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Method, control unit, and system for controlling an automated vehicle

Abstract

A method for controlling an automated vehicle. In a first method part, the instantaneous surroundings of the automated vehicle are detected using an on-board surroundings sensor system. A localization of the automated vehicle takes place based on a comparison of the data of the surroundings sensor system to a previously provided HD localization map. A map-based surroundings model is generated, in a second method part representing a normal mode, and is used for planning the behavior and the trajectory of the automated vehicle. In a third method part representing a safety mode, carried out in parallel to or as an alternative to the first method part, the instantaneous surroundings of the automated vehicle are detected using the on-board surroundings sensor system. Based on the data ascertained in the process, a map-less surroundings model is generated and used for planning the behavior and the trajectory of the automated vehicle.

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Background/Summary

CROSS REFERENCE

(1) The present application claims the benefit under 35 U.S.C. § 119 of German Patent Application No. DE 10 2021 211 463.6 filed on Oct. 12, 2021, which is expressly incorporated herein by

reference in its entirety.

FIELD

(2) The present invention relates to a method for controlling an automated vehicle. The present invention furthermore relates to a control unit for carrying out the method as well as to a computer program and to a memory medium including such a computer program.

BACKGROUND INFORMATION

(3) High definition (HD) planning and localization maps are indispensable for highly automated driving starting at Level 2+, the system performance and reliability required for this purpose drastically increasing compared to simpler assistance systems. For localization, the automated vehicle uses a suitable localization map, a vehicle-internal localization module being able, based on this localization map serving as a knowledge base, to ascertain the instantaneous location and position of the automated vehicle by a comparison of certain features detected with the aid of on-board surroundings sensors to the map. The data for localization maps are collected in the process by a certain sensor, e.g., radar, LIDAR or camera, with the aid of multiple trips on the same route. Subsequent to the localization module, a vehicle-internal planning module makes certain behavior and movement decisions on the basis of a planning map, which was also collected in advance. In contrast to the localization map, the planning map additionally also includes the road topology and geometry information at the traffic lane level as well as semantic context, such as traffic signs and traffic light positions. The accuracy and wealth of information of these two map types undoubtedly surpasses today's sensor performance. The extraction of comprehensive semantic pieces of information directly from raw sensor data in real time represents a major challenge, in particular, in complex traffic scenarios. Prepared HD maps are thus indispensable for a reliable and intelligent maneuvering from point A to B.

(4) Yet, situations occur, even with the aid of connectivity services and cloud sourcing, in which the HD maps are no longer up-to-date or the localization module no longer supplies sufficient accuracy. Since a navigation based on such data which no longer agree with the real physical world may have fatal consequences, most current HD map-based planning systems either simply shut down or carry out dangerous maneuvers so that the safety driver has to take over the control.

SUMMARY

(5) It is an object of the present invention to also ensure the safety of the automated driving function of vehicles in those situations in which a localization based on an HD map is not possible with sufficient accuracy. This object may be achieved with the aid of features of the present invention. Advantageous embodiments of the present invention are disclosed herein.

(6) According to the present invention, a method for controlling an automated vehicle is provided. According to an example embodiment of the present invention, in a first method part, the instantaneous surroundings of the automated vehicle are detected with the aid of an on-board surroundings sensor system, and a localization of the automated vehicle takes place based on a comparison of the data of the surroundings sensor system to a previously provided HD localization map. In the process, a map-based surroundings model of the instantaneous surroundings of the automated vehicle is generated, in a second method part representing a normal mode, based on a global position of the automated vehicle ascertained during the localization and is used for planning an instantaneous trajectory of the automated vehicle. Furthermore, in a third method part representing a safety mode, which is carried out in parallel to or as an alternative to the first method part, the surroundings of the automated vehicle are detected with the aid of the on-board surroundings sensor system, and, based on the data ascertained in the process, a map-less surroundings model of the instantaneous surroundings of the automated vehicle is generated and used for planning an instantaneous trajectory of the automated vehicle. Finally, the instantaneous trajectory calculated in the normal mode or in the safety mode is output for controlling the movement of the automated vehicle along the particular trajectory. As a result of the additional safety mode (fall-back mode), a fall-back function is created, which allows an automated vehicle to

continue its trip even when no HD maps are available, or when a sufficiently precise localization is not possible based on the provided HD maps. While the normal mode offers an intelligent driving function thanks to the HD maps, the safety mode focuses on the handling of essential physical conditions. As a result of the safety mode, the automated vehicle is able to maneuver safely before coming to a safe stop, instead of effectuating a thoughtless emergency brake application in the case of a changed road structure or a malfunction of the localization. Overall, the driving safety is enhanced by the additional safety mode when using the highly automated driving function.

(7) In one specific example embodiment of the present invention, it is provided that, in a fourth method part, the accuracy of the localization from the first method part is checked. In the case that, during the localization, a precise global position of the automated vehicle was ascertained, the instantaneous trajectory calculated in the second method part is output for controlling the movement of the automated vehicle. In the case that, during the localization, no or only an imprecise global position of the automated vehicle was ascertained, the instantaneous trajectory calculated in the third method part is output for controlling the movement of the automated vehicle. Due to the repeated check of the localization results, it is ensured that, in the case of an error, a switch from the normal mode into the safety mode may take place particularly quickly and seamlessly.

