Novel Map Platform based on Primitive Elements of Traffic Environments for Automated Driving Technologies

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ABSTRACT: To realize driver assistance systems based on automated driving technologies, intelligent vehicles need to recognize surrounding driving environments. On this point, sensing technologies with high-cost sensors have several problems for future popularization. Therefore, this research aimed at developing automated driving technologies with lean sensors via the enhancement of existing ADAS Horizon. As a result of experiments for confirming the feasibility of our system, we completed autonomous driving on a test course with several temporary stops and left turns.

KEY WORDS: safety, intelligent vehicle, road environment recognition/digital map, ADAS horizon [C1]

1. Introduction

Since public transportation systems are declining in country areas in accordance with the growth of aged society in Japan, we need new technologies to support the elderly in country areas for their daily travel. To this end, our research group(1) considered making automobiles intelligent as the solution for safe daily travel; further, we have been developing intelligence for automated vehicles. Although we have some choices of practical systems toward our purpose, namely fully automated driving and partially automated driving that collaborates with a human driver, we need the technologies that enable the vehicle to complete the fully automated driving, at first and at least. Thus, we need to start from developing the fully automated driving for our final goal.

Unlike existing automatic emergency braking systems, what our research group aim to develop is a highly mature driving intelligence based on the techniques of mature drivers that enable proactive driving without approaching surrounding risks. To realize such systems, it is necessary for intelligent vehicles to recognize the surrounding situations at a long distance. However, we have problems regarding such long-range sensing only by vehicular sensors since such high-spec sensors cost too much to be practically used. On the contrary, although technologies of virtual long-range sensing based on communication technologies with roadside infrastructures have been developed, such systems focus not on the community roads of country areas but on the highways of urban areas. Thus, we cannot currently apply such technologies to driver assistance systems for elderly drivers of country areas, though we have the possibility of applying them in future.

Given these motivations, we focused on technologies regarding maps to realize proactive vehicle controls only by using lean components of a system platform. Since existing technologies regarding maps focus only on navigation of a driving route and providing information, we need to discuss the requirement of digital maps for automated driving in this study. Furthermore, based on the assumption of the lean components of a system platform, we need to complementally combine the vehicular sensors with digital maps. Thus, in this study, we will design a system platform of sensing based on the abovementioned limitations.

2. Sensing Platform Complementally Combined with Digital Map

2.1. Usages of Digital Map

In general, usages of digital maps are roughly classified into two categories: route navigation and road information. Although we need both to realize autonomous driving, technologies regarding the former have been developed to date; thus, we focused on the latter.

Similarly, usages of road information are also roughly classified as follows:
- Localization: Based on the information of digital maps and landmarks detected by vehicular sensors, the intelligent vehicle grasps the current position on the map.
- Long-range sensing: Based on the information of digital maps and current position of the vehicle on the map, the intelligent vehicle grasps the elements of the traffic environment in front of the vehicle, which comprise waypoints for lateral control, crossings, crosswalks, and stop lines for longitudinal control.

Regarding the abovementioned technologies, although various approaches have been developed to date, requirements of
technologies depend on the goal and limitations; thus, we need to discuss requirements based on our goals and our limitations.

2.2. Requirement of localization

In regard to localization on a digital map, technologies based on GPS such as car-navigation systems have been developed. However, since the precision of localization for car-navigation based on common GPS is approximately of the order of several meters, a much more precise localization is necessary for autonomous driving. On this point, when we assume an example of turning left on a crossing with an error of localization more than 1.0 m, some parts of the vehicle body may enter the opposite lane after finishing the left turn. Thus, precision of less than 0.5 m is necessary for autonomous driving.

