Development of Control Technology for Controlling Automated Valet Parking

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Abstract

Development for Automated Valet Parking (hereinafter, "AVP") is progressing in Japan and overseas to reduce accidents and improve efficiency in parking lots. The Japan Automobile Research Institute (hereinafter, "JARI") has been entrusted with AVP system development and has promoted it since 2016.

For putting the AVP to practical use, we, DENSO TEN Limited, considered that it would be possible to verify the early practical use of AVP by coordinately operating the following three elements "AVP equipped vehicles," "Control center," and "Parking lot infrastructure" for ensuring safety.

We were in charge of the development of "Control center," serving as the JARI 81st laboratory, and verified the validity whether the specifications met the functional requirements by performing the review and demonstration experiment of the control technology for control and operating management technology, in consideration of the optimal functional sharing and safety for the three elements.

As a result of the verification, the operation of demonstration scenario for assuming the use case was successful 51 times out of 73. In the evaluation of control technology for control, it was confirmed that the calculation accuracy of node transit time and inter-vehicle distance met design intent.

1. Introduction

Practical use of automated driving has high expectations for reducing traffic accidents, mitigating traffic congestion, responding to an aging society, and others. Therefore, the "Automobile Business Review Committee" which is reviewed by industry, government and academia, has been established as one of national commitments toward the early practical use.

The Japan Automobile Research Institute (hereinafter, "JARI") has been entrusted with Automated Valet Parking (hereinafter, "AVP") system development and has promoted it since 2016[1), 2)].

For putting the AVP to practical use, we, DENSO TEN Limited, considered that it would be possible to verify the early practical use of the AVP by coordinately operating the following three elements "AVP equipped vehicles," "Control center," and "Parking lot infrastructure" for ensuring safety. We were in charge of the development of "Control center," and verified the validity whether the specifications met the functional requirements by performing the review and demonstration experiment of the control technology for control and operating management technology, in consideration of the optimal functional sharing and functional safety for the three elements.

This article describes the AVP system configuration, the main function of the control center, the control specifications for control devised this time, and evaluation results of the demonstration experiments. Furthermore, the results which were introduced in this article were achieved from the commissioned business "Research & Development/Demonstration Project for Implementation of a Highly Automated Driving System in Society: demonstration test of AVP and research & development necessary for realizing a highly automated driving system" of Automobile Division, Manufacturing Industries Bureau, the Ministry of Economy, Trade and

Industry.

2. AVP System

2.1 AVP

AVP is the service which performs parking and pickup by driverless automated driving to the parking lot frame via the route followed instructions from the control center when a user send a request by smartphone operation to the control center for entering or leaving at a pick-up/drop-off area of a target facility entrance or others.

The AVP system consists of three elements “AVP equipped vehicle,” “Control center,” and “Parking lot infrastructure” as shown in **Fig. 1**, then each of them shares their roles and cooperates to perform automated driving and automated parking control.

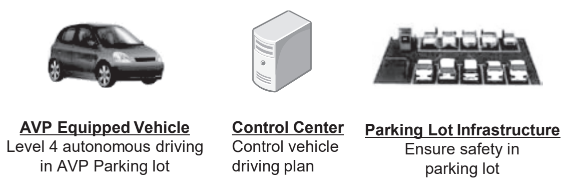


Fig. 1　AVP Structural Element

2.2 Functional Sharing of Three Elements

The functional sharing of the AVP system is considered as the following 3 types; vehicle-dependent type such as sensing and control function of an AVP equipped vehicle, infrastructure-dependent type which remotely controls the vehicle by using sensors or others installed in the parking lot, and vehicle-infrastructure cooperative type which shares the function by taking the middle of both types in a balanced manner. As a result of discussions among the persons concerned in development, we considered that business investment could be suppressed as much as possible, by making an improvement based on the vehicle equipped with an automatic parking system that future product development was already anticipated, and by establishing the control center and parking lot infrastructure which support a dedicated parking area where safety was ensured. Therefore, the vehicle-infrastructure cooperation type was adopted **(Fig. 2)**.