(8) In one further specific example embodiment of the present invention, it is provided that the distance traveled by the vehicle is detected with the aid of an on-board odometry unit. In the case that the localization, in a present method cycle, does not supply a precise global position of the automated vehicle, the instantaneous global position of the automated vehicle is ascertained based on the global position of the automated vehicle ascertained during the last accurate localization, and the distance of the automated vehicle detected since then with the aid of the odometry unit. This procedure makes it possible to reconcile the map segment generated locally in the safety mode with the available planning map. In this way, a particularly seamless switch into the normal mode is made possible.

(9) In one further specific example embodiment of the present invention, it is provided that the map-less surroundings model ascertained in the third method part is used for validating the correctness of at least one provided HD map and/or for checking the results of the localization from the first method part. By checking the correctness of the provided HD maps and checking the results of the localization, it may be decided more quickly whether a switch into the safety mode is necessary. In both instances, the driving safety of the automated vehicle is enhanced.

(10) In one further specific example embodiment of the present invention, it is provided that the planning of the behavior of the automated vehicle in the second method part takes place with a focus which is directed both at the driving safety and at an intelligent and comfortable mode of driving, while the planning of the behavior of the automated vehicle in the third method part takes place with a focus which is essentially directed at the driving safety. Due to the degradation of the planning of the behavior of the automated vehicle in the safety mode, more computing capacity is available for the computing operations necessary for ensuring the driving safety. In this way, the driving safety of the automated vehicle may be enhanced with the aid of this procedure.

(11) In one further specific example embodiment of the present invention, it is provided that a traffic lane model is generated based on roadway boundaries of a presently negotiated road which are detected with the aid of the on-board surroundings sensor system, the traffic lane model in the third method part being used for generating a corresponding segment of a local planning map, and subsequently, with the aid of the on-board surroundings sensor system, dynamic objects and obstacles detected in the surroundings of the automated vehicle being added to the newly generated segment of the local planning map to generate the map-less surroundings model. In this way, a local planning map may be generated in a particularly effective manner in the safety mode.

(12) In one further specific example embodiment of the present invention, it is provided that the map-less surroundings model in the third method part is generated in a vehicle-based local

coordinate system. In the process, the objects included in the map-less surroundings model are transformed from the vehicle-based local coordinate system into a global coordinate system underlying the HD planning map to ensure a seamless transition from the normal mode into the safety mode. This procedure enables a particularly rapid switch between the normal mode and the safety mode, thereby enhancing the driving safety.

(13) In one further specific example embodiment of the present invention, it is provided that the planning of the behavior and of the trajectory of the automated vehicle carried out in the second method part based on the map-based surroundings model is paused when the localization in a present method cycle does not supply a precise global position of the automated vehicle. In this way, the computing capacity available for the safety mode may be increased. A particularly precise map-less surroundings model may be generated in this way, and the calculation of the driving trajectory based thereon may be optimized. In this way, the driving safety of the automated vehicle is enhanced.

(14) According to one further aspect of the present invention, a control unit for an automated vehicle is provided, which is configured to carry out at least some of the steps of the aforementioned method. The control unit includes a localization module designed for ascertaining a global position of the automated vehicle, based on a comparison of a digital HD localization map to data of an on-board surroundings sensor system, as well as a primary planning unit and a secondary planning unit. The primary planning unit includes a primary surroundings modeling module, designed for generating a map-based digital model of the surroundings of the automated vehicle, using a provided HD planning map, data of the on-board surroundings sensor system, and data of an on-board odometry unit, as well as a primary planning module, designed for planning a behavior and a trajectory of the automated vehicle, based on the global position of the automated vehicle ascertained by the localization module and a provided HD planning map. The secondary planning unit includes a map-less surroundings modeling module, designed for generating a map-less surroundings model of the surroundings of the automated vehicle, based on the data provided by the surroundings sensor system and the odometry unit, as well as a secondary planning module, designed for planning the behavior and the trajectory of the automated vehicle, based on the map-less surroundings model. The control unit results in the advantages described in connection with the method according to the present invention.

(15) In one specific embodiment of the present invention, it is provided that the control unit furthermore includes a switching module, designed for checking the accuracy of the global position of the automated vehicle ascertained by the localization module. In the process, the activation module is furthermore designed to switch the operation of the automated vehicle from a normal mode, in which the control of the automated vehicle is carried out based on the trajectory provided with the aid of the primary planning module, to a safety mode, in which the control of the automated vehicle is carried out based on the trajectory provided with the aid of the secondary planning module, if the check shows that no precise global position of the automated vehicle was ascertained by the localization module. The advantages described in connection with the method result for such a control unit.

(16) According to one further aspect of the present invention, a computer program encompassing commands is furthermore provided, which, during the execution of the computer program by a computer, prompt the computer to carry out the above-described method. The advantages described in connection with the method also result for the computer program.

