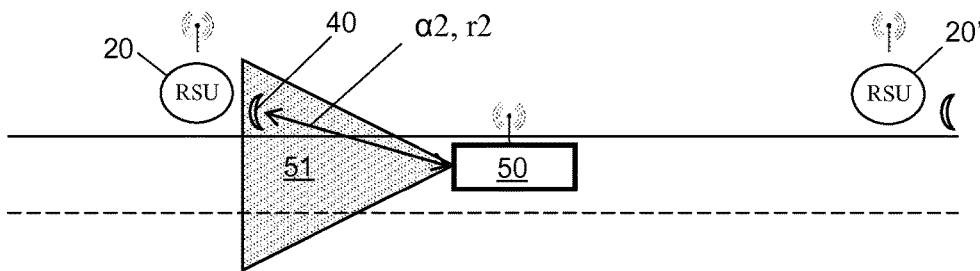* cited by examiner

Fig. 1

Fig. 2
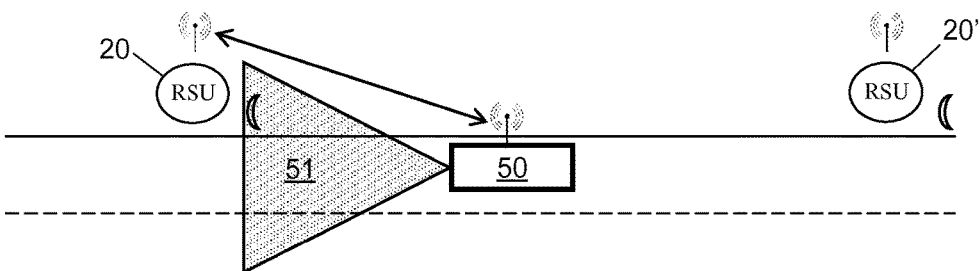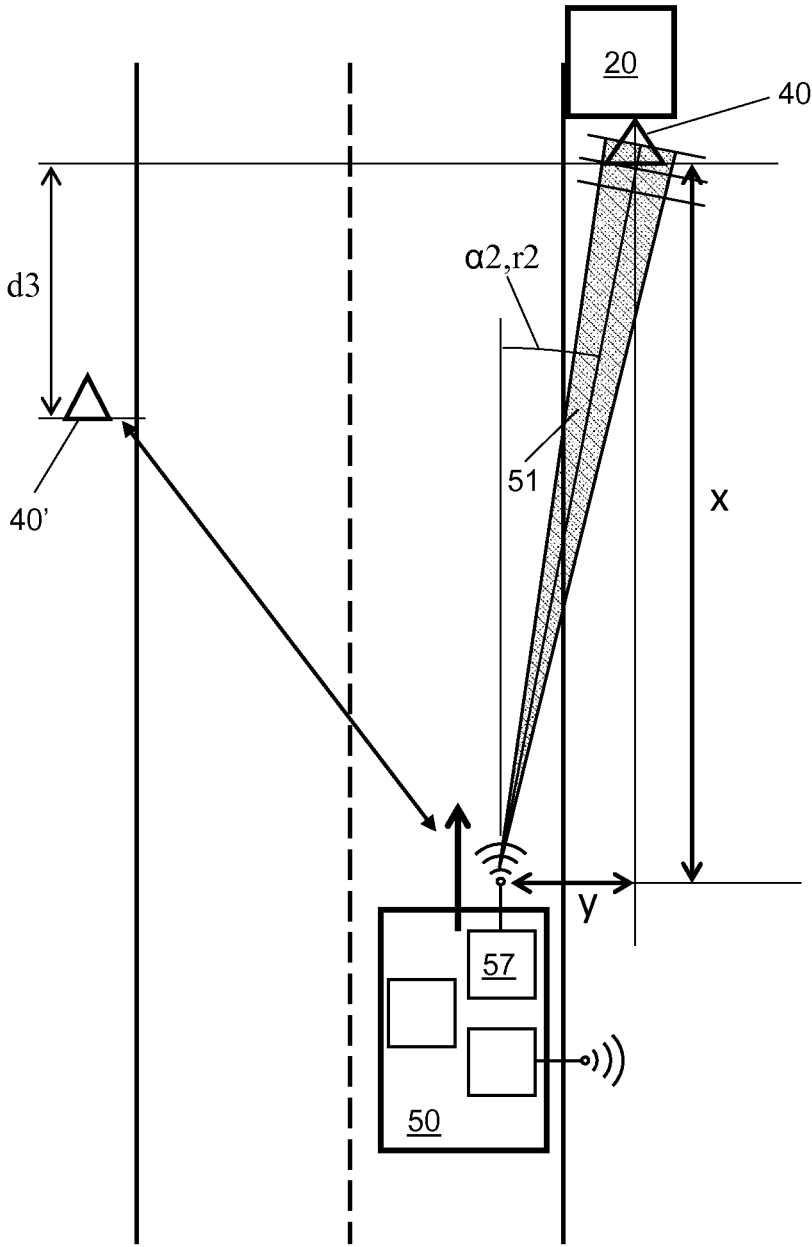
Fig. 3A