To fulfill this requirement of precision in localization, although an existing research\(^2\) realized autonomous driving by RTK-GPS, such sensors have inherent cost problems for our purpose. Moreover, although we need digital data of waypoint map for autonomous driving, we have problems regarding the size of data on the assumption that RTK-GPS is simply used and a waypoint map is simply combined with a GPS coordination system on the precision of RTK-GPS. Even though such approaches with in-vehicle data storage can be applied for autonomous driving in limited areas such as parking areas, it is difficult for us to store such large amounts of data for all community roads of country areas within the in-vehicle storage. Furthermore, although some existing researches proposed on-demand acquisition of digital maps via a high-speed communication network, such approaches can be applied only in urban areas where wireless network infrastructures are well constructed, and not in country areas. Moreover, although some researches\(^3\) have proposed a localization method utilizing simultaneous localization and mapping (SLAM) methods, they have problems of high-cost sensors and exceedingly large amounts of digital data for the general use of autonomous driving on community roads similar to the case of RTK-GPS.

Considering the approaches for our problems based on the above discussions, since using sensors specialized only for the localization causes a problem of the cost, simple sensors used for various functions of advanced driver assistance systems (ADAS), such as common GPS, cameras, and so on, have the possibility of solving the cost problem. On the other hand, regarding data overabundance for a digital map, preliminarily preparing the precise landmark map on the global coordination system causes the problem. For solving this problem, dynamically reconstructing landmark maps based on primitive elements of the traffic environment on the local coordination system, such as stop lines, crosswalks, and so on, has the possibility of solving the problem of data size. Furthermore, since we need to complementally utilize the digital maps and vehicular sensors for both approaches, we need to focus not only on developing the individual sensing technologies, but also on developing the entire system platform.

2.3. Requirement of Long-Range Sensing

Regarding the usage of digital maps as a long-range sensor, researches around the PReVENT project\(^4\) proposed the ADAS Horizon system. ADAS Horizon defines a map as the combination of a main path and sub paths. Sub paths separate from the main path at a node which is called as stub. The position of the vehicle and various associated elements of the traffic environment is defined as the “Offset,” which is the distance measured from the origin stub of the main path. Fig. 1 shows a schematic of the path and stub concept. The orange solid line in the figure indicates the main path, whereas the blue dotted lines indicate the sub paths. Moreover, the green circles, which are the divaricated points of the sub paths, indicate stubs. The positions of the vehicle, stubs, and elements of the traffic environment on the main path are expressed as the offsets, which are shown in the figure. In this way, since the expression of the ADAS Horizon is based not on the X-Y orthogonal coordinate system but rather on the path-oriented coordinate system, it is relatively easy to combine the ADAS Horizon system with an existing car navigation system, which will realize future merits of easy popularization.

ADASIS v2 protocol, which has already been published as a protocol of ADAS Horizon, defines various information such as the limitation of velocity, lane information, slope of the road, and so on. Since it assumes the ADAS providing the information to drivers and one simply controlling the vehicle, such as eco-drive, ADASIS v2 protocol does not directly assume autonomous driving; thus, information necessary for autonomous driving on community roads of country areas, such as positions of stop lines, and so on, is not defined. In addition, ADASIS v2 protocol defines the offset values as integers since the protocol does not assume precise vehicle controls unlike our purpose. Therefore, since we cannot use the precise offset of various types of information, it is hard for us to use the ADAS Horizon via current protocol as the long-range sensor for our target situations.

However, the expression of offset defined in the ADAS Horizon is quite useful for our problem that we need to dynamically reconstruct the digital map on a local coordination system based on primitive elements of the traffic environment because definition of offset is relative based on the assumption that the origin point of map information changes in accordance with changing situations. Fig. 2 shows the schematic of a digital map via a global coordinate system. For the global coordinate system, we need precision regarding relative positions of various traffic environment elements and waypoint maps over a large area. On the other hand, Fig. 3 shows the schematic of a digital map via a local coordinate system. For the local coordinate system, we assume many origin stubs for each path and define the offset information of various information based on the positions of the origin stubs. Thus, we need precision of the relative positions of various objects only within each path, and connectivity between an end point of a previous path and the stub of a next path. For the
latter, we have a merit that we can easily measure and prepare data of digital maps owing to numerical expressions of map data with relatively low-precision of position information. In addition, relatively low-precision of position information can realize the benefit of a reduction in data size. In this way, the reason of referring to the ADAS horizon is that an offset can easily achieve these merits of managing digital maps.