(17) A computer-readable memory medium is also provided, on which the aforementioned computer program is stored. In this respect, the advantages described in connection with the method also result for the computer-readable memory medium.

(18) The present invention is described in greater detail hereafter based on figures.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** schematically shows a system including an automated vehicle as well as an external server, according to an example embodiment of the present invention.

(2) FIG. **2** shows a block diagram of the vehicle-internal control unit including a normal mode pipeline, a safety mode pipeline, and a switching module, according to an example embodiment of the present invention.

(3) FIG. **3** shows a more detailed block diagram of the vehicle-internal control unit from FIG. **2**.

(4) FIG. **4** shows a flow chart of various method parts of the method, according to an example embodiment of the present invention.

(5) FIG. **5** shows a map-less digital surroundings model superimposed on a map-based surroundings model of the same surroundings, according to an example embodiment of the present invention.

(6) FIG. **6** shows a digital surroundings model including the trajectories generated by the two planning modules, according to an example embodiment of the present invention.

(7) FIG. **7** shows a diagram for illustrating the transformations between the various coordinate systems, according to an example embodiment of the present invention.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

(8) FIG. **1** schematically shows an automated vehicle **100** driving on a road **310**. Automated vehicle **100** includes a surroundings sensor system **110** for detecting objects and structures in its surroundings **300** as well as a control device **120** for controlling automated vehicle **100**. In the present example, surroundings sensor system **110** includes multiple surroundings sensors, such as, e.g., a radar sensor **111**, a LIDAR sensor **112**, and a video camera **113**. Furthermore, automated vehicle **100** also includes sensors for detecting various measured variables and parameters, such as, e.g., inertial sensors **114** for detecting the instantaneous movement condition of automated vehicle **100**, a steering angle sensor **115**, a GNSS unit **116** for the satellite-based ascertainment of the global position of automated vehicle **100**, as well as an odometry unit **117** for ascertaining the traveled distance, e.g., based on the rotary motion of the vehicle wheels. Automated vehicle **100** furthermore includes a wireless communication device **190** for establishing a wireless communication link **201** to an external server **210**. As is shown in FIG. **1**, automated vehicle **100** and the external server are part of a system **200** which may encompass further vehicles and servers and offers certain services (cloud services). In the present example, server **210** includes a memory unit **211** in which various digital HD maps **400**, **410** are stored. During operation, automated vehicle **100** receives, from server **210**, HD maps **400**, **410** of the particular surroundings **300** in which automated vehicle **100** is presently situated. These digital HD maps **400**, **410** are then stored in a memory unit **122** of control device **120**.

(9) As is furthermore shown FIG. **1**, control device **120** includes at least one memory unit **122** for storing digital HD maps **400**, **410**, a control unit **121** for ascertaining an optimal trajectory **412**, **422**, as well as a movement control unit **170** for controlling the movement of automated vehicle **100** along the ascertained trajectory **412**, **422**.

(10) FIG. **2** schematically shows further details of control unit **121** from FIG. **1**. Accordingly, control unit **121** includes a localization module **130**, which ascertains the instantaneous global position of automated vehicle **100** based on the provided digital HD localization map **400** and the data provided by surroundings sensor system **110**. Control unit **121** furthermore includes a primary planning unit **140**, which is assigned to a normal mode and which, based on the ascertained global position and the provided digital planning map **410**, ascertains a suitable trajectory **412** for automated vehicle **100**. Control unit **121** furthermore also includes a secondary planning unit **150**, which is assigned to a safety mode and which ascertains a suitable trajectory **422** for automated

vehicle **100** only based on the data provided by surroundings sensor system **110**. In addition, control unit **121** includes a switching module **160**, which switches between the normal mode and the safety mode. For this purpose, switching module **160** checks the accuracy of the localization of localization module **130**. When a suitable localization result is available, switching module **160** switches to the normal mode, in this case trajectory **412** ascertained in a map-based manner by primary planning unit **140** being transferred to movement control unit **170**. If no suitable localization result is available, switching module **160**, in contrast, switches to the safety mode, in this case trajectory **422** ascertained in a map-less manner by secondary planning unit **150** being transferred to movement control unit **170**. Movement control unit **170** subsequently carries out a corresponding longitudinal control and lateral control of automated vehicle **100** to guide automated vehicle **100** along trajectory **412**, **422** instantaneously provided by the particular selected planning unit **140**, **150**.

(11) FIG. **3** schematically shows further details of the two planning units **140**, **150** from FIG. **2**, which each include a surroundings modeling module **141**, **151** as well as a planning module **142**, **152** downstream therefrom. Primary surroundings modeling module **141** of primary planning unit **140** receives digital HD planning map **410** provided by external server **210** from a memory unit **122**, the localization result instantaneously ascertained based on digital HD localization map **400** from localization module **130**, and corresponding sensor data from surroundings sensor system **110** and corresponding odometry data from odometry unit **117**. Based on these data, surroundings modeling module **141** cyclically creates a map-based surroundings model **411** of the instantaneous surroundings **300** of automated vehicle **100**. Based on this map-less surroundings model **411**, primary planning module **142** cyclically generates suitable trajectories **412**, one of these trajectories **412** in each case being selected for transfer to movement control unit **170**. For this purpose, primary planning module **142** includes a behavior planner **143**, a reference line generator **144** downstream therefrom, as well as a trajectory planner **145** downstream therefrom.