Fig. 3B

Fig. 4A
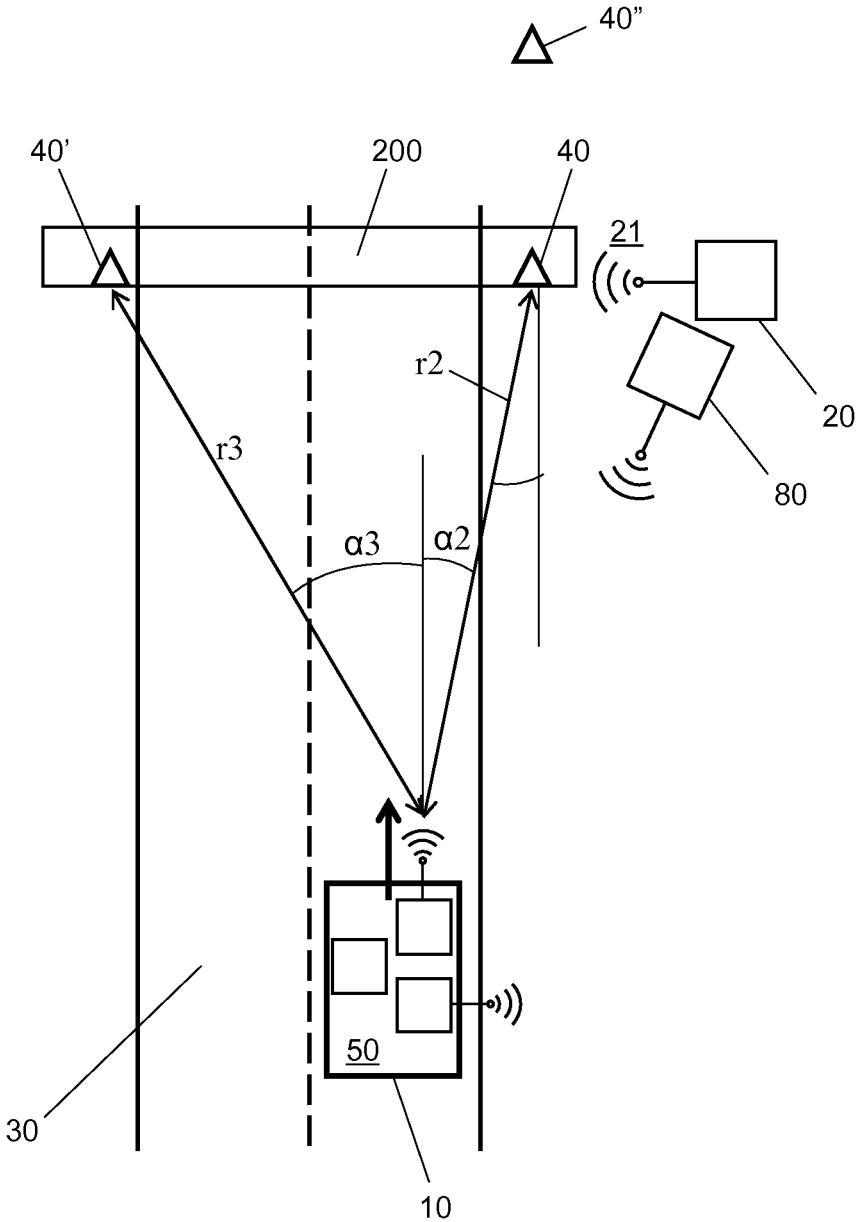

Fig. 4B

Fig. 4C

Fig. 5

Fig. 6

ASSURED VEHICLE ABSOLUTE LOCALISATION

FIELD OF INVENTION

The invention relates to a method and device for localizing a vehicle in a field provided with localization markings.

