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(54) Title: CONTROL SYSTEM FOR AUTONOMOUS VEHICLES, AND A METHOD FOR THE CONTROL SYSTEM

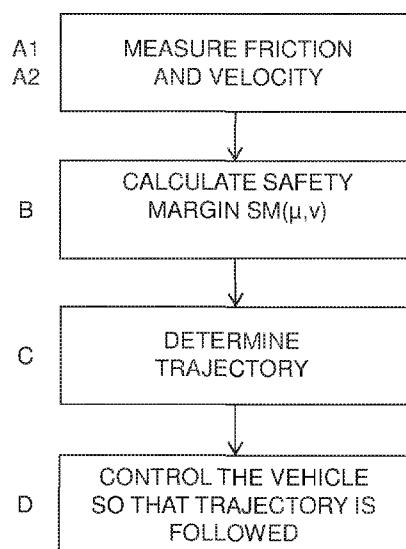


FIG. 2

(57) Abstract: A control system (2) adapted so as to control an autonomous vehicle (4) along a planned route, wherein the control system is adapted so as to receive a friction signal (6) that contains information about the friction μ for a roadway on which the vehicle is to travel, and a velocity signal (8) that contains information about the vehicle velocity v . The control system (2) comprises a processing unit (10) and a control unit (12), wherein the processing unit is adapted so as to determine a variable safety margin $8M(\mu, v)$ relative to an object in proximity to the vehicle based on the measured friction μ and the vehicle velocity v ; and to determine a trajectory (14) for the planned route such that said safety margin SM is met. The control unit is further adapted so as to control the vehicle by means of a control signal (16) so that the trajectory is followed by influencing at least the steering and the velocity of the vehicle by applying a set of control rules, wherein said control rules include a rule that takes into account the lateral acceleration a_y of the vehicle.

Control system for autonomous vehicles, and a method for the control system

Technical field of the invention

The present invention concerns a method and a control system according to the
5 preambles of the independent claims.

More specifically, the invention concerns a method and a control system that improves the safety of autonomous vehicles when driving on a slippery surface.

Background of the invention

10 A vehicle that can be driven on the ground without a driver is known as an unmanned ground vehicle, or UGV. There are two types of unmanned ground vehicles, those that are remote-controlled and those that are autonomous.

A remote-controlled UGV is a vehicle that is controlled by a human operator via a
15 communication link. All actions are determined by the operator based on either direct visual observation or by means of sensors such as digital video cameras. A remote-controlled toy car is a simple example of a remote-controlled UGV. There are major variations among remote-controlled vehicles in use today. These vehicles are often used in dangerous situations and environments that are
20 unsuitable for the presence of humans, such as in disarming bombs and in connection with hazardous chemical spills. Remote-controlled unmanned vehicles are also used in connection with surveillance work and the like.

An autonomous vehicle refers here to a vehicle that is capable of navigating and
25 maneuvering without human control. The vehicle uses sensors to obtain an understanding of its surroundings. Sensor data are then used by control algorithms to determine what the next step for the vehicle to take is, taking into account an overall objective for the vehicle, e.g. to retrieve and deliver goods at various locations. More specifically, an autonomous vehicle must be able to
30 interpret its surroundings well enough to be able to perform the task it has been assigned, e.g. "move the block of stone from point A to point B via the mine gallery C". The autonomous vehicle needs to plan and follow a route to the

selected destination while detecting and avoiding obstacles in its path. The autonomous vehicle must also perform its tasks as quickly as possible, without making mistakes. Autonomous vehicles have also been developed for use in dangerous environments, such as in the defense and war industry, and in the mining industry, both above ground and underground. If people or normal manually controlled vehicles approach the work area of the autonomous vehicles, they normally cause an interruption in the work for safety reasons. The vehicles are ordered to resume their work once the work area is free again.

10 The autonomous vehicle utilizes information concerning the road, the surroundings and other factors that affect its forward travel in order to automatically control its gas pedal depression, braking and steering. A careful assessment and identification of the planned forward travel is necessary in order to determine whether a route is passable, and necessary to be able to
15 successfully replace human assessments in terms of driving the vehicle. The road conditions can be complex, and the driver of a normal manned vehicle makes hundred of observations per minute and adjusts the operation of the vehicle based on the perceived road conditions in order, for example, to find a passable route past objects that may be present on the road. The ability to replace the
20 capacity of human perception with an autonomous system involves, among other things, the ability to perceive objects in a precise manner in order to be able to effectively control the vehicle so that it steers past said objects.