(12) In contrast thereto, secondary surroundings modeling module **151** of secondary planning unit **150** generates a corresponding map-less surroundings model **421** only based on the data of surroundings sensor system **110** and of odometry unit **117**. As is apparent from FIG. **3**, a segment **420** of a local planning map is generated for this purpose based on a traffic lane model **156** obtained from the sensor data, from which a map-less surroundings model **421** is finally generated by enrichment with further sensor data, such as, e.g., the dynamic agents recognized in the vehicle surroundings. Based on this map-based surroundings model **421**, secondary planning module **152** also cyclically generates suitable trajectories **422**, one of these trajectories **422** in each case being selected for transfer to movement control unit **170**. For this purpose, primary planning module **142** also includes a corresponding behavior planner **153**, a reference line generator **154** downstream therefrom, as well as a trajectory planner **155** downstream therefrom.

(13) The present invention provides for an additional secondary planning unit **150** including a secondary planning module **152**, which takes over the control if primary planning module **142** cannot supply any results, or cannot supply any meaningful results, due to the aforementioned situations. For this purpose, automated vehicle **100** uses on-board surroundings sensors **111**, **112**, **113** for recognizing roadway markings **314** through **317** and creates a segment **420** of a local planning map therefrom.

(14) Thereafter, dynamic agents **330** through **335** recognized with the aid of surroundings sensors **111**, **112**, **113** are associated with the newly created segment **420** of the local planning map to generate a map-less surroundings model **421** of the immediate surroundings of automated vehicle **100**. When localization module **130** does not supply a precise localization result, the odometry data collected by odometry unit **117** since the last precise localization are used for estimating the instantaneous global position of automated vehicle **100**. Subsequently, behavior planner **153** within second planning module **152** is degraded into a special mode which forces automated vehicle **100** to remain in the present negotiable corridor. In contrast to behavior planner **143** of primary

planning module **142** used in the normal mode, behavior planner **153** does not supply any semantic information, but only physical information for trajectory planner **155** downstream therefrom to plan a safe trajectory **422**. Secondary planning module **152** preferably always runs in parallel to primary planning module **142** and thus also acts as a supervisor to check the correctness of the data of provided HD maps **400**, **410**. As soon as the change between the normal mode and the safety mode is triggered, secondary planning module **152** may link its trajectory **422** to the previous one, by which a smooth movement control of automated vehicle **100** is ensured.

(15) The normal mode, which is based on digital HD maps **400**, **410** collected in advance, preferably focuses on comfort and intelligence. In contrast, the safety mode preferably focuses on the safety and the physical world in the close range detectable by the on-board sensors. These two systems do not conflict with one another, but work together within the meaning of “being prepared for the worst, but driving comfortably and intelligently when the situation allows.”

(16) FIGS. **2** and **3** show a functional overview of the described architecture. In primary planning unit **140** representing the planning pipeline for the normal mode, the data from the localization, odometry **117** and surroundings sensor system **110**, together with the previously collected HD planning map **410**, are fed into a map-based primary surroundings modeling module **141**. For the safety mode, a further surroundings model **421** around automated vehicle **100** is created, which utilizes the pieces of information detected by sensors **111**, **112**, **113** for creating a segment **420** of the local planning map in each planning cycle.

(17) Surroundings model **421** for the safety mode is referred to as “map-less” here to illustrate that no map collected in advance is used for this purpose. These two surroundings modeling modules **141**, **152** are started in two parallel process strands. When the map-based normal mode reaches an error state, secondary planning module **152** sends its instantaneously calculated trajectory **422** to movement control unit **170**.

(18) The devices, units, and modules described here may be implemented both in the form of software or hardware, or a combination of software and hardware.

(19) FIG. **4** shows a simplified flowchart of the method described here. The method is broken down into three different method strands **601**, **602**, **603**, which are carried out independently of one another and are at least partially temporally superimposed. For better illustration, the various method strands **601**, **602**, **603** are shown next to one another. In the process, first method strand **601** represents the normal mode in which the trajectory planning takes place regularly, i.e., based on HD maps. In a first method part **610**, a method step **611** takes place, in which a HD localization map **400** is provided. Furthermore, in method step **612**, the detection of the surroundings of automated vehicle **100** with the aid of surroundings sensor system **110** takes place. Thereafter, in method step **613**, a localization of automated vehicle **100** is carried out based on a comparison of the data of surroundings sensor system **110** to features of HD localization map **400**. In the subsequent second method part **620**, a suitable trajectory for automated vehicle **100** is calculated based on the localization result from first method part **610**. For this purpose, a map-based surroundings modeling is carried out in method step **621**, in which a map-based surroundings model **411** is generated. In the subsequent method step **623**, a map-based generation of a reference line takes place. Finally, in method step **624**, a map-based trajectory planning is carried out, in which an optimal trajectory **422** for the present planning cycle is ascertained.