BACKGROUND

Nowadays, instantaneous measurements of moving objects, vehicles in particulars, have become common place technology. Widely known and used in the current technology for geographical position measurement is the GPS satellite measurement technique. These techniques have become the work horse for all kinds of applications, where a precise measurement of a vehicle position is necessary. E.g. for calculating a position on a map, calculating driving directions, calculating distances travelled etc.

However, GPS techniques suffer from various drawbacks that makes them vulnerable for malfunction and misuses. Absence of secure positioning will be a game stopper for cooperative applications that depend upon the users' (absolute) location and traces. Such applications may be financial applications, that tax travelling, in particular, in time and geographical zones.

To save money consumers might spoof/mislead the GPS sensor. On the other hand, safety applications cannot rely on an insecure GPS sensor, where the reliability of reception is always a challenge, especially for difficult terrains, such as urban areas and tunnels.

It is an objective to provide an alternative on GPS based locations, that uses fixed landmarks of known geographical positions. WO 20120154117 provides such a system, that tracks road side based delineator posts by radar reflection. However, this system relies on visibility of a tag that provides the position information, which may be difficult in practical circumstances e.g. when pollution or wear reduces the visibility. Also, the system has to know in advance that a certain radar reflective object needs to be scanned for visible inspection, which may be confusing with many reflective objections in the area.

JP2006275904 teaches a system of passive lane markers buried in the road that are registered in an annexed road side unit. The lane markers are only detected when passed by a vehicle.

US2011/0238306 is another prior art that relies on line of sight detection with other remote vehicles or objects, for example road side units. However, determination of a line of sight signal is done by comparing multipath signals or using a rule scheme for selecting preferred sources. In practice this calls for solutions where further reliability of the detection of a vehicle's location is desired.

SUMMARY OF THE INVENTION

To overcome these drawbacks it is proposed to provide a system for localizing a vehicle in a marked environment, i.e. provided with a set of markers, e.g. on a road side, the markers emitting a position signal indicative of a respective marker's known geographical position. The system comprises a processing unit and a distance detection unit provided in the vehicle, the processing unit adapted to receive said position signal of a respective marker. The processing unit is adapted to receive said known geographical position from the position signal of said respective marker; and to

estimate a first distance measure of the vehicle relative to the respective marker based on a position signal measurement. The processing unit feeds said estimated first distance measure to the distance detection unit; the distance detection unit being adapted to detect said marker within the first distance measure by a second distance measure. The distance detection unit is further adapted to provide the processing unit with the second distance measure of the vehicle relative to the detected marker; and the localization unit calculating an instantaneous geographical position of said vehicle from the second distance measure and the marker's known geographical position. The first distance measure has a lower accuracy than the second distance measure.

Accordingly, a secure and accurate absolute position can be received in a vehicle, that is suited for difficult terrain, such as urban areas and tunnels.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 shows a schematic arrangement of the system as set forth here below;

FIG. 2 shows a schematic arrangement of the localization unit in the vehicle; and

FIG. 3 shows a schematic illustration of a first distance measurement;

FIG. 4 shows a series of actions as carried out according to the disclosure;

FIG. 5 shows an angle estimation, based on radar detection; and

FIG. 6 shows a further embodiment including multiple reflectors.

DETAILED DESCRIPTION

In the example of FIG. 1, schematically, a system 100 is provided for localizing a vehicle 10 in a marked environment, i.e. provided with a set of markers 20, e.g. on a side of a road 30, the markers 20 emitting a position signal 21 indicative of a respective marker's known geographical position P.

While the position signal may be any suitable signal in the electromagnetic spectrum, preferably it is transmitted using the IEEE802.11p radio communication protocol, i.e. a radio signal in combination with the ITS-G5 protocol. This is a harmonized standard for 5.9 GHz (ETSI EN 302 571), commonly known to the skilled person. Other suitable signals may be provided by communication media, including cellular, 5 GHz, 63 GHz, optical spectrum, infra-red links.