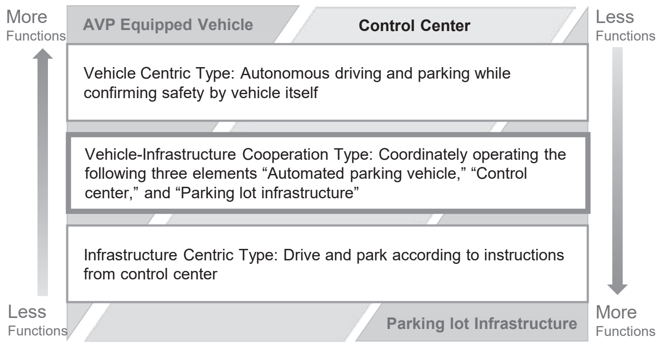


Fig. 2　Function Sharing Image

3. Field Operational Test Plan and Specification Review

We confirm that the designed system and function work as expected by actually establishing the AVP system and performing the functional field operational tests. This chapter describes the demonstration scenario, system configuration, and verification contents of the control center function for the functional field operational tests.

3.1 Demonstration Scenario

The demonstration scenario for assuming the use case was set as follows **(Fig. 3)**.

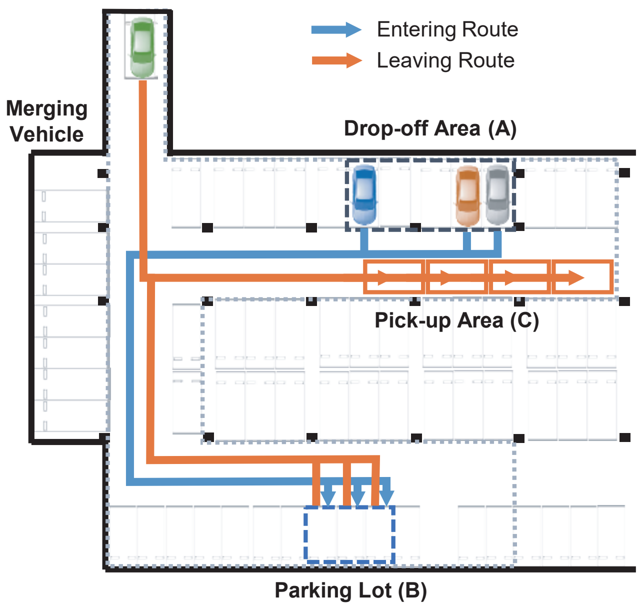


Fig. 3　Demonstration Scenario of Entering/Leaving

3.1.1 Entering

1) Request for entering by stopping the AVP vehicle at drop-off area (A) in the AVP dedicated parking lot which is prepared for a commercial facility or others.
2) The control center distributes a route, parking location, and landmark information to each vehicle, and the vehicle moves to the parking lot (B) and parks by low-speed automated driving.

3.1.2 Leaving

1) When the driver gives a leaving instruction, it starts low-speed automated driving.
2) The control center controls the control including merging vehicles from other parking areas in consideration of the priority of leaving, and confirms the emergency stop/recovery.
3) Vehicles are stopped at a pick-up area (C) designed in the image of a carriage porch of facility while lining up behind each other, and then complete the leaving.

3.2 System Configuration

The control center receives an entering/leaving instruction from the user and sets a guidance route for each vehicle by using map information and full/vacant information at the control center. The control center and the AVP equipped vehicles are connected by LTE, and the guidance routes, landmark information, and others are distributed from the control center to the vehicles.

The vehicles use an omnidirectional camera and sonar to recognize surrounding obstacles and parking spaces, and drive autonomously while correcting its own position based on the route information and landmark information sent from the control center (**Fig. 4**).

