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(54) Title: CALIBRATION METHOD FOR ANGULAR RATE SENSOR

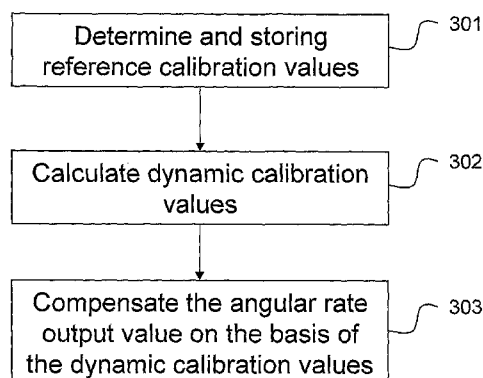


FIG 3

(57) Abstract: The present invention relates to a method for improving the accuracy of an angular rate sensor adapted to generate an angular rate output value in response to the moving direction of a vehicle. The method comprises the steps of: - determining and storing 301 a plurality of reference calibration values on the basis of the angular rate output when the vehicle is at a complete stop, - calculating 302 a plurality of dynamic calibration values on the basis of the reference values, - compensating 303 the angular rate output value at different vehicle operating conditions on the basis of the dynamic calibration values.

TITLE

Calibration method for angular rate sensor

TECHNICAL FIELD

- 5 The present invention relates to a method and a device for improving the accuracy of an angular rate sensor adapted to generate an angular rate output value in response to the moving direction of a vehicle.

BACKGROUND ART

- 10 A MEMS gyroscope is a sensor that is sensitive to Coriolis forces. To create a Coriolis force a movement must be induced. The gyro has an actuated oscillating mechanical structure (primary mode). The Coriolis force creates a second oscillating movement when the gyroscope rotates (secondary mode).

- As Coriolis force is usually extremely weak, the primary mode is driven into
15 resonance to keep the mechanical noise level low for the signal bandwidth used and to have a good sensitivity. A capacitance change in the secondary mode is detected and transformed into an output voltage by the electronic interface circuitry.

- A change in the sensor capacitance C is converted into a change in
20 transducer output voltage on the basis of the bias and sensitivity, which are adjustable over temperature in order to compensate for the TC of sensor and readout. After adjusting the bias and sensitivity values and after setting operating mode switches during the calibration process, the transducer output voltage versus angular rate must stay over the specified temperature
25 range.

These MEMS sensors are often used to detect the moving direction and the position when used in vehicle applications. This information is for instance used for course predictions algorithms in relation to active security systems.

The accuracy of the Zero Rate Output (ZRO) from these sensors is influenced by a number of parameters during the complete life time of the product, such as:

- Chip temperature
- 5 - Supply voltage tolerances
- Individual component tolerances
- Component aging
- Installation properties (tolerances in the mounting angle of the sensor)

Since the accuracy is influenced by these parameters, there is a need to
10 calibrate each sensor before installing them in the vehicle control system.
The calibration is vital since the sensor for instance might be used by active safety systems in the vehicle.

However, the individual calibration procedure is very time-consuming and expensive. This adds costs relating to the use of these kinds of sensors.

15 SUMMARY OF THE INVENTION

The object of the present invention is therefore to provide an alternative calibration procedure for the angular rate sensor.

The object is achieved by means of a method according to claim 1. More specifically, the present invention relates to a method for improving the
20 accuracy of an angular rate sensor adapted to generate an angular rate output value in response to the moving direction of a vehicle. The method comprises the steps of:

- determining and storing a plurality of reference calibration values on the basis of the angular rate output when the vehicle is at a complete stop,
- 25 - calculating a plurality of dynamic calibration values on the basis of the reference values,

- compensating the angular rate output value at different vehicle operating conditions on the basis of the dynamic calibration values.

The object is also solved by means of a vehicle control system being adapted to improve the accuracy of an angular rate sensor, adapted to generate an angular rate output value in response to the moving direction of a vehicle.
5 The vehicle control system being adapted to perform the steps of:

- determining and storing a plurality of reference calibration values on the basis of the angular rate output when the vehicle is at a complete stop,
- calculating a plurality of dynamic calibration values on the basis of the
10 reference values,
- compensating the angular rate output value at different vehicle operating conditions on the basis of the dynamic calibration values.

It is also solved by means of a vehicle comprising said vehicle control system.

- 15 In an advantageous development of the present invention the reference calibration values and the dynamic calibration values consists in the angular rate output value and its relation to a corresponding sensor operating temperature.