In the vehicle 10 a localization unit 50 is provided. The unit will be described in more detail with reference to FIG. 2 (below). It comprises a processing unit, a communication unit and a distance detection unit. The communication unit is able to receive a marker position signal 21 of a corresponding marker 20, preferably, at a reception distance larger than 200 m.

If the signal emitting marker 20 and the passive marker 40 are physically combined in a single structure, this may have an advantage that the markers can be located with more sustained reliability. Such a structure may also be called a road side marker unit (RSMU). The processing unit in unit 50 is suited for calculating an instantaneous geographical position of the vehicle 10. A first, relatively course distance (r1), between the emitting marker 20 and the localization unit 50, can be detected by the communication unit 56. The distance detection unit may be suited for more accurate distance measurements (r2, r3) of a second, relatively fine

distance measure and/or angle measurements ($\alpha2$, $\alpha3$) of the vehicle **10** to respective markers **40**, which in the example is a passive marker structure distinct from the signal emitting marker **20**. The advantage is that a number of passive markers **40** can be provided for each signal emitting marker **20**.

In more detail, FIG. **2** shows building blocks **52**, **56** and **57** of the localizing unit **50**, that is provided in the vehicle **10**. The communication unit is typically a radio receiver **56** (see FIG. **2**) having an antenna **55**, or optionally an optical receiver having an optical sensor or any suitable means for receiving the position signal. In the example, the radio receiver **56** has an antenna **55** suited for reception of e.g. the ITS-G5 signal. The receiver **56** is under control of the processing unit **52**, and is able to tune in on the signal **21** that corresponds with a subsequently detected marker **20**. This may be realized by the receiver **56** having detection functionality to measure a received signal strength, in order to lock in to a carrier frequency or any suitable method to connect to the transmission signal.

The localizing unit **50** further comprises a distance detection unit **57** typically in the form of a radar detector and corresponding emitter **58** having a position accuracy between 0.1 and 10 meter that can be achieved at ranges between 10 and 100 meter; and a distance measurement unit (not shown) coupled to the radar detector **58**. The radar detector unit **57** may be a conventional radar sensing unit as commercially available and currently employed in automotive applications, wherein the distance measurement unit is formed by circuitry that may be included in the distance detection unit **57**, or may be provided in the processing unit **52**. The distance detection unit **57** may be in two way communication with the processing unit **52**. Furthermore processing unit **52** is adapted to receive, via said communication unit **56**, said position signal **21** of a respective marker **20**. The position signal **21** comprises digitally encoded position information of the marker **20**, for instance an indication of the marker's geographical coordinates P.

The signal received from the communication unit **56** is processed by the processing unit **52** thus adapted to receive said known geographical position from the position signal **21** of said respective marker **20**.

The received signal strength indication (RSSI) or time of flight (ToF) can also be used to measure the first distance (r1) of the vehicle, in particular, the localizing unit **50**, relative to a marker **20** emitting the position signal **21**. This is shown in the steps A and B illustrated in FIG. **3**.

In the step of FIG. **3A**, once the vehicle's localizing unit **50** is locked in on the signal **21** so that two-way communication may be enabled, wherein, for instance, a ToF measurement can be performed to measure a first distance D of the vehicle, in particular, the localizing unit **50**, relative to a marker **20** emitting the position signal **21**.

The ToF may be measured by exchanging a timestamp between the moving vehicle **50** and road side marker unit **20**. In this FIG. **3A**, the vehicle sends a message to a road side marker unit, the road side marker unit reacts by sending its delta (i.e. t2−t1) which the vehicle can subtract from its own delta (t3−t0), to obtain the communication time, which can be used to compute the distance between the vehicle and road side marker unit. A first distance between the vehicle **50** and the marker unit **20** may be expressed as

$$((T3-T0)-(T2-T1))*speed\_of\_light*\tfrac{1}{2}$$

This first distance measurement is sensitive to inaccuracies, because a 3 ns delay corresponds to 1 m and results to a course distance measure.

Alternatively, a received signal strength indication (RSSI) measures the range by determining the strength of the received signal **21**, or the radio energy. This value is part of the IEEE 802.11 standard. Preferably, when no relation between the signal strength and the returned value is defined this value may be calibrated. This approach may be somewhat sensitive to multipath of the signal, i.e. signal reflections which occur more close to the signal source and in urban areas. Nevertheless, RSSI may be a good indication when the signal source is approached.