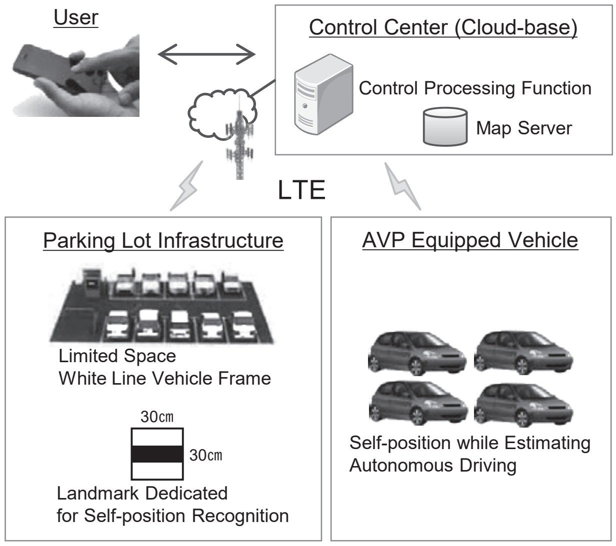


Fig. 4 System Configuration for Field Operational Tests

3.3 Parking Map Structural Element

A map, which is used by the control center for route calculation, has information on lines connecting between nodes, passages excluding structures, parking frames, drop-off/pick-up areas, and landmarks. **Fig. 5** shows the map used in the demonstration experiment. A red dot (A) indicates a node for showing a route of the vehicle, and a gray region (B) indicates a driving boundary where the vehicles can avoid a structure.

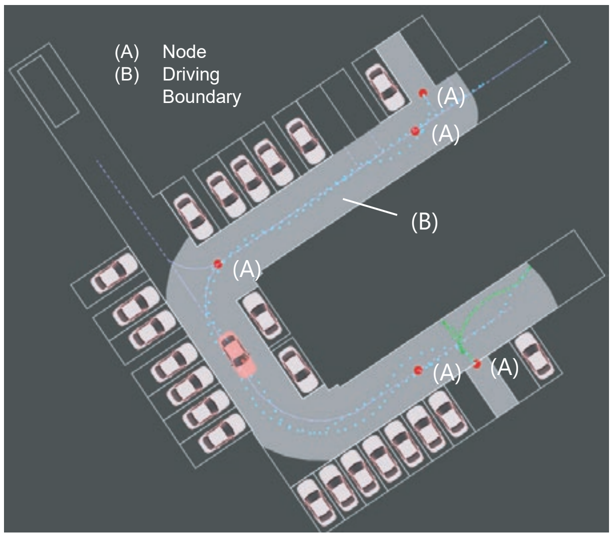


Fig. 5 Node and Driving Boundary

3.4 Method for Control by Low-speed Automated Driving

There are four plans for the control center to instruct the AVP vehicle on driving plan, and plan 1 was adopted this time **(Fig. 6)**. Plan 1 is a method instructing the vehicle on the node passage time. If the vehicle can move according to the specified time, the planned driving is easily controlled. We considered that it was easy to lay out a route plan accurately according to the time when the user wanted to leave.

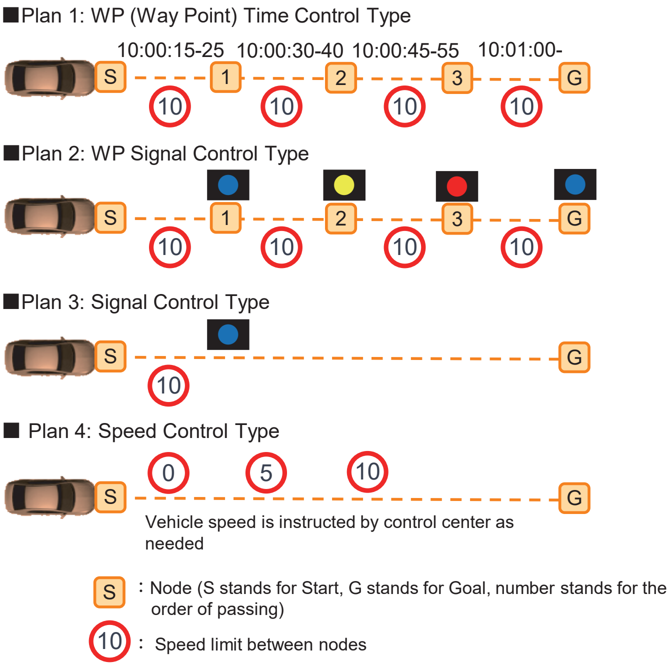


Fig. 6 Control Plan for AVP Equipped Vehicle

3.5 Measures and Strategy for Control

There are three measures against control as follows; ① Since arriving/passing through the node accurately on time as instructed by the control center is difficult for the vehicles, the control center shall plan extra time for a route. ② Operate each vehicle in consideration of safety even when multiple vehicles are running simultaneously. ③ Even if the vehicle cannot run as planned, it can be recovered.