Thus, we decided to enhance the existing protocol of the ADAS Horizon to realize a small-sized digital map that fulfils functions of both localization and long-range sensing. In this study, to contrastingly discuss the function of long-range sensing of control targets such as stop lines, crossings, crosswalks, and so on, with waypoint map and landmark map, we call the digital map regarding long-range sensing of control targets as control target map from this point forward. Thus, preparing and using control target maps are functionally equivalent to long-range sensing of control targets via digital maps.

2.4. Enhancement of ADAS Horizon

ADAS Horizon assumes the combined use of an ADAS Horizon provider, which provides the information of digital maps, and ADAS applications, which use the provided information. Although there are various types of ADAS applications, such as warning systems, eco-drive systems, and so on, we focus on the dynamic reconstructor of three types of digital maps that are used for autonomous driving: a waypoint map, a landmark map, and a control target map. These maps have common elements of traffic environments. For example, information of stop line is used as both a landmark for localization and a control target for deceleration. This type of commonality is the key to data size reductions; thus, we need to discuss the enhancement of the protocol with considering the common uses of the primitive elements of traffic environments.

Since the existing protocol assumes the CAN bus I/F as the connection between the provider and the applications, the maximum size of every message is limited to less than 8 bytes. Furthermore, the exiting protocol defines the bit assignment of a message header and a message container based on the type of message. Since the existing protocol defines the type “Profile Long,” which is denoted as universal for enhancements, aside from the existing types of messages, we discussed the enhancement of existing protocol based on “Profile Long.” The former 4 bytes of “Profile Long” is assigned as the message header, whereas the latter is assigned as a data container. The challenging facet was defining the necessary information via only the latter 4 bytes.

2.5. Waypoint Map

Since the ADAS Horizon manages the discontinuous information with discrete values of offset, information regarding the state change is more important than information regarding the constant state. Thus, information of curves is more important than information of straight roads to dynamically reconstruct a waypoint map. Although there are many methods to define information of curves, usable ones are as follows:

- Definition as simple arcs: This definition is simple enough to summarize necessary information into one message. Moreover, it is easy to apply this information to the reconstruction of the control target maps. However, it is difficult to flexibly depict gradually curving roads.
- Definition as analytic curves: This definition has the merit to easily express various curves including gradually curving roads. On the other hand, this definition has the demerits that numerical expressions are complex so that relatively large amounts of information are necessary for expressing a single curving road.

Although the abovementioned methods have both merits and demerits respectively, we selected the former as the first step. Table 1 shows the detailed expression. Since the data size of the expression shown in the table was only 25 bits, we can put all necessary information into the one message, of which size of the data container was only 32 bits. Important point is that we add a first decimal place of offset expression into the enhanced protocol since the expression of offset based on the existing protocol is managed only by an integer value, which is expressed in the header.

| Contents                                      | bit type | Num. of bit | LSB   |
|-----------------------------------------------|----------|-------------|-------|
| First decimal place of offset for start point | Unsigned | 4           | 0.1 m |
| of simple arc                                 |          |             |       |
| Angle of the curve                            | Unsigned | 4           | 15 degree |
| Radius of curvature                           | Unsigned | 9           | 0.1 m |
| Various Flags                                 | Totally 8|             |       |

When the reconstructor of the waypoint map receives the curve information from the ADAS Horizon provider, the reconstructor considers the corresponding areas as curved roads while the reconstructor considers the other areas as straight roads. Based on this information, the reconstructor dynamically creates the waypoint map at the necessary density. In this study, we reconstructed the waypoint with a density of 0.02 m. Fig. 4 shows the schematic of reconstructing the waypoint map. For the situations of the upper row in the figure, the system alternately reconstructs the waypoint of the straight part and the curved part based on the information of curves, as provided in the lower row of the figure.
need to be drawn. If there is a real stop line in front of the guardrail, we use the offset information of the real stop line.