The RSSI and ToF can be used to determine at the first distance D (up to 550 m) the range until the radar reflector can be expected. An accuracy in the order of 5-30 m is expected.

This range estimate D is used to filter radar object detections and to find the RSU radar reflector **40**.

From the first distance measure D of the vehicle **50** relative to the respective marker **40** based on measurement of the position signal **21**, a second distance measurement d can be performed in the step of FIG. **3B**. To this end, the processing unit **52** feeds said estimated first distance measure D to the distance detection unit **57**, wherein the distance detection unit **57** is adapted to detect said marker **40** within the first distance measure D by a second distance measure d (see FIG. **3b**).

The distance detection unit may operate with a field of view, which defines an angle range dφ, as indicated in FIG. **3B**. As may be illustrated in subsequent examples, alternative angle measurements or estimations may be used to identify the second distance relative position (d, α) within a field of view dφ relative to the road side marker unit **20**. Alternative to an angle measurement additional distance measurements may be carried out to triangulate an exact position of the vehicle **50**. Alternatively a camera may be used for estimating a lateral position of the vehicle relative to the road side. By using lateral distance y and the second, fine detection measure d, angle α can be calculated.

To determine the second distance relative position, the distance detection unit **57** is adapted to provide the processing unit with the second distance measure d of the vehicle relative to the detected marker **51** and with a detection angle α, eg, relative along a longitudinal axis in the forward direction of the vehicle of the detected marker. From the radio signal **21**, an absolute marker's known geographical position P can be determined by decoding the digitally position information; and the processing unit **52** calculates an instantaneous geographical position Q of said vehicle **50** from the second distance measure d the marker's known geographical position Q and, in the current example, detection angle α in the field of view, with an accuracy that is better than the accuracy of the first distance measure. For example the second distance measure d can have a meter or even sub-meter accuracy, wherein the first distance measure may have an accuracy larger than 10 meter.

FIG. **4** illustrates a realistic arrangement of several road side marker units **20**, **20'** arranged on the side of a road **30**, and a moving vehicle **50**, that is in communication with these road side markers **20**, **20'**. In a method for localizing the vehicle **50** in this marked environment, i.e. a road side provided with a set of markers **20**, **40**, the markers **20** emit a position signal **21** indicative of a respective marker's known geographical position.

The vehicle's localization unit **50** performs the method of (A) estimating a first distance measure of the vehicle relative to the respective marker **20** based on a position signal measurement. Upon deriving said first distance from the position signal measurement, in (B), said first distance is fed

to a distance detection adapted to detect, via radar detection **51**, said marker **40** within the first distance measure by a second distance measure. In (C), the localizing unit **50** is provided with the second distance measure of the vehicle relative to the detected marker **20** a known geographical position of said respective marker **20** is received from the position signal **21**. An instantaneous geographical position of said vehicle **50** is then calculated from the second distance measure the marker's known geographical position.

FIG. **5** shows in more detail radar detection and angle estimation by the localizing unit **50**. Radar detection is carried out by radar **57** to detect a passive radar reflector **40**; which is in a known geographical position, for example with fixed position relative to the marker **20**. The radar reflector can be of a conventional type, e.g. a passive metal radar reflector enabling reliable detection of the marker unit **20**. For example, a triangular trihedral reflector, with faces of 30 cm length has a half-power-beamwidth of 40 degrees and a maximum RCS response of 34 dBsm, which is comparable to the response of a large truck. In addition, the reflector can also be a specific form of active marking, e.g. containing time or frequency encoded information.

In the example, the localizing unit **50**, in particular, the distance measurement unit **57** may have an angle detection block, which can be formed by circuitry that may be included in the distance detection unit **57**. The angle detection block has an angular aperture that detects a reflected radar signal **51** in the forward direction of the vehicle' localization unit **50** within a certain margin of error.

A constellation of one active marker unit **20** and a number of passive reflectors **40** can be used to improve the absolute position accuracy of a vehicle. By relating the vehicle to multiple reflectors results in more corner distance pairs a relative position to the RSU **20** can be improved.

For example, an additional displaced reflector **40'** can be used at a second known position relative to the marker unit **20** to remove ambiguities based on detected a range and angle. Using a number of passive radar reflectors, makes the system robust for obstruction by other traffic, e.g. a truck blocking radar detection of a radar reflector. The reflectors are preferably placed at sufficient interdistances, e.g. in a range of 30-70 meters to address a condition that a reflector is not detected.