As solutions to the above;

①It's not like the vehicle always operate at constant speed, and it accelerates/decelerates while being affected by the shape of a parking lot (curve, slope, etc.), which makes the vehicle difficult to accurately operate on time as instructed by the control center. Therefore, the flexibility was given to the node transit time calculated by the control center, and various parameters were narrowed down to appropriate values so that the driving plan would not be redundant in the prior evaluation of the demonstration experiment.

②There is a risk of contact due to a gap in the expected vehicle position accuracy or movement start timing, or the like. We considered that it was necessary to set the safe vehicle distance in consideration of the vehicle length, speed, and time to start moving, and then efficiently move each vehicle by an adjustment while waiting for parking or at an intersection. Therefore, a node less than the specified node interval can no longer be reserved for following vehicles until the preceding vehicles pass. **(Fig. 7)**

③If the vehicle cannot run as planned and arrives late at the node, driving plans of other vehicles are also affected. When such a situation occurs, all vehicles to be affected are stopped and the route is recalculated/redistributed, which enables the continued driving.

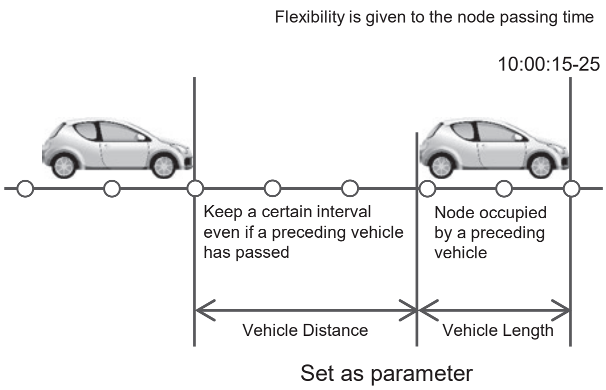


Fig. 7 Vehicle Distance and Node Transit Time

4. Implementation of Functional Field Operational Tests

In the demonstration experiment, we evaluate that "normal operation of entering/leaving," "emergency stop," and "Multi-vehicle coordination" included in the demonstration scenario can be correctly performed, and that the vehicle can pass through the node transit time and node interval calculated by the control center as instructed.

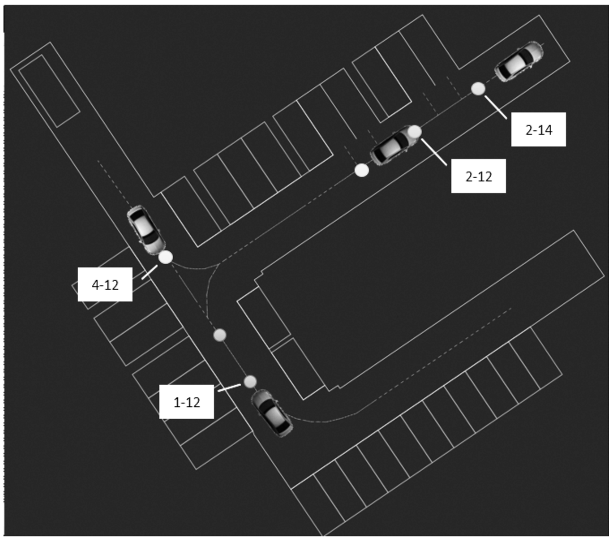
4.1 Implementation Result of Demonstration Scenario

It was confirmed that the "normal operation of entering/leaving," "emergency stop," and "multi-vehicle coordination" according to the scenario worked as expected 51 times out of the 73 trials. The main reason for not operating as expected is the problem of vehicle's self-position estimation[3]. The vehicle recognizes landmarks installed in a place with the omnidirectional camera and corrects its own position by collating the position. There were some cases that the landmarks could not be recognized correctly due to reflected light or others, and the vehicle deviated from track as a result of the wrong self-position. For details, refer to references.