The technical methods used to identify an object in connection with the vehicle
25 include the use of one or a plurality of cameras and radar to generate images of the surroundings. Laser technologies are also used, both scanning lasers and fixed lasers, to detect objects and measure distances. These are often referred to as LIDAR (Light Detection and Ranging) or LADAR (Laser Detection and Ranging). The vehicle is also equipped with various sensors in order to sense
30 velocity and accelerations in various directions. Positioning systems (e.g. GPS) and other wireless technologies can also be used to determine whether, for

example, the vehicle is approaching an intersection, a narrowing of the road, and/or other vehicles.

The control of an autonomous vehicle so that it travels along a planned route is achieved essentially by influencing the steering and velocity of the vehicle, i.e. its acceleration and retardation. This generally occurs in that the vehicle control system transmits control parameters to various units in the vehicle, such as the engine, steering, gearbox and brake systems.

- 10 US-2010/0114416 concerns a system and method for navigating an autonomous vehicle using detection and distance measurements made by means of lasers.

- US-2012/0035788 concerns a navigation and control system for autonomous vehicles and comprises sensors, such as laser sensors, configured so as to localize objects in front of the vehicle so that it can be driven without colliding with said objects.

- A driver of a goods vehicle can adapt his driving behavior based on the prevailing conditions; if it is slippery he can, for example, increase the safety distance to other drivers and obstacles along the road. A machine is not as good as a human at adapting itself to different situations. This means that an autonomous vehicle will either be driven with a margin to other drivers that is too small, so that the vehicle crashes, which can occur in particular on a slippery surface, or be driven with a margin that is sometimes too great, so that the vehicle is sometimes unable to reach places where it would actually have found room.

The following documents concern various types of systems and methods in connection with the control of vehicles, including connection with slippery surfaces.

30

US-2012/0083959 concerns a system and a method for autonomous control of a vehicle with a view to avoiding wear in various vehicle parts. The control is based

in part on input signals from two sensors, where one sensor senses the effects on other vehicle parts while another sensor senses environmental parameters such as the presence of objects near the vehicle, temperature, humidity, etc. A first or a second maneuver is then selected that is best in terms of avoiding wear in various vehicle parts.

EP-2407357 describes an autonomous brake system for a vehicle. A sensor device is adapted so as to detect obstacles in the surroundings of the vehicle, and braking parameters are determined based on the distance to the vehicle so that the vehicle automatically brakes to avoid the obstacle. Information concerning the friction against the roadway is used to determine the braking parameters, and braking parameters for the autonomous brake system are adapted accordingly.

DE-19933782 describes a method for preventing collisions between two vehicles that are driving one after the other. Properties of the roadway, such as friction, are measured, and the measurement values are used to calculate a safety distance to the trail vehicle. If the actual distance is too small, the vehicle accelerates automatically.

The present invention is based on the observations of the inventors that, for a manned vehicle, the vehicle driver adapts his driving behavior based on the prevailing road conditions and increases, for example, the distance to surrounding traffic in slippery conditions. An autonomous vehicle is not as adaptable and consequently sometimes has an unnecessarily large, or alternatively overly small, safety margin, with the result that the forward travel of the autonomous vehicle is unsatisfactory on a slippery surface.

The general object of the present invention is to improve the ability of an autonomous vehicle to travel on a slippery surface.

Summary of the invention

The foregoing objects are achieved by means of the invention defined in the independent claims.

Preferred embodiments are defined by the dependent claims.

5

According to the present invention, a detection of the surface friction is performed, and the autonomous vehicle adapts its driving behavior based on the friction value, with the result that it is possible to achieve a good balance between safety and transport efficiency at all times. The driving behavior is adapted in such a way that the velocity is reduced and the margins to surrounding traffic and obstacles are increased, so that the likelihood of a collision will be low.