In another advantageous development of the present invention the reference
20 calibration values are stored in a reference value table or graph. The dynamic calibration values are stored in a dynamic value table or graph.

In another advantageous development of the present invention the method comprises the step of calculating a confidence level value, which indicates the quality of the reference calibration values. The confidence level value
25 depends on the number of determined reference calibration values.

In another advantageous development of the present invention the method comprises the step of filtering the determined reference calibration values before storing the reference values. The filtering properties are determined on the basis of statistical information derived from known data collected during system design.

- In another advantageous development of the present invention the method comprises the step of determining if the vehicle is at a complete stop on the basis of the status of a the vehicle parking brake, the vehicle speed and the speed of the vehicle engine.
- 10 In another advantageous development of the present invention at least some of the dynamic calibration values are calculated by interpolation or least square regression of the reference calibration values. At least some of the dynamic calibration values are further calculated by copying the reference calibration values. The end dynamic calibration values are truncated using
- 15 the reference calibration values.

- In a final advantageous development of the present invention the stored dynamic calibration values are re-calculated each time at least one of the stored reference values are updated or each time a start-up of a vehicle control system is performed.
- 20 An advantage with the present invention is that it considers all parameters affecting the Zero Rate Output (ZRO). Temperature, supply voltage tolerances, individual component tolerances and component aging as well as installation properties (tolerances in the mounting angle of the sensor) during the complete life time of the product.
- 25 Another advantage is that the present invention does not add cost to the system solution, since no hardware is added or required. Moreover, the system (vehicle) is never required to be calibrated at workshop since the system adapts to the operating conditions itself.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following text the invention will be described in detail with reference to the attached drawings. These drawings are used for illustration only and do not in any way limit the scope of the invention:

- 5 Figure 1 illustrates a vehicle comprising a vehicle control system and an angular rate sensor.

Figure 2 illustrates a dynamic table according to the present invention.

Figure 3 schematically illustrates the method for improving the accuracy of an angular rate sensor according to the present invention.

10 MODES FOR CARRYING OUT THE INVENTION

The invention will now be described in detail with reference to embodiments described in the detailed description and shown in the drawings. The embodiments of the invention with further developments and described in the following are to be regarded only as examples and are in no way to limit the
15 scope of the protection provided by the patent claims.

This method is performed by a calibration algorithm. It should be realized that a vehicle control system 10 according to figure 1, performing the method steps described in the following, is adapted to perform said steps. It should furthermore be understood that a vehicle 11, comprising said system is also
20 adapted to perform said steps. The system and the vehicle are therefore also illustrated in the following. The vehicle 11 may for instance be a truck, a car or a loader of some kind. The invention is not restricted to the type of vehicle into which the calibration algorithm according to the present invention is introduced.

- 25 The invention relates to a method for improving the accuracy of an angular rate sensor 12. This sensor is connected to a vehicle control system 10 in a vehicle 11. The sensor is adapted to generate an angular rate output value in response to the moving direction of the vehicle.

The sensor 12 may for instance be a gyroscope. The angular rate output value is represented by a Zero Rate Output (ZRO) value when there is no movement (caused by a course change). The accuracy of the Zero Rate Output (ZRO) from these sensors is influenced by temperature, supply
5 voltage tolerances, component tolerances/aging and installation properties.

To improve the accuracy of the sensor 12, certain method steps are performed, see figure 3. Firstly, a plurality of reference calibration values is determined 301. These values are determined on the basis of the angular rate output, when the vehicle 11 is at a complete stop.

10 This method step defines the calibrating conditions. Said reference values refer to the angular rate output values and the sensor 12 temperatures. The reference values are determined at a known condition (when the vehicle 11 is at a complete stop). The goal is to have a fixed condition for using the method.

15 The reference calibration values are used to create a reference table, or set, of calibration data. The reference table with the reference calibration values is stored in non-volatile memory. How the reference calibration values are determined and stored will be described more in detail in the following.

In a second method step, a plurality of dynamic calibration values is
20 calculated 302 on the basis of the reference values. How the dynamic calibration values are calculated will be described more in detail in the following.

In a third step the angular rate output value is compensated 303 at different vehicle operating conditions on the basis of the dynamic calibration values.