2.6. Landmark Map

To grasp the current position of the vehicle, the vehicle requires information regarding the positions of unmoving elements of traffic environments. Moreover, to realize the localization via a lean sensing platform, we had better to target landmarks that can be detected only by common sensors, such as cameras and simple LIDARs, and so on. Although there are many candidates for landmarks that meet the abovementioned requirements on the community roads, we focus on a stop line and a guardrail of a T-junction as the first step. Figs. 5 and 6 show the schematics of parameters of landmarks, whereas Tables 2 and 3 show the detailed expressions of corresponding landmarks. For guardrails, since sometimes there is no stop line in front of a curve, we define a virtual stop line at the point where a stop line needs to be drawn. If there is a real stop line in front of the guardrail, we use the offset information of the real stop line.

![Schematic of the course](image)

Fig. 4 Schematic of reconstructing a waypoint map

Regarding the involved data sizes, the size of a preliminarily prepared waypoint map and a dynamically reconstructed one are calculated as follows. As is shown below, our proposal achieves the reduction of data size for usual cases.

- Total data size of preliminary prepared waypoint map = (Data size of an individual way point) × (Density of waypoint map) × (Length of the course)
- Total data size of dynamically reconstructed waypoint map = 8 byte × (Number of curves)

2.7. Control Target Map

To realize autonomous driving, first of all, we need to consider basic elements of driving, namely acceleration, steering, and deceleration. For the steering, waypoint maps can provide necessary information. For rest ones, constant driving with acceleration to the limited speed is the regular state, while deceleration is deemed to be the irregular state of driving. Thus, we need simple information for acceleration such as the limited speed of current roads. On the other hand, regarding the deceleration, we need detailed information, namely target velocity of deceleration and offset information on the point where the vehicle needs to complete the preliminary deceleration, such as deceleration for stopping in front of a stop line, deceleration before curves, and so on.

![Expression of a guardrail](image)

Table 2 Expression of a stop line

| Contents                                      | bit type | Num. of bit | LSB    |
|-----------------------------------------------|----------|-------------|--------|
| Lateral deviation from left side of stop line to the center of the road | Signed   | 8           | 0.1 m  |
| Lateral deviation from right side of stop line to the center of the road | Signed   | 8           | 0.1 m  |
| First decimal place of offset of stop line   | Unsigned | 4           | 0.1 m  |

![Expression of a guardrail](image)

Table 3 Expression of a guardrail

| Contents                                      | bit type | Num. of bit | LSB    |
|-----------------------------------------------|----------|-------------|--------|
| Lateral deviation from left side of guardrail to the center of the road | Signed   | 8           | 0.1 m  |
| Lateral deviation from right side of guardrail to the center of the road | Signed   | 8           | 0.1 m  |
| Distance from virtual stop line to the guardrail | Unsigned | 8           | 0.1 m  |
| First decimal place of offset of virtual stop line | Unsigned | 4           | 0.1 m  |

Although what we mainly focus on is information regarding position of landmarks for localization, we add the definitions regarding the sizes of landmarks as support information of landmark detection to effectively utilize the limited size of the data container. Furthermore, although we use other definitions of enhanced messages for the trial, which will subsequently be described in the next chapter, we omit these other definitions except for the abovementioned main landmarks.