In further detail, this is achieved according to the invention by calculating a future route for the vehicle, a so-called trajectory, given the measured friction values and a predetermined probability model that indicates the likelihood that the predetermined route can be followed given at least said friction values along the predetermined route. The autonomous vehicle is controlled based on this probability, so that the probability that the predetermined route can be followed is higher than a predetermined probability threshold. The purpose of using a probability model is to attempt to emulate the assessments that a vehicle driver makes continuously. According to the model, there are a large number of coherent values for the friction, the vehicle velocity, the curvature of the future route, the safety margin, etc. In applying the invention, it is assumed that the probability threshold is constant independent of the other values.

25

Measuring the friction and then adapting the velocity to maintain a distance to a lead vehicle is known according to the prior art discussed above, but the object of the present invention is to allow the vehicle itself to adapt the parameters pertaining to its control in both the lateral and longitudinal directions, which increases the capacity of the autonomous vehicle to be driven where the surface is slippery. Improved control on slippery surfaces is thus achieved by means of the present invention, in part by taking into consideration the lateral acceleration

30

to which the vehicle is subject in connection with the control of the vehicle, and to thereby improve its control in the lateral and longitudinal directions.

Applying the present invention to autonomous unmanned vehicles achieves an
5 optimal balance between efficiency (velocity) and safety (avoidance of accidents) that depends in part on the friction of the surface, with the result that it is possible to influence the future position of the vehicle by specifying a safety margin for the trajectory that the vehicle is to follow.

10 Brief description of the drawing

Figure 1 is a simplified block diagram that illustrates the present invention schematically.

Figure 2 is a flow diagram that illustrates the method according to the present invention.

15 Figure 3 is a schematic depiction intended to illustrate the present invention.

Figure 4 is a schematic block diagram that illustrates an embodiment of the present invention.

Detailed description of preferred embodiments of the invention

20 The invention will now be described in greater detail with reference to the accompanying figures.

With reference first to Figure 1, the present invention concerns a control system 2 adapted so as to control an autonomous vehicle 4 along a planned route.

25 A planned route can be viewed as a general concept, and can, for example, pertain to a road the vehicle must follow in order to progress from a point A to a point B.

The control system is adapted so as to receive a friction signal 6 that contains
30 information about the friction μ for the roadway on which the vehicle is to travel, and a velocity signal 8 that contains information about the velocity v of the vehicle.

The friction for the roadway is determined, for example, by optical means by shining a beam of light on the roadway and analyzing the reflected light. An example of such a measurement is described in EP2402737.

- 5 According to another example for determining the friction of the roadway, a known measurement device is used to analyze the speeds of the wheels of the vehicle 4. A measurement of the friction of the roadway can be obtained by determining the wheel speeds for wheels on the same axle and analyzing the difference between them. Detection can also be achieved by measuring how much driving or braking
10 force is required to drive on the surface.

- According to yet another example, the vehicle comprises a known measurement device for analyzing a steering torque for the front wheels on the vehicle 4 and comparing it to the threshold value, wherein a lower torque entails lower friction,
15 i.e. a more slippery roadway.

The vehicle velocity v is, for example, available on a suitable data bus, where the information is obtained from, for example, the vehicle speedometer.

- 20 According to the invention, the control system 2 comprises a processing unit 10 and a control unit 12, wherein the processing unit is adapted so as to determine a variable safety margin $SM(\mu, v)$ relative to an object in the proximity of the vehicle based on the measured friction μ and the vehicle velocity v . The processing unit 10 is further adapted so as to determine a trajectory 14 for the planned route such
25 that said safety margin SM is met.

Trajectory refers here to the curve that the vehicle follows on the route, i.e. the position on the route that the vehicle is going to have.

- 30 The control unit is adapted so as to control the vehicle by means of a control signal 16 so that the trajectory is followed. This is achieved by influencing at least the steering, e.g. the yaw angle of the vehicle, and the velocity of the vehicle by

applying a set of control rules, wherein said control rules include a rule that takes into account the lateral acceleration a_y of the vehicle.

5 The extent of the vehicle, i.e. its length and width in relation to the upcoming route, is naturally taken into account in the control process, e.g. with regard to the available room on the route (i.e. the width and curvature of the route).

According to one embodiment, said set of control rules includes a rule that entails that the sum of the lateral forces for the front wheels and rear wheels (F_{12} and F_{34})
10 of the vehicle must be equally great regardless of the friction value, and that the equation $F_{12} + F_{34} = m \times a_y$ applies, where m is the vehicle mass. This will be explained further below.

Said set of control rules preferably includes a number of equations for stationary
15 cornering (see below).