25 The reference calibration values and the dynamic calibration values consist in the angular rate output value and its relation to a corresponding sensor 12 operating temperature. This means that the reference calibration values hold the angular rate sensor value versus temperature. Since the reference values

are stored at known conditions (complete stop), see step one, the stored values also (implicit) includes supply voltage tolerance, individual component tolerance, component aging and installation properties. The determination regarding whether the vehicle 11 is at a complete stop is made on the basis of status of a vehicle parking brake, the vehicle speed and the speed of the vehicle engine.

The reference calibration values are stored in a reference value table or graph. The same also counts for the dynamic values, which are stored in a dynamic value table or graph. A table or graph represents any means for storing the values in a structured way, to indicate the operation temperature for each reference or dynamic value.

In the following, the calibration conditions and the determination of the reference calibration values and the dynamic calibration values will be described. Moreover, a quality indication procedure and a pre-filtration of the determined reference values will be described. The methodology may be applied to different vehicle 11 electronic architectures. Several calibration conditions can be considered. However, it is required that the sensor 12 allows for reading of the angular rate sensor values and the operating temperature at the chip level.

20 Calibration conditions

Whether to use the basic calibration condition described in the following, or to implement more advanced calibration conditions, is much up to the vehicle control system 10 and the allowed complexity of the design. The advantage of implementing the more advanced conditions is that it reduces the learning time of the system. This is due to the simple fact that the amount of situations where calibration is allowed is increased.

When the system 10 is new and no reference calibration data exist, several EOL (End Of Line) activities can be defined to allow the system to build a basic set of reference calibration values, in the following named "points". In

the simplest case, several occurrences of the basic calibration conditions below will occur during manufacturing. To further put this in focus, one or more of these conditions can be specified for the EOL test to secure an initial reference calibration curve.

5 Basic calibration conditions

The basic decision for building the reference calibration value, in the following named "data", is proposed to be at a complete stop, when parking brake is applied; vehicle speed is at zero and when engine is not running. Proper backup for these signal sources may be derived. The decision for these conditions is based on minimizing vibrations and noise from vehicle movements and engine vibrations during the learning phase in the system. Several concepts may be considered, but these rules have the advantage that it maximizes the amount of calibration data since it maximizes the time available for calibration, and minimizes the inaccuracies when building the reference calibration data.

Qualification (filtration) of the reference calibration data is required before storing the data in the reference calibration table. The proposed rule for this is described below:

- Moving averaging filter for a number of samples. The filter characteristics shall be determined after statistical measurements. The statistical information is derived from known data collected during system design. The goal would be to minimize the influence of noise while maintaining the ability to catch the trend of the ZRO (Zero Rate Output).
- Qualification of the samples (raw data) using an acceptance interval. If any sample is outside a predefined range, it shall be discarded.

The practical situations where these conditions are fulfilled would typically be at system startup and system shutdown. At startup more calibration data

is learned at the temperature boundaries, preferably in the lower region. At shutdown, calibration data at typical operating temperatures is learned.

Advanced calibration conditions

More advanced calibration conditions can be implemented if parking brake is applied, vehicle speed is at zero and when engine is running. Proper backup for these signal sources may be derived. Since the engine vibrations is expected to have an effect of the level of noise in the data, it is proposed to use an acceptance interval for the allowed engine speed (idling within +/- x rpm). To further improve the qualification of data in these situations, it is proposed to use a filter with optimized characteristics for the situation.

The practical situations where these conditions are fulfilled would typically be when loading or unloading the vehicle 11 or at longer stops when engine is idling. It is expected that calibration data at a wider typical operating temperature range is learned.

Reference calibration data

The proposed algorithm uses a reference table and a dynamic table. The reference table is stored in non-volatile memory and used for holding true calibration data, stored under the defined valid calibration conditions. Initially, it could be expected that the system 10 does not have any stored reference calibration data. However, the component comprising the algorithm can be calibrated with the described method without being mounted in the vehicle 11, i.e. by supplier. However, this places requirements on a specified environment and installation which is similar to the vehicle properties.

It is proposed to use a checksum when building or modifying the reference table to validate all writings of reference data. The reference table shall be parsed and if the checksum for some reason would be incorrect, the complete table could be discarded. The advantage of this is that it allows for

detection of corrupt data, hence reducing the effect of incorrect dynamic calibration.

The algorithm performing the method according to the present invention can be used as a complement even when each sensor 12 already has been
5 calibrated before use. The system 10 shall allow for readout of the reference calibration data. This allows for evaluation and analysis of data which can be used to optimize the method i.e. filter characteristics.