E.g. the active marker may transmit information of a number of passive reflectors that are within a first distance range of the vehicle, with corresponding position information, so that the distance detection unit **57** can select radar reflections matching this first distance position information.

In a first approach relative positions of the radar reflectors **40** in relation to the road may be communicated to the vehicle **50** by marker unit **20**. The radar reflectors **40, 40'** are distanced from each other over d3, such that the in-vehicle radar can clearly distinguish which reflector is observed closest. If marker **40'** is observed closer to the vehicle than marker **40**, a vehicle driving direction can be derived. This approach is suitable for intersections and corners.

In an alternative approach, in case a reflector is missed a radar **57** observes marker **40** and derives e.g. a detection angle and detection distance ($\alpha2, r2$), assuming the direction of the road is followed. From ($\alpha2, r2$) the lane to marker distance (y) can be determined. It can also be determined if the marker **40** of RSU **20** is observed left or right, where e.g. right means we are driving north and left that we are driving south. Given the width of the vehicle and the lane width, an error margin for (y) can be determined.

In a further alternative approach wireless communication can be used on the detected marker **40, 40'**. If communica-

tion and position information from a marker **20** is received and it is given that marker (**40'**) is located south of (**40**), the vehicle can use this information to determine it is driving north.

The range and angle between the RSU radar reflector **40** and the vehicle's localizing unit **50** can be determined based on the output of a radar sensor **57** on the vehicle. Typical automotive radar sensors may have an expected accuracy in range and angle 1 m and 1 degrees, respectively. An absolute position estimation relative to a marker unit **20**, for example, when the reflector **40** is positioned with a lateral distance of 5 m from the localizing unit **50**, may at different ranges estimated to be:

Distance	Error (dx, dy)
@ x = 10 m:	(1.0; 0.6) m
@ x = 25 m:	(1.1; 0.6) m
@ x = 50 m:	(1.1; 1.0) m
@ x = 75 m:	(1.1; 1.4) m
@ x = 100 m:	(1.1; 1.8) m
@ x = 150 m:	(1.1; 2.7) m

With a standard automotive radar a position error close to 1 m can be achieved at ranges below 50 m.

FIG. **6** provides an alternative embodiment of a road side unit that may extend over the span of a road **30**, e.g. in the form of a traffic light or road signalling structure **200**. The marker unit may have multiple passive markers **40,40'**, etc. that can be used for triangulation and second distance position measurement of the vehicle **50** relative to the marker unit **20**, in a way as previously described. When plural passive markers **40, 40'** are used, the robustness of the system **200** can be increased by recalibrating the system, e.g. omitting passive markers **40** that may appear to be outside an expected position from the first distance measurement. That is, when a radar detection of a passive marker **40"** is detected outside an expected first distance, this may be communicated to the marker system **200**.

This may be convenient when not all passive markers are fixed to the marker system **20** but separately positioned at a certain distance.

Conversely in an alternative (re)calibration, vehicles may detect a fine (second) distance of a designated passive marker to be recalibrated and communicate their absolute position and the measured second distance back to the road side unit, resulting in a statistically corrected passive marker location.

Moreover a suitable alternative use of the localization method is to calibrate road observation units **200** including a road side unit **20** and a detection camera **80**. The detection camera **80** requires calibration of observed vehicles to absolute positions. The observation unit **200** may be of a visual inspection type (e.g. camera), but can also be of a non-visual type (e.g. IR, radar, laser scanning). Conventionally a special RTK GPS equipped vehicle records a trajectory in parallel to a trajectory recorded by a camera, which also uses his RTK GPS position. These are compared to determine the offset of the camera. With the disclosed detection method, the RSU **200** knows its position and a vehicle having a localization unit **50** can determine its position when approaching the RSMU **200**. A trajectory recorded by a localization unit **50** in a vehicle can be used to (re) calibrate the camera **80**. Therefore, the localization unit **50** transmits the trajectory to the RSMU **200**. This may require clock synchronization for the points in a trajectory, to correlate locations observed by the camera **80** and the

localization unit **50** based on these timestamps. Accordingly, as a subsequent step to the localization method, a vehicles instantaneous absolute or relative position may be transmitted back to the road side unit; and coupled to a visual detection system **80**, that can be provided with the location information. After calculating the vehicle's instantaneous geographical position from the second distance measure and the marker's known geographical position a vehicle's instantaneous geographical position may be transmitted back to the marker system **200**; the marker comprised in a road side unit having a vehicle detection system **80**; and feeding the instantaneous geographical position to the vehicle detection system **80**; comparing the instantaneous geographical position with a vehicle position s detected by the vehicle detection system **80**; and adjusting the vehicle position detected by the vehicle detection system with the instantaneous geographical position d to calibrate the vehicle detection system **80**.