According to the invention, a safety margin SM is thus calculated based on the vehicle velocity and the friction of the roadway. The safety margin is calculated so that the probability, i.e. the risk, of driving into an obstacle, will be low. The
20 trajectory is then determined, i.e. the calculated future route with a pre-determinable length of on the order of up to 100 meters, so that the obstacle can be avoided.

Control parameters for the vehicle are then calculated so that the calculated
25 trajectory is followed. A number of generally available equations for stationary cornering are taken into account, as will be clarified below.

These equations describe, among other things, how the friction affects the control process.

$F_{12} + F_{34} = m \times a_y$ is applicable, where F_{12} is the lateral force on the front wheels, F_{34} is the lateral force on the rear wheels, a_y is the lateral acceleration and m is the mass of the vehicle.

5 The following also applies for linear tires:

$$F_{12} = -C_{12} \times \alpha_{12}, \text{ and}$$

$$F_{34} = -C_{34} \times \alpha_{34}$$

C designates the lateral force coefficient, and α designates the drift angle for the
10 respective wheel.

This means that a condition for the vehicle to follow a predetermined trajectory, given the same mass and same lateral acceleration a_y – where the lateral acceleration is directly linked to the curvature of the trajectory and the velocity of
15 the vehicle – is that the sum of F_{12} and F_{34} must be equally great even if the friction is low.

For F_{12} and F_{34} to be equally great at low friction when the lateral force coefficients decrease, the drift angles must increase, which is accomplished by
20 turning the steering wheel. The friction coefficient thus also plays a part in the step when the vehicle is to be controlled, including its steering wheel angle, in order to follow a trajectory.

According to the invention, the calculations are preferably made for the velocity
25 that the vehicle is estimated to have at each position, and if the friction is not high enough to meet the requirement that $F_{12} + F_{34}$ must be constant, then a calculation must be made to determine the velocity at which the vehicle will be able to drive successfully in the relevant environment, and its velocity must be reduced to that value.

30 The anticipated vehicle velocity at a future position is calculated, for example, by always attempting to increase the velocity as much as the vehicle can tolerate up to its maximum velocity, or to comply with posted speed limits. According to

another alternative, a velocity profile can be followed that is, for example, received from a separate module designed to achieve the lowest possible fuel consumption.

- 5 Another situation that can occur is when the degree of safety margin that the threshold value SM requires for the relevant velocity and friction is not possible, which will result in a reduction in the velocity.

The vehicle dynamics term "drift angle" (also known as slip angle) is the angle
10 between the direction of travel of a rolling wheel and the direction in which the wheel is pointing (i.e. the angle of the vector sum for the forward velocity v_x of the wheel and the lateral velocity v_y of the wheel.)

The drift angle results in a force that is parallel to the wheel axle, and the force component that is perpendicular to the direction of wheel travel is called the lateral
15 cornering force. This lateral force increases essentially linearly for the first degrees of the drift angle. At higher slip angles the lateral force increases non-linearly up to a maximum, after which it decreases.

The drift angle α is defined as:

$$\alpha = -\arctan\left(\frac{v_y}{v_x}\right)$$

20

According to another embodiment, said set of control rules includes a velocity rule that entails that the velocity must be as high as possible, naturally under the condition that other control rules are complied with.

- 25 According to the invention, the trajectory is preferably determined so that the distance between the vehicle and an object is not less than SM when the trajectory is followed.

An object can, for example, be a fixed object along the route, e.g. a quarry wall, but it can also be a movable object, such as another vehicle.

Figure 3 schematically depicts a route 20 on which two different trajectories have been drawn, T1 (solid line) and T2 (broken line).

The calculated safety margins SM1 and SM2 for each respective trajectory have been marked, where SM1 is the safety margin for T1, and SM2 for T2.

As the figure shows, SM1 is greater than SM2, which is to be interpreted to mean that the measured friction for T1 is lower than for T2, i.e. the roadway is more slippery in the case where T1 is calculated, and the safety margin must consequently be greater than in the T2 case, when the vehicle can be driven with a lower safety margin.

The present invention also includes a method in a control system adapted so as to control an autonomous vehicle along a planned route.

The method will now be described with reference to the flow diagram in Figure 2. Reference is also made to the foregoing description of the control system.