Dynamic reference data

The dynamic table holds the actual calibration points used when creating the
10 angular rate output value. The dynamic table would be applied at all current angular rate values versus measured temperatures, in real time.

The dynamic table is proposed to be re-calculated at every system 10 start-up and stored in some available volatile memory. A more advanced option would be to re-calculate this table when any change in the reference table is
15 made. This is however much up to the target system and the allowed complexity of the design.

An obvious caveat with the reference table is that it holds only true calibration data versus temperature. That is, it exist reference points (temperature points) where no calibration data is stored. The amount of missing points
20 defines the level of confidence of the reference table. Preferably, the reference calibration values could be accompanied by a confidence level to characterize the quality of the reference table.

The confidence level could preferably be sent in the vehicle network for monitoring and analyzing the learning grade of the system 10. A simple way
25 to build the confidence would be to measure the amount of points interpolated when building the dynamic table versus the amount of stored reference calibration points from the reference table.

The dynamic table is proposed to be built from the reference table using the below rules.

- Available data from the reference table is directly copied to the dynamic table.
 - 5 - Missing data or unknown reference calibration points in the reference table are calculated, using i.e. interpolation or at least square regression, to build the dynamic table.
 - The end points of the reference table are truncated in the dynamic table to cover the boundaries.
- 10 Figure 2 shows a simplified dynamic table. The correction curve that the dynamic table builds is used in real-time for each sampled temperature/angular rate value. The missing points in the reference table are calculated using i.e. interpolation or at least square regression of the available reference calibration points. At the ends, the last known reference
- 15 value is used (truncation).

The invention is not to be regarded as being limited to the embodiments described above, a number of additional variants and modifications being possible within the scope of the subsequent patent claims. The invention embraces any kind of algorithm performing the method steps described and

20 any sensor 12 being able to generate an angular rate output value and an operating temperature. The invention also embraces any system 10 using this sensor, or similar sensors where a high accuracy Zero Rate Output (ZRO) is required, without degradation or "drift" over time and under different operating conditions.

CLAIMS

1. A method for improving the accuracy of an angular rate sensor (12) adapted to generate an angular rate output value in response to the moving direction of a vehicle (11), the method comprising the steps of:
 - 5 - determining and storing (301) a plurality of reference calibration values on the basis of the angular rate output when the vehicle (11) is at a complete stop,
- calculating (302) a plurality of dynamic calibration values on the basis of the reference values,
 - 10 - compensating (303) the angular rate output value at different vehicle operating conditions on the basis of the dynamic calibration values.
2. A method according to claim 1 wherein the reference calibration values and the dynamic calibration values consists in the angular rate output value and its relation to a corresponding sensor operating temperature.
- 15 3. A method according to any of the preceding claims wherein the reference calibration values are stored in a reference value table or graph.
4. A method according to any of the preceding claims wherein the dynamic calibration values are stored in a dynamic value table or graph.
5. A method according to any of the preceding claims comprising the step of:
 - 20 - calculating a confidence level value, which indicates the quality of the reference calibration values.
6. A method according to claim 5 wherein the confidence level value depends on the number of determined reference calibration values.
7. A method according to any of the preceding claims comprising the step of:
 - 25 filtering the determined reference calibration values before storing the reference values.

8. A method according to claim 7 wherein the filtering properties are determined on the basis of statistical information derived from known data collected during system (10) design.

5 9. A method according to any of the preceding claims comprising the step of determining if the vehicle (11) is at a complete stop on the basis of the status of a the vehicle parking brake, the vehicle speed and the speed of the vehicle engine.

10 10. A method according to any of the preceding claims wherein at least some of the dynamic calibration values are calculated by interpolation or least square regression of the reference calibration values.

11. A method according to any of the preceding claims wherein at least some of the dynamic calibration values are calculated by copying the reference calibration values.

15 12. A method according to any of the preceding claims wherein the end dynamic calibration values are truncated using the reference calibration values.

20 13. A method according to any of the preceding claims wherein the stored dynamic calibration values are re-calculated each time at least one of the stored reference values are updated or each time a start-up of a vehicle control system (10) is performed.