2.8. Prototype Implementation

Based on the design of the enhanced ADAS Horizon discussed in the previous sections, we implemented prototypes of recognition platforms complementary combined with digital
maps and vehicular sensors. Fig. 7 shows the appearance of experimental vehicle. Table 4 shows the main sensors equipped with the experimental vehicle. The driving distance of the vehicle is calculated via the rotation pulses of additional sensors in the rear wheels. In addition, we developed a microcomputer-based prototype of the provider of the enhanced ADAS Horizon. As we aim to develop technologies for autonomous driving via lean sensors, we selected vehicular sensors that are currently lean, or ones that will likely become lean in the near future. For example, cameras are becoming popular as the sensor for the current ADAS; therefore, their costs are becoming inexpensive in these days. Similarly, the cost of LIDARs is estimated to become inexpensive due to the recent MEMS technologies(5). Furthermore, since the ADAS Horizon provides the forward information of the traffic elements far from the vehicle, the precision of the GPS is not so important. Thus, the concept of ADAS Horizon can be realized via a usual GPS although we used a DGPS for other purposes that have nothing to do with ADAS Horizon.

First, the system sends GPS information to the enhanced ADAS Horizon provider, and then the GPS-based localizer receives roughly estimated offset information via the ADAS Horizon provider. At the same time, the landmark-based detector receives feature information of the nearest landmark and detects the landmark based on the provided information by cameras and LIDARs. Subsequently, the landmark-based localizer receives the detected information from the landmark detector, and position information of landmark from the enhanced ADAS Horizon provider. Based on the comparison of these kinds of information, landmark-based localizer then updates the precise offset information of the vehicle.

On the other hand, waypoint map reconstructor receives curve information from enhanced ADAS Horizon provider, and dynamically makes the waypoint map. Moreover, waypoint map reconstructor classifies the situation of each waypoint into three categories: the straight part, the curve entrance part, and the curve part. Fig. 9 shows the schematic of this classification. Based on this classification, the system changes the parameters of vehicle control, such as target velocity for acceleration control, preview time for steering control, and so on. After that, the digital map reconstructor adds information of the stop position, which is received from the enhanced ADAS Horizon provider, and then dynamically integrates the three kinds of map: the waypoint map, the landmark map, and the control target map.

Fig. 8 shows the schematic of the perception platform developed in this research. To implement this platform, we used ROS(6), which is the middleware for developing robots.

| Sensor          | Model                  | Purpose                  |
|-----------------|------------------------|--------------------------|
| Monocular Camera| Point Grey Research GRAS-1455C-C | Stop line Detection     |
| Monocular Camera| Mobileye 560           | Lane Detection           |
| LIDAR           | IBEO LUX               | Guardrail Detection      |
| GPS             | Hemisphere A100        | Rough Localization       |
| IMU             | TAMAGAWA SEIKI A7428   | Estimating Vehicle Dynamics |

Fig. 8 shows the schematic of the perception platform.
Based on the offset information and lateral position in the lane, which is measured by a lane detection camera, the localizer updates the position of the vehicle on the integrated digital map. Regarding the information of lateral position for steering control, we do not directly use the result of lane detection, but rather, indirectly use the result of localized position on integrated digital maps since indirect use of lateral information has the merit of easily calculating lateral deviations between a preview point, which is used for preview control, and the nearest waypoint. In addition, indirect use of lateral information has another merit in which the system can easily estimate the preview lateral deviation based on the information of dynamics via IMU, even though the camera cannot detect the lane marks during curves.

Separate from the above topics of digital maps, each sensor detects, recognizes, and tracks surrounding traffic participants. The perception horizon integrates the results of these processes with digital maps. The integrated results are then transmitted to the motion planner. Regarding the algorithms for vehicle controls, we implemented relatively simple ones. For lateral controls, we adopted a preview driver model based on risk potential, which our collaborators developed and described some parts in the previous paper\(^7\). On the other hand, for the longitudinal control, we adopted the following algorithms:

1. The system set the target velocity of acceleration based on the information of speed limits and curves via the enhanced ADAS Horizon.
2. The system set the target velocity of deceleration and the offset where the vehicle needs to complete the deceleration based on the nearest control target regarding deceleration such as stop lines, curves, and so on.
3. The system calculates the necessary distance for deceleration on the assumption of a certain deceleration rate, such as 0.1 G.
4. If the rest distance to the control target becomes less than the necessary distance for deceleration, the system starts to decelerate. Otherwise, the system accelerates to the target velocity of acceleration.