The method comprises:

A1 – measuring the friction μ for a roadway on which the vehicle is to travel;

A2 – measuring the velocity v of the vehicle.

The measurement of the friction is made, for example, using the methods described above.

Information about the vehicle velocity is available via a suitable data bus in the vehicle, where the information is obtained from, for example, a speedometer.

The method according to the invention further comprises:

B – determining a variable safety margin $SM(\mu, v)$ relative to an object in the proximity of the vehicle, based on the measured friction μ and the velocity v of the vehicle;

C – determining a trajectory for the planned route so that said determined safety

margin SM is met, and

D – controlling the vehicle so that the trajectory is followed by influencing at least the steering and the velocity of the vehicle by applying a set of control rules, wherein said control rules include a rule that takes into account the lateral
5 acceleration a_y of the vehicle.

Said set of control rules preferably include a rule that entails that the sum of the lateral forces for the front wheels and rear wheels (F_{12} and F_{34} , respectively) must be equally great regardless of the friction value, and that the correlation $F_{12} + F_{34}$
10 $= m \times a_y$ applies, where m is the vehicle mass.

The set of control rules further preferably includes a number of equations for stationary cornering. These have been described above.

According to one embodiment, said set of control rules includes a velocity rule
15 that entails that the velocity must be as high as possible.

The step B in the method preferably comprises the determination of the trajectory in such a way that the distance between the vehicle and an object is not less than SM when the trajectory is followed.
20

The present invention further comprises a computer program (P) in the vehicle, wherein said computer program (P) contains program code for causing a processing unit 10; 500 or another computer 500 connected to the processing unit 10; 500 to perform the steps according to the method as described above.

25 The invention further comprises a computer program product containing a program code stored on a computer-readable medium for performing the method steps as described above when said program code is run on a processing unit 10; 500 or another computer 500 computer connected to the processing unit 10; 500.

30 The computer 500 will now be described with reference to the block diagram in Figure 4.

The program P can be stored in executable form or compressed form in a memory 560 and/or in a read/write memory 550. When it is stated that the data-processing unit 510 performs a given function, it is to be understood that the data-processing unit 510 executes a certain part of the program that is stored in the memory 560, or a certain part of the program that is stored in the read/write memory 550.

The data-processing device 510 can communicate with a data port 599 via a data bus 515. The non-volatile memory 520 is intended to communicate with the data-processing unit 510 via a data bus 512. The separate memory 560 is intended to communicate with the data-processing unit 510 via a data bus 511. The read/write memory 550 is arranged to communicate with the data-processing unit 510 via a data bus 514. The units that are connected to the processing unit 10 (see Figure 1) can be connected to the data port 599.

When data are received at the data port 599, they are stored temporarily in the second memory section 540. Once received input data have been stored temporarily, the data-processing unit 510 is arranged so as to execute code in a manner as described above.

Parts of the methods described herein can be carried out by the apparatus 500 (corresponding to the processing unit in Figure 10) with the help of the data-processing unit 510, which runs the program stored in the memory 560 or the read/write memory 550. When the apparatus 500 runs the program, the methods described herein are carried out.

The present invention is not limited to the preferred embodiments described above. Various alternatives, modifications and equivalents can be used. The foregoing embodiments are consequently not to be viewed as limiting the protective scope of the invention, which is defined by the accompanying claims.

Claims

1. A method in a control system adapted so as to control an autonomous vehicle along a planned route, wherein the method comprises:
A1 – measuring the friction μ for a roadway on which the vehicle is to travel;
5 A2 – measuring the vehicle velocity v ;
characterized in that the method comprises:
B – determining a variable safety margin $SM(\mu, v)$ relative to an object in proximity to the vehicle based on the measured friction μ and the vehicle velocity v ;
C – determining a trajectory for the planned route so that said determined safety
10 margin SM is met, and
D – controlling the vehicle so that the trajectory is followed by influencing at least the steering and the velocity of the vehicle by applying a set of control rules, wherein said control rules include a rule that takes into account the lateral acceleration a_y of the vehicle.
15
2. The method according to claim 1, wherein said set of control rules includes a rule that entails that the sum of the lateral forces for the front wheels and the rear wheels (F_{12} and F_{34} , respectively) must be equally great regardless of the friction value.
20
3. The method according to claim 2, wherein the correlation $F_{12} + F_{34} = m \times a_y$ applies, where m is the vehicle mass.
4. The method according to any of the preceding claims, wherein said
25 set of control rules includes a velocity rule that entails that the velocity must be as high as possible.
5. The method according to any of the preceding claims, wherein said set of control rules includes a number of equations for stationary cornering.
30
6. The method according to any of the preceding claims, wherein the trajectory is determined so that the distance between the vehicle and an object is

not less than SM when the trajectory is followed.