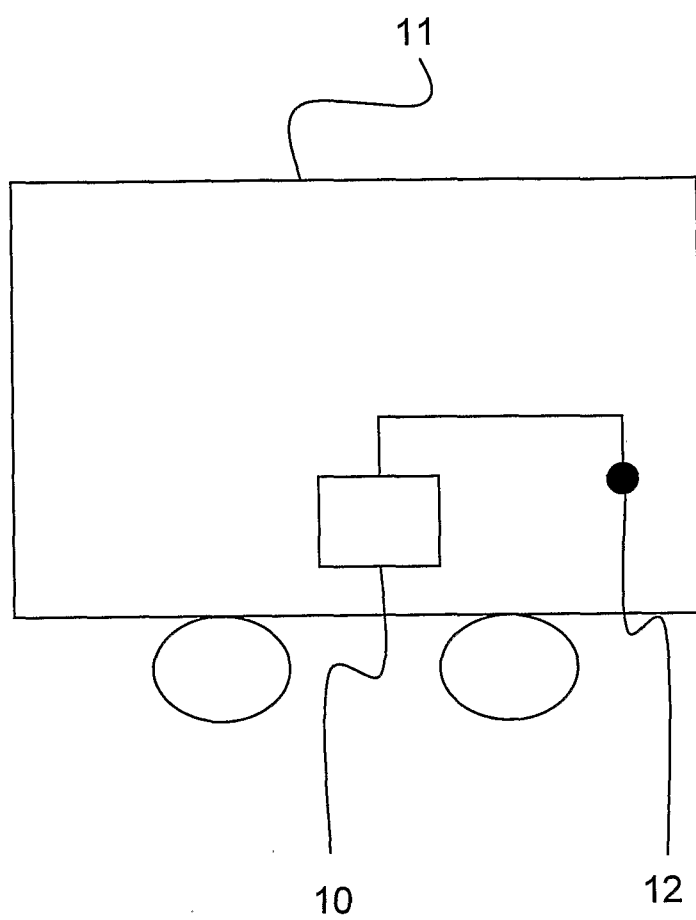
14. Vehicle control system (10) being adapted to improve the accuracy of an angular rate sensor (12) adapted to generate an angular rate output value in response to the moving direction of a vehicle (11),

characterized in that

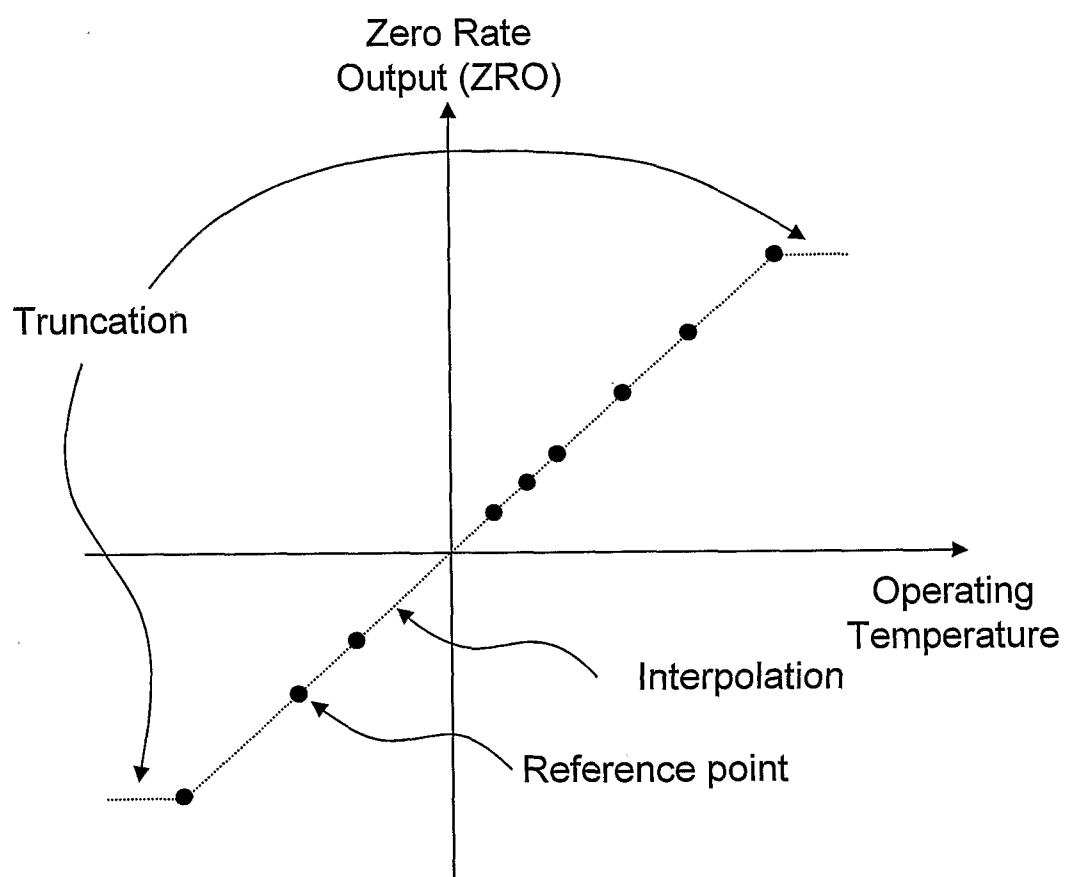
25 the vehicle control system (10) being adapted to perform the steps of:

- determining and storing (301) a plurality of reference calibration values on the basis of the angular rate output when the vehicle (11) is at a complete stop,
 - calculating (302) a plurality of dynamic calibration values on the basis of the
5 reference values,
 - compensating (303) the angular rate output value at different vehicle operating conditions on the basis of the dynamic calibration values.
15. Vehicle (11) comprising a vehicle control system (10) according to claim 14.

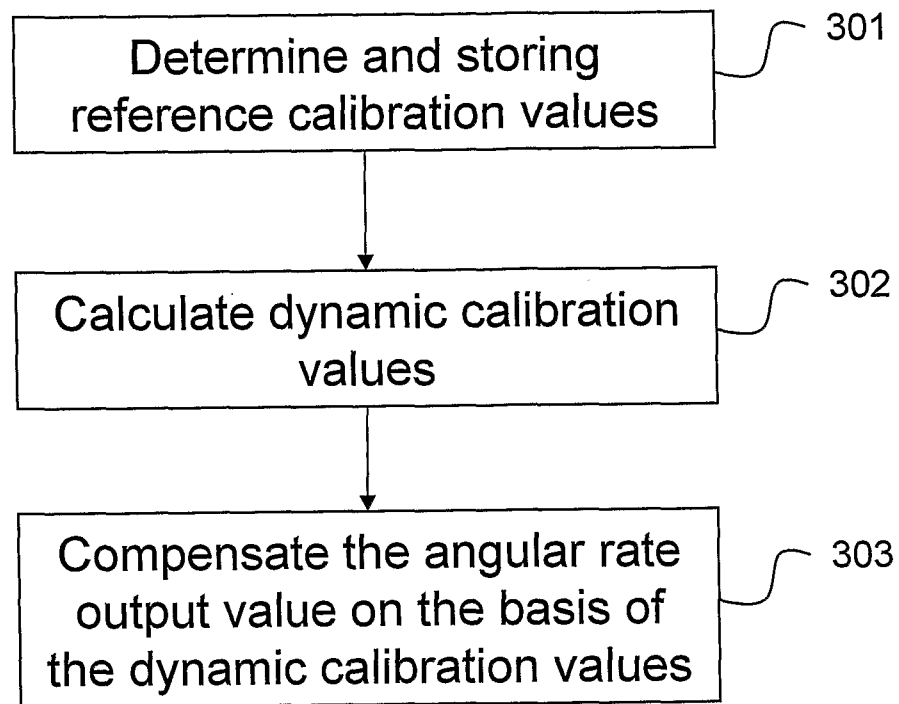
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**FIG 1**

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**FIG 2**

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**FIG 3**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE2009/000174

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: G01C, G01P

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5297028 A (ISHIKAWA), 22 March 1994 (22.03.1994), column 3, line 65 - column 4, line 58, figure 6, abstract --	1-4,9-15
X	EP 1221586 A2 (MOTOROLA, INC.), 10 July 2002 (10.07.2002), abstract, paragraphs (0052),(0060) --	1-15
X	US 20010003170 A1 (SCHUPFNER), 7 June 2001 (07.06.2001), paragraphs (0017)-(0020) --	1-4,9-15
A	GB 2340611 A (VISTEON TECHNOLOGIES LLC), 23 February 2000 (23.02.2000), claims 1-4 -- -----	1-15

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Date of the actual completion of the international search

25 November 2009

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Cited literature, if any, will be enclosed in paper form.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SE2009/000174

US	5297028	A	22/03/1994	NONE		
EP	1221586	A2	10/07/2002	JP	2002303533 A	18/10/2002
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				US	20030036847 A	20/02/2003
US	20010003170	A1	07/06/2001	NONE		
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