(20) Second method strand **602**, in contrast, represents the additional safety mode in which the trajectory planning takes place without the HD maps. In the process, only method step **612** from first method part **610** is used, which represents the detection of the vehicle surroundings with the aid of surroundings sensor system **110**. Thereafter, a map-less surroundings modeling takes place in method step **631**. In the process, initially a segment **420** of the local planning map is generated based on the data provided by surroundings sensor system **110**, from which a map-less surroundings model **421** is generated by enrichment with further data of surroundings sensor system **110**. Furthermore, a map-less localization takes place in method step **635**, in which the

position of automated vehicle **100** in segment **420** of the local planning map or map-less surroundings model **421** is determined. In the subsequent method step **632**, a map-less behavior planning takes place. Thereafter, in method step **633**, a map-less generation of a suitable reference line takes place. Finally, in method step **634**, a map-less trajectory planning takes place, in which an optimal trajectory **422** for the present planning cycle is calculated.

(21) In third method strand **603**, which encompasses a fourth method part **640**, it is decided which of the two trajectories **412**, **442** ascertained in the various modes is to be used for controlling automated vehicle **100**. For this purpose, in method step **641**, initially a check of the instantaneous result of the localization carried out in method step **613** based on HD localization map **400** takes place. As a function of the result of this check, a selection of the particular operating mode takes place in the subsequent method step **642**. In the process, it is decided whether the normal mode is activated and trajectory **412** ascertained with the aid of primary planning unit **140** is used for controlling automated vehicle **100**, or whether the safety mode is activated and trajectory **422** ascertained with the aid of secondary planning unit **150** is used for controlling automated vehicle **100**. Finally, in method step **650**, an output of trajectory **412**, **422** calculated in the respective selected operating mode to movement control unit **170** of automated vehicle **100** takes place.

(22) FIG. **5** illustrates the local generation of local planning map segment **420** based on the data provided by surroundings sensor system **110**. In this way, a video camera **113** may be integrated into the system, for example, which is already able to recognize roadway markings **314** through **317** and to provide high-quality roadway models in clothoids. In FIG. **5**, center lines **315**, **316** represent the boundary lines of present traffic lane **312** of automated vehicle **100**, and outer lines **314**, **317** represent the boundary lines of adjoining traffic lanes **311**, **313**. Moreover, video camera **113** is able to recognize open negotiable space, which provides additional specifications to secondary planning module **152** in the next phase. Subsequent to the traffic lane model generation based on clothoids, the data are converted into an internal map format, so that secondary planning module **152** may access it. Segment **420** of the local planning map thus generated is initially present in vehicle-based coordinate system **520** and moves along with vehicle **100** in each planning cycle. With the aid of the transformation formulas explained in connection with FIG. **7**, local planning map **420**, however, may always be transformed into global coordinate system **510**, regardless of whether localization module **130** fails or not.

(23) In FIG. **5**, the hatched area marks a segment **420** of the local planning map which is instantaneously generated by vehicle **100** and which is superimposed with the provided HD planning map **410**. When localization module **130** is fully functional, the instantaneously generated segment **420** of the local planning map should be aligned with the previously detected HD planning map **410** in the map plane situated therebeneath and projected well thereon.

(24) So-called “negotiable corridors” may be derived from the locally generated planning map segment **420**, which show continuous trajectories on which automated vehicle **100** may move in the present situation. The negotiable corridor is typically represented by a sequence of vector **3**D points and a sequence of widths measured at the particular points. Based on these pieces of information, an optimization process may then be carried out to obtain a denser and smoother curve, which describes this negotiable corridor. Since the negotiable corridor, in the close range of automated vehicle **100**, in general only changes slightly from one to the other planning cycle, a new optimization process is not necessary for each planning cycle. An algorithm may therefore be provided, which only triggers the optimization process when automated vehicle **100** makes a significant movement forward, which is parameterizable.

(25) As was already described in connection with FIG. **2**, trajectory **412** created by primary planning module **142** for the normal mode is transferred in the normal mode to movement control unit **170** of automated vehicle **100** to control the vehicle movement. This trajectory **412** is also buffered for both planning modules **142**, **152** for the next planning cycle, so that planning modules **142**, **152** are able to append their respective newly ascertained trajectories **412**, **422** to the previous