7. The method according to any of the preceding claims, wherein said object is a fixed object.

5

8. A control system (2) adapted so as to control an autonomous vehicle (4) along a planned route, wherein the control system is adapted so as to receive a friction signal (6) that contains information about the friction μ for a roadway on which the vehicle is to travel, and a velocity signal (8) that contains information

10 about the vehicle velocity v ;

characterized in that the control system (2) comprises a processing unit (10) and a control unit (12), wherein the processing unit is adapted so as to determine a variable safety margin $SM(\mu, v)$ relative to an object in proximity to the vehicle based on the measured friction μ and the vehicle velocity v ; and so as to

15 determine a trajectory (14) for the planned route so that said determined safety margin SM is met, and wherein the control unit is adapted so as to control the vehicle by means of a control signal (16) so that the trajectory is followed by influencing at least the steering and the velocity of the vehicle by applying a set of control rules, wherein said control rules include a rule that takes into account the
20 lateral acceleration a_y of the vehicle.

9. The control system according to claim 8, wherein said set of control rules include a rule that entails that the sum of the lateral forces for the front wheels and the rear wheels (F_{12} and F_{34} , respectively) must be equal regardless
25 of the friction value.

10. The control system according to claim 9, wherein the correlation $F_{12} + F_{34} = m \times a_y$ applies, where m is the vehicle mass.

30 11. The control system according to any of claims 8-10, wherein said set of control rules includes a velocity rule that entails that the velocity must be as high as possible.

12. The control system according to any of claims 8-11, wherein said set of control rules includes a number of equations for stationary cornering.

13. The control system according to any of claims 8-12, wherein the
5 trajectory is determined in such a way that the distance between the vehicle and any object is not less than SM when the trajectory is followed.

14. The control system according to any of claims 8-13, wherein said object is a fixed object.

10

15. A computer program (P) in the vehicle, wherein said computer program (P) contains program code for causing a processing unit (10; 500) or another computer (500) connected to the processing unit (10; 500) to perform the steps according to the method according to any of claims 1-7.

15

16. A computer program product containing a program code stored on a computer-readable medium for performing the method steps according to any of claims 1-7 when said program code is run on a processing unit (10; 500) or another computer (500) connected to the processing unit (10; 500).

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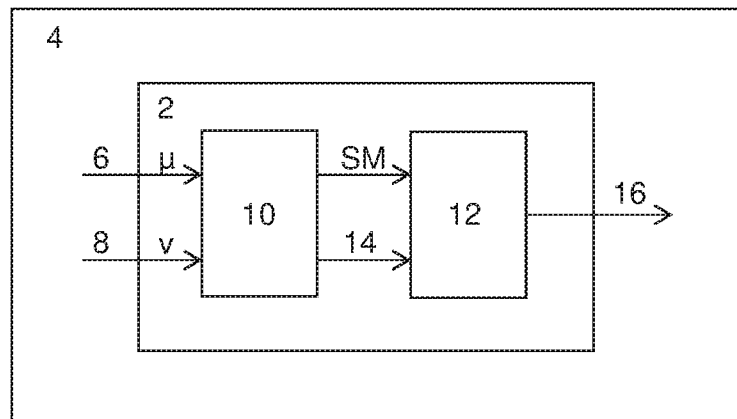