Since the main focus of this paper is usage of digital maps, we skip the more details of vehicle controls.

3. Feasibility Test of Autonomous Driving on Test Course

3.1. Test Course

To confirm the feasibility of our concept of automated driving via the enhanced ADAS Horizon, we conducted the experiments of autonomous driving on a test course. Fig. 10 shows a schematic of the test course. This course contains seven left turns, which are denoted C1 to C7, respectively. The total distance of the course is approximately 450 m. In this course, since four left turns at C1, C4, C6, and C7 are ones from a non-priority road to a priority road, the vehicle needs to stop before turning left. For other curves, the vehicle needs to decelerate until approximately 10 km/h in preparation for the left turn.

Fig. 10 Schematic of the test course

Approximately 150 m

Fig. 11 Appearance of landmarks

Regarding the target velocity of acceleration, we set it to 30 km/h for straight lines, and 10 km/h for left turns. Moreover, for the short straight segments such as between C4 and C5, we set it to 20 km/h since the vehicle starts to decelerate before completing the acceleration for the target velocity of 30 km/h.

As for the stub, the original ADAS Horizon assumes an update of the stub at the crossing. However, since we aimed to confirm the feasibility of our concept of an enhanced ADAS Horizon, we skipped the implementation of a stub as the first step. Thus, we simply assumed a single path course although the test course actually had many crossings. For such an assumed single path, we measured the test course and prepared the data of the enhanced ADAS Horizon, which was stored in the prototype provider of the enhanced ADAS Horizon.

3.2. Results

As we focused on the usage of digital maps in this research, the prime point of this experiment was to confirm whether or not the vehicle set adequate values of the control target based on the provided information of the enhanced ADAS Horizon. Thus, we focused on the abstracts of whole driving, and skipped the details of vehicle-control dynamics data.

Fig. 12 shows the time series offset and its adjustment. The horizontal axis depicts time. The vertical axis of the upper row indicates the offset of the vehicle, while the vertical axis of the lower row indicates adjustment values. Orange-colored rectangles indicate the offset adjustment at the curves. At curves C1 and C7, the system updated its offset by detecting the stop lines. On the contrary, at C4 curve, the system updated its offset by the detecting the guardrail. Regarding the adjustment values, we simply added the offset values at that time. At each curve, although the initial values of offset adjustment are relatively large, the values after the initial one are almost equivalent to 0. Based on this tendency, we can confirm that the offset values were well adjusted as a whole.
Regarding the errors of offset, not only the factors caused by the vehicle dynamics, such as slips of tires during acceleration and deceleration, but also the factors of precision of digital maps are the reasons. An important point is that our complementarily combined system of vehicular sensors and digital maps can equally manage these factors of offset errors. Moreover, since the concept of the ADAS Horizon manages various information of road within each path between stubs, we need the relative precision of offset for various information only within each path between stubs. Thus, since global precision of offset is not necessary, we have another inherent advantage of this system that we do not need excessively high precision for globally measuring and preparing data for the digital map.

Fig. 13 shows the time series target velocity based on map information and lane detection state. The first row indicates the time series map information regarding the curve based on the provided curve information and current offset of the vehicle. The curve numbers in orange rectangles above the graph indicate segments for the corresponding situations. At first, the vehicle moves on a straight course from the start point. Then, the vehicle approaches the curve of C1, and enters into the curve. Subsequently, the vehicle approaches the curve of C2. As is observable in the figure, the vehicle recognizes the state of the road based on the provided information.

The second row in Fig. 13 shows the time series state of lane detection via the monocular camera. The red dotted line indicates the state based only on map information, and the system does not rely on the result of lane detection during left turns. On the other hand, the blue solid line indicates the state based on both the map information and the sensor. Since the monocular camera cannot detect the lane mark just after finishing left turns, the system does not rely on the result of lane detection just after the left turn.