one. When the transition from the normal mode to the safety mode is triggered, the process strand for the surroundings modeling in the normal mode may be stopped, and the trajectory generation in the normal mode will be skipped, while the surroundings modeling and the trajectory generation for the safety mode continue to run. In this transition cycle between normal mode and safety mode, secondary planning module **152** continues to use trajectory **412** of primary planning module **142** ascertained in the normal mode from the previous planning cycle to create its instantaneous trajectory **422**. Following the transition cycle, secondary planning module **152** uses trajectory **422** previously generated by itself to ensure its instantaneous trajectory **422**. To illustrate the transition from the normal mode to the safety mode, FIG. **6** shows a map-based surroundings model **411** including a vehicle **100** driving on a multi-lane road **310**. Surroundings model **411** also encompasses a further vehicle **330**, whose driving direction and speed are visualized with the aid of an arrow. For the normal mode, a bundle of different trajectories is generally generated by primary planning module **142**, the vertical distance of the trajectories with respect to the roadway plane typically indicating the respective vehicle speed. The single trajectory **412** shown in FIG. **6** is that which was ascertained by primary planning module **142** as the best from the bundle of calculated trajectories, and which the movement control of automated vehicle **100** followed up until this point in time. The second line represents trajectory **422** instantaneously calculated by secondary planning module **152**, which is attached to the existing trajectory **412** and which the movement control of automated vehicle **100** now follows after the transition from the normal mode to the security mode.
(26) FIG. **7** illustrates the various coordinate systems used in the method as well as the fundamental coordinate transformations. Accordingly, in the normal mode, HD planning map **410** supplies information, such as, e.g., points on roadway markings **314** through **317**, in a global coordinate system **510**, which is referred to as map enu frame. In contrast, sensor system **110** supplies the conditions of the surrounding agents (objects in the surroundings of the automated vehicle) in a local coordinate system **520** which is fixedly assigned to vehicle **100** and referred to as vehicle_origin frame. To fuse the data from the various coordinate systems **510**, **520**, primary planning module **142** in each planning cycle must calculate the following transformation between the two coordinate systems **510**, **520**:
$$\text{map\_}T\text{\_vehicle\_origin}=\text{map\_}T\text{\_ecef}\times\text{ecef\_}T\text{\_vehicle\_origin}$$
(27) In the process, map_T_ecef corresponds to the static transformation **501** from an earth-centered and earth-based coordinate system **500**, which is referred to as Earth-Centered Earth-Fixed (ECEF) frame, to global coordinate system **510** of HD map **410**. Furthermore, ecef_T_vehicle_origin refers to a transformation **502** from the earth-centered and earth-fixed coordinate system **500** to vehicle-based coordinate system **520**, which corresponds to the instantaneous localization result or may be derived therefrom.
(28) When localization module **130** supplies no or only an imprecise global vehicle position, the result must be ascertained based on the last known precise global localization of automated vehicle **100**. This also takes place with the aid of the ecef_T_vehicle_origin transformation **502**, which in this case, however, is calculated as follows:
$$\text{ecef\_}T\text{\_vehicle\_origin}=\text{ecef\_}T\text{\_map}\times\text{last\_map\_}T\text{\_odom}\times\text{odom\_}T\text{\_vehicle\_origin}$$
(29) In the process, last_map_T_odom corresponds to the last known precise transformation **504** from global coordinate system **510** into an odom coordinate system **530**, which is assigned to the location of the last accurate position of automated vehicle **100**.
(30) This transformation **505** is always recorded standard in the normal mode and does not change, as long as no new precise localization result is present. In contrast, odom_T_vehicle_origin refers to a transformation **503** from odom coordinate system **530** into vehicle-based coordinate system **520**.
(31) This transformation **503** results based on the odometry data updated in each planning cycle. The odometry data correspond to distance **440** traveled since the last precise localization of vehicle **100**, which is detected with the aid of an on-board odometry unit **117**. From the above-mentioned

formula, furthermore the following conversion results for the transformation from global coordinate system **510** into vehicle-based coordinate system **520**:
map_*T*_odom=ecef_*T*_map.inv×ecef_*T*_vehicle_origin×odom_*T*_vehicle_origin.inv
(32) As a result, automated vehicle **100**, even after a malfunction of the localization module, is still able to transform agents (e.g., other road users) perceived in its surroundings **300**, roadway markings, and obstacles, from vehicle-based coordinate system **520** (vehicle_origin) into global coordinate system **510** assigned to the global map, which enables a smooth transition from the normal mode to the safety mode.
(33) In addition to a normal mode, in which the highly automated driving function takes place based on HD maps, the concept introduced here also provides an additional safety mode, which also renders the highly automated driving function (HAD, highly autonomous driving) safe for the user in such situations in which no sufficient localization with the aid of an HD map is ensured. While the normal mode continues to enable intelligent driving functions in the case of a functioning map-based localization thanks to the HD maps, the safety mode preferably focuses on essential physical conditions which are necessary for ensuring the driving safety.
(34) The new concept may be used in HAD systems above Level 3, in which a permanent monitoring by the driver is not required. This relates, for example, to functions such as the traffic jam pilot, the highway pilot, or the urban robotic taxi. The concept may furthermore also be used to improve the performance in L2+ADAS systems which are based on HD maps, such as, e.g., the hands-free function.
(35) Although the present invention was illustrated and described in detail by the preferred exemplary embodiments, the present invention is not limited by the described examples. Rather, other variations may be derived therefrom by those skilled in the art without departing from the scope of protection of the present invention.