Other variations to the disclosed embodiments can be understood and 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. A single unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

The invention claimed is:

1. A system for localizing a vehicle in a marked environment, i.e. provided with a set of markers, e.g. on a road side, the markers emitting a position signal indicative of a respective marker's known geographical position; the system comprising:
   a localization unit provided in the vehicle, the localization unit comprising a processing unit, a communication unit and a distance detection unit, the processing unit adapted to receive, via said communication unit, said position signal of a respective marker;
   the processing unit adapted to receive said known geographical position from the position signal of said respective marker; and to estimate a first distance measure of the vehicle relative to the respective marker based on a position signal measurement;
   the processing unit feeding said estimated first distance measure to the distance detection unit; the distance detection unit adapted to detect a second distance measure of said respective marker within the first distance measure;
   the distance detection unit adapted to provide the processing unit with the second distance measure of the vehicle relative to the detected respective marker; and
   the processing unit calculating an instantaneous geographical position of said vehicle from the second distance measure and the marker's known geographical position.

2. A system according to claim **1**, wherein the position signal is a radio signal.

3. A system according to claim **1**, wherein a reception distance of the position signal is larger than 200 m; and wherein the first distance measure has an accuracy of 10 m.

4. A system according to claim **1**, wherein the position signal measurement is a time of flight measurement or received signal strength measurement.

5. A system according to claim **1**, wherein the distance detection unit is adapted to detect the second distance measure with a distance smaller than 200 m.

6. A system according to claim **1**, wherein the distance detection unit comprises a radar emitter and radar receiver; and a distance measurement unit coupled to the radar emitter and receiver.

7. A system according to claim **1**, wherein the distance measurement unit comprises an angle detection block.

8. A system according to claim **7**, wherein the angle detection block comprises an angular aperture in the forward direction of the vehicle.

9. A system according to claim **1**, wherein the position signal additionally comprises localisation information of a set of passive markers nearby the respective marker that are detectable by the distance detection unit.

10. A system according to claim **9**, wherein the set of passive markers is detected within a first distance window calculated from the first distance measure and the localisation information received from the position signal.

11. A method for localizing a vehicle in a marked environment, i.e. provided with a set of markers, e.g. on a road side, the markers emitting a position signal indicative of a respective marker's known geographical position; and the vehicle comprising a localization unit provided in the vehicle, the localization unit comprising a processing unit, a communication unit and a distance detection unit, the method comprising:
   receiving, by the processing unit, said known geographical position from the position signal of said respective marker; and estimating a first distance measure of the vehicle relative to the respective marker based on a position signal measurement;
   feeding said estimated first distance measure to the distance detection unit; the distance detection unit adapted to detect a second distance measure of said respective marker within the first distance measure;
   providing the processing unit with the second distance measure of the vehicle relative to the detected respective marker; and
   calculating an instantaneous geographical position of said vehicle from the second distance measure and the marker's known geographical position.

12. A method according to claim **11**, further comprising: transmitting, via the communication unit, a vehicle's instantaneous geographical position to the marker; the marker comprised in a road side unit having a vehicle detection system; and feeding the instantaneous geographical position to the vehicle detection system; comparing the instantaneous geographical position with a vehicle position detected by the vehicle detection system; and adjusting the vehicle position detected by the vehicle detection system with the instantaneous geographical position to calibrate the vehicle detection system.

13. A method according to claim **11**, wherein the position signal further comprises localisation information of a set of passive markers nearby the respective marker that are detectable by the distance detection unit, when receiving the localisation information further comprising: transmitting, via the communication unit, a vehicle's instantaneous geographical position relative to a passive marker and distance of a designated passive marker and updating the localisation information of the set of passive markers by comparing multiple transmitted distances of a designated passive marker.

14. A system according to claim **1**, wherein the position signal is an ITS-G5 signal.

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