FIG. 1

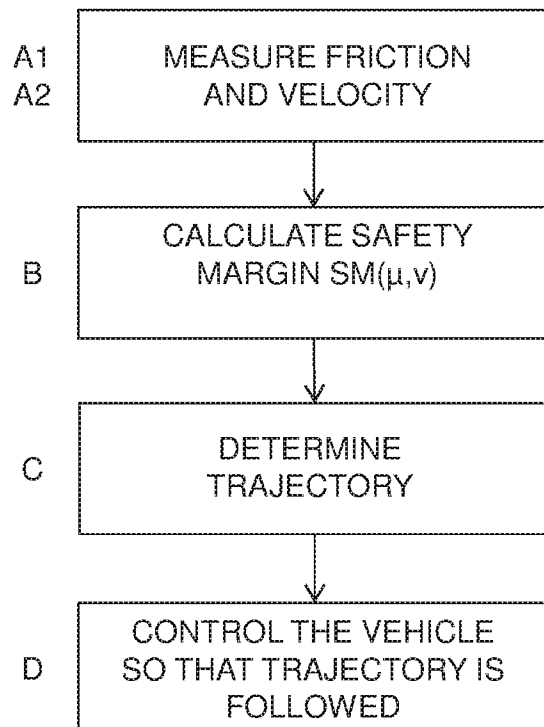


FIG. 2

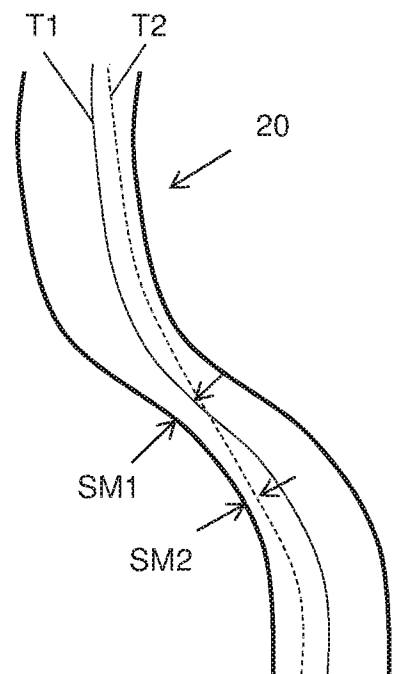


FIG. 3

2/2

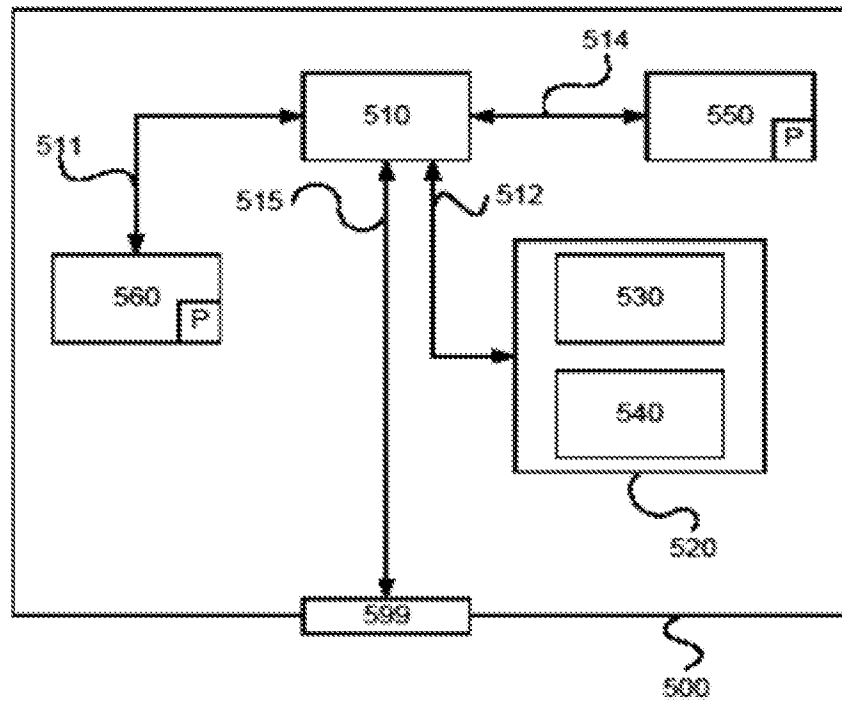


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
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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: B60W, G05D

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, PAJ, WPI data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2011009009 A1 (MASSACHUSETTS INST TECHNOLOGY ET AL), 20 January 2011 (2011-01-20); paragraphs [0002]-[0010], [0036], [0043]-[0045], [0061]-[0064], [0074], [0083], [0090]-[0091] --	1-16
Y	DE 19933782 A1 (VOLKSWAGEN AG), 25 January 2001 (2001-01-25); column 6, line 40 - column 6, line 64 --	1-16



Further documents are listed in the continuation of Box C.



See patent family annex.

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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