Claims

1. A method for controlling an automated vehicle, the method comprising: in a first method part, detecting instantaneous surroundings of the automated vehicle using an on-board surroundings sensor system, and localizing the automated vehicle based on a comparison of data of the surroundings sensor system to a previously provided digital HD localization map; in a second method part representing a normal mode, generating a map-based surroundings model of the instantaneous surroundings of the automated vehicle based on a global position of the automated vehicle ascertained during the localization and a previously provided digital HD planning map, the map-based surroundings model being used for planning an instantaneous trajectory for the automated vehicle; and in a third method part which represents a safety mode and carried out in parallel to or as an alternative to the first method part, detecting the instantaneous surroundings of the automated vehicle using the on-board surroundings sensor system, generating, based on data ascertained in the process, a map-less surroundings model of the instantaneous surroundings of the automated vehicle, the map-less surroundings model being used for planning the instantaneous trajectory of the automated vehicle; wherein: the instantaneous trajectory calculated in the normal mode or in the safety mode is output for controlling movement of the automated vehicle along the trajectory; and the method includes at least one of the following features (I)-(III): (I) a seamless transition is provided between the normal mode and the safety mode by at least one of: (i) running the generating and planning of the safety mode while the normal mode is running and being used for the calculation of the instantaneous trajectory; and (ii) performing trajectory linking that blends a portion of the instantaneous trajectory planned with the safety mode to another portion of the instantaneous trajectory planned with the normal mode, using an end point of the portion planned with the normal mode as a start point of the portion planned with the safety mode; (II) the planning of the instantaneous trajectory in the safety mode is degraded compared to the planning of the

instantaneous trajectory in the normal mode in that the planning in the normal mode is according to safety and comfort considerations and the planning in the safety mode is according to the safety considerations and not the comfort considerations; and (III) the generation of the map-less surroundings model in the safety mode includes: using the on-board surroundings sensor system to detect boundaries of a roadway being traversed by the automated vehicle and to detect dynamic objects; generating from the detected roadway boundaries a traffic lane model that represents an organization of traffic lanes within the roadway; and generating, as the map-less surroundings model, a portion of a local planning map using the traffic lane model with positions of the detected dynamic objects added to the portion of the local planning map.

2. The method as recited in claim 1, wherein in a fourth method part, an accuracy of the localization from the first method part being checked, and wherein, when, during the localization, a precise global position of the automated vehicle was ascertained, the instantaneous trajectory calculated in the second method part is output for controlling the movement of the automated vehicle, and, when, during the localization, no or only an imprecise global position of the automated vehicle was ascertained in the first part, the instantaneous trajectory calculated in the third method part being output for controlling the movement of the automated vehicle.

3. The method as recited in claim 2, wherein a distance traveled by the automated vehicle is detected using an on-board odometry unit, and when the localization in a present method cycle does not supply a precise global position of the automated vehicle, the instantaneous global position of the automated vehicle is ascertained based on the global position of the automated vehicle ascertained during a last accurate localization, and the distance of the automated vehicle detected since then using the odometry unit.

4. The method as recited in claim 1, wherein the map-less surroundings model ascertained in the third method part is used for validating correctness of at least one provided digital HD map and/or for checking results of the localization from the first method part.

5. The method as recited in claim 1, wherein in the third method part, the map-less surroundings model is generated in a vehicle-based local coordinate system, objects included in the map-less surroundings model being transformed from vehicle-based local coordinate system into a global coordinate system underlying the HD planning map to ensure a seamless transition from the normal mode into the safety mode.

6. The method as recited in claim 1, wherein the planning of the behavior and of the trajectory of the automated vehicle carried out in the second method part based on the map-based surroundings model is paused when the localization in a present method cycle does not supply a precise global position of the automated vehicle.

7. The method as recited in claim 1, wherein the method includes the seamless transition by the running of the generating and planning of the safety mode while the normal mode is running and being used for the calculation of the instantaneous trajectory.

8. The method as recited in claim 1, wherein the method includes the seamless transition by the performing of the trajectory linking that blends the portion of the instantaneous trajectory planned with the safety mode to the other portion of the instantaneous trajectory planned with the normal mode, using the end point of the portion planned with the normal mode as the start point of the portion planned with the safety mode.

9. The method as recited in claim 8, wherein: the method further comprises transforming data between global and vehicle-based coordinate systems; and the trajectory linking is performed based on the transformation of the data between the global and vehicle-based coordinate systems.

10. The method as recited in claim 9, wherein: the HD localization map and the HD planning map represent map elements relative to the global coordinate system; and the map-less surroundings model represents elements relative to vehicle-based coordinate system in which locations are represented relative to the automated vehicle.