The third row in Fig. 13 shows the time series target velocities of acceleration and deceleration. Red dotted line indicates the acceleration target, and the system selects the appropriate velocity based on both map information and state of lane detection. On the contrary, blue solid line indicates the deceleration target, and the system selects the appropriate velocity based on the provided information of the nearest control target. As is observable in the figure, the vehicle appropriately selects the target velocities based on the provided information.

Fig. 14 shows the example of the time series velocity and rest distance to the nearest deceleration position from the starting point to the curve C1. In addition, Fig. 15 shows the schematic of the corresponding course around C1. The first row in Fig. 14 indicates the time series rest distance to the nearest control target for deceleration. On the other hand, black solid line, red dotted line, and blue dashed line of the second row in Fig. 14 indicate the current velocity, target velocity for acceleration, and target velocity for deceleration, respectively.

At first, the vehicle accelerates to the target velocity for acceleration from the start point. Then, the vehicle keeps the velocity at around the upper limit. At approximately 17 s, the actual rest distance to the control target, which is a stop line at C1 in this case, becomes less than the necessary distance for deceleration towards the nearest control target, and the vehicle starts to decelerate. After the vehicle stops in front of the stop line at C1 for approximately 2 s, the vehicle updates the control target from C1 to C2. Since the left turn at C2 does not demand a temporary stop before the curve, the system sets 10 km/h as the target velocity for deceleration. Similarly, since the road between C1 and C2 is a curve, the system sets 10 km/h as the target velocity for acceleration. Then, the vehicle restarts with acceleration toward the next control target. This is an example of velocity control based on the information provided via the enhanced ADAS Horizon.
Fig. 15 Schematic of the course around C1

Fig. 16 shows the time series velocity and distances to the nearest control targets from the start point to the goal point. As is observable in the figure, the vehicle stops at the points in front of the curves C1, C4, C6, and C7 where a temporary stop of the vehicle is necessary, while the vehicle turns left with a deceleration to 10 km/h at the other curves. For all other parts, the vehicle appropriately accelerates to the speed limit.

Fig. 17 shows the time series results of lateral control. The first and second rows in the figure indicate the time series deviation angles for the waypoint map and the time series lateral deviations, respectively. For both rows, the blue solid line indicates results on the straight road, whereas the red dotted line indicates results during left turns. The system calculates risk potential based on the reconstructed waypoint map and these values. Furthermore, the system calculates the necessary lateral force based on the risk potential, and then the necessary steering angle, which is the control value of the experimental vehicle, for achieving the necessary lateral force. The third and fourth rows in the figure indicate time series steering wheel angle and yaw rate, respectively. As is observable in the figure, the vehicle appropriately controls the steering with reference to the reconstructed waypoint map.

4. Conclusions

To support the daily travel of the elderly in country areas, we aimed to develop the technologies for autonomous driving with a lean system platform for various types of driver assistance systems. To this end, we focused on the problems of excessively high-spec sensors and large amounts of digital maps; further, we focused on enhancing the ADAS Horizon to realize a complementally combined platform with lean vehicular sensors and small-sized digital maps. Moreover, we developed the prototypes of proposed systems, and confirmed the feasibility of our concept through the experiment of an autonomous driving trial on a test course.

As a next step, we have many more topics to develop for realizing autonomous driving on public roads in country areas. First, since our targets are public roads in country areas, the landmarks are sometimes damaged and grazed. Thus, we need to enhance the landmark detector from the viewpoints of the variety of target landmarks and the robustness. Since we focused only on stop lines and guardrails for localization in this research, we need to focus on other landmarks for localization, such as crosswalks, diamond marks, and so on. In addition, we need to develop more robust detection technologies for such landmarks. Second, since we aimed at confirming the feasibility of our concept, we skipped the implementation of a stub. As there are many crossings in the real world, we need to try implementation of a stub. Third, though the focus of this research was how to realize basic autonomous driving in the country areas, we need other types of autonomous driving modes, such as proactive driving and emergency driving. For totally supporting elderly drivers, we need to integrate such technologies with basic driving developed in this research.

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