11. The method as recited in claim 10, wherein: the transformation is performed using a geocentric

coordinate system as an intermediary coordinate system.
12. The method as recited in claim 1, wherein the planning of the instantaneous trajectory in the safety mode is degraded compared to the planning of the instantaneous trajectory in the normal mode in that the planning in the normal mode, the planning is according to the safety and comfort considerations and, in the safety mode, the planning is according to the safety considerations and not the comfort considerations.
13. The method as recited in claim 1, wherein the generation of the map-less surroundings model in the safety mode includes: the using of the on-board surroundings sensor system to detect the boundaries of the roadway being traversed by the automated vehicle and to detect the dynamic objects; the generating from the detected roadway boundaries of the traffic lane model that represents the organization of the traffic lanes within the roadway; and generating, as the map-less surroundings model, of the portion of the local planning map using the traffic lane model with the positions of the detected dynamic objects added to the portion of the local planning map.
14. A control unit for an automated vehicle, the control unit comprising: a processor system that includes at least one processor, the processor system being configured to: ascertain a global position of the automated vehicle based on a comparison of an HD localization map to data of an on-board surroundings sensor system; in a normal mode: generate a map-based surroundings model of instantaneous surroundings of the automated vehicle based on the ascertained global position and, using a provided HD planning map; and plan a trajectory of the automated vehicle based on the map-based surroundings model; and in a safety mode: generate a map-less surroundings model of the surroundings of the automated vehicle based on the data provided by the surroundings sensor system and an odometer; and plan the trajectory of the automated vehicle based on the map-less surroundings model; wherein the control unit includes at least one of the following features (I)-(III): (I) a seamless transition is provided between the normal mode and the safety mode by at least one of: (i) running the generation and planning of the safety mode while the normal mode is running and being used for the calculation of the instantaneous trajectory; and (ii) performing trajectory linking that blends a portion of the trajectory planned with the safety mode to another portion of the trajectory planned with the normal mode, using an end point of the portion planned with the normal mode as a start point of the portion planned with the safety mode; (II) the planning of the trajectory in the safety mode is degraded compared to the planning of the trajectory in the normal mode in that the planning in the normal mode is according to safety and comfort considerations and the planning in the safety mode is according to the safety considerations and not the comfort considerations; and (III) the generation of the map-less surroundings model in the safety mode includes: using the on-board surroundings sensor system to detect boundaries of a roadway being traversed by the automated vehicle and to detect dynamic objects; generating from the detected roadway boundaries a traffic lane model that represents an organization of traffic lanes within the roadway; and generating, as the map-less surroundings model, a portion of a local planning map using the traffic lane model with positions of the detected dynamic objects added to the portion of the local planning map.
15. The control unit as recited in **14**, wherein the processor system is further configured to check an accuracy of the ascertained global position of the automated vehicle ascertained, switch operation of the automated vehicle from controlling based on the normal mode, in which control of the automated vehicle is carried out based on the trajectory generated in the normal mode, to controlling based on the safety mode, in which the control of the automated vehicle is carried out based on the trajectory generated in the safety mode, based on the check showing that no precise global position of the automated vehicle was ascertained by the localization module.
16. A non-transitory computer-readable memory medium on which is stored a computer program for controlling an automated vehicle, the computer program, when executed by a computer, causing the computer to perform a method that includes the following: in a first method part, detecting instantaneous surroundings of the automated vehicle using an on-board surroundings sensor

system, and localizing the automated vehicle based on a comparison of data of the surroundings sensor system to a previously provided digital HD localization map; in a second method part representing a normal mode, generating a map-based surroundings model of the instantaneous surroundings of the automated vehicle based on a global position of the automated vehicle ascertained during the localization and a previously provided digital HD planning map, the map-based surroundings model being used for planning an instantaneous trajectory for the automated vehicle; and in a third method part which represents a safety mode and carried out in parallel to or as an alternative to the first method part, detecting the instantaneous surroundings of the automated vehicle using the on-board surroundings sensor system, generating, based on data ascertained in the process, a map-less surroundings model of the instantaneous surroundings of the automated vehicle, the map-less surroundings model being used for planning the instantaneous trajectory of the automated vehicle; wherein: the instantaneous trajectory calculated in the normal mode or in the safety mode is output for controlling movement of the automated vehicle along the trajectory; and the method includes at least one of the following features (I)-(III); (I) a seamless transition is provided between the normal mode and the safety mode by at least one of: (i) running the generating and planning of the safety mode while the normal mode is running and being used for the calculation of the instantaneous trajectory; and (ii) performing trajectory linking that blends a portion of the instantaneous trajectory planned with the safety mode to another portion of the instantaneous trajectory planned with the normal mode, using an end point of the portion planned with the normal mode as a start point of the portion planned with the safety mode; (II) the planning of the instantaneous trajectory in the safety mode is degraded compared to the planning of the instantaneous trajectory in the normal mode in that the planning in the normal mode is according to safety and comfort considerations and the planning in the safety mode is according to the safety considerations and not the comfort considerations; and (III) the generation of the map-less surroundings model in the safety mode includes: using the on-board surroundings sensor system to detect boundaries of a roadway being traversed by the automated vehicle and to detect dynamic objects; generating from the detected roadway boundaries a traffic lane model that represents an organization of traffic lanes within the roadway; and generating, as the map-less surroundings model, a portion of a local planning map using the traffic lane model with positions of the detected dynamic objects added to the portion of the local planning map.