4.2 Evaluation Result of Control Technology

In addition to the fact that the node transit within the specified time, the stop at the specified node, and the maintenance of the vehicle distance from 6.5m to 9.0m while waiting for parking were performed, we confirmed that the system could be operated according to the design specifications throughout the whole process. An example of the evaluation result is shown in **Fig. 8**.

Furthermore, as a result of measuring the implemented time of the demonstration scenario, we found that the vehicle could be moved within the scenario time excluding the parking, which was the almost same time as the control center calculated, but the time required for parking varies from vehicle to vehicle, and also found that the number of quick turns varies according to parking environment, resulting in occurrence of variations in time. **(Table 1)**



Did the vehicle arrive at the parking target node by the specified time?　Delay from control center instruction time (Sec)

	Node	1st time	2nd time	3rd time	4th time	5th time	6th time	7th time	8th time	9th time	10th time	Average
No. 2 vehicle	2-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Did the vehicles pass through the waiting node at the specified time?　Delay from control center instruction time (Sec)

	Node	1st time	2nd time	3rd time	4th time	5th time	6th time	7th time	8th time	9th time	10th time	Average
No. 1 vehicle	1-12	2.5	2.8	3.2	2.2	2.8	2.0	2.5	1.8	2.7	2.1	2.5
No. 2 vehicle	2-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
No. 4 vehicle	4-12	3.2	2.7	1.9	2.1	2.3	0.0	3.0	2.5	3.1	2.6	2.3

Was the distance between the waiting nodes of a preceding vehicle and its following vehicle from 6.5m to 9.0m as designed ?

	1st time	2nd time	3rd time	4th time	5th time	6th time	7th time	8th time	9th time	10th time
No. 2 to 4 vehicles	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
No. 4 to 1 vehicles	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

Fig. 8　Evaluation Perspective and Example Result

Table 1　Measurement Result of Demonstration Scenario

No	Outward Route Scenario Time (including parking time)	Outward Route Scenario Time (excluding parking time)	Outward Scenario　Parking Time				Return Route Scenario Time
			Vehicle No.	Frequency of Quick Turn	Parking Time	Total of Parking Time for 3 Units	
1	0:05:01	0:01:57	1	0	0:00:50	0:03:04	0:02:51
			2	Once	0:01:00		
			3	Once	0:01:14		
2	0:05:16	0:01:55	1	0	0:00:52	0:03:20	0:02:50
			2	Once	0:01:12		
			3	Once	0:01:16		
3	0:04:52	0:01:55	1	0	0:00:50	0:02:57	0:02:51
			2	Once	0:00:52		
			3	Once	0:01:15		
4	0:05:14	0:01:56	1	Once	0:01:32	0:03:18	0:02:54
			2	0	0:00:29		
			3	Once	0:01:17		
5	0:04:47	0:01:55	1	0	0:00:52	0:02:52	0:02:51
			2	Once	0:00:56		
			3	Once	0:01:04		
6	0:04:30	0:01:55	1	0	0:00:45	0:02:35	0:02:52
			2	Once	0:00:46		
			3	Once	0:01:04		
7	0:04:27	0:01:57	1	0	0:00:47	0:02:30	0:02:52
			2	0	0:00:41		
			3	Once	0:01:02		
8	0:04:36	0:01:56	1	0	0:00:45	0:02:40	0:02:47
			2	0	0:00:37		
			3	Once	0:01:18		
9	0:04:55	0:01:56	1	0	0:00:47	0:02:59	0:02:54
			2	Once	0:00:54		
			3	Once	0:01:18		
10	0:04:40	0:01:55	1	0	0:00:46	0:02:45	0:02:51
			2	Once	0:00:41		
			3	Once	0:01:18		

4.3 Future Activities

For a reason of the parking time that varies from vehicle to vehicle, elimination of this variation and improvement of the time calculation accuracy of the control center are activities in future. As proposed measures, there is a method for setting the maximum value of the time required for parking and estimating extra time for the parking completion time. For example, although the turn for parking is normally performed about once, turning for parking three times are estimated in advance by assuming that it occurs up to three times. In this case, it can meet the user's desired time, but confirmation whether it is influenced or not is necessary due to an increase in the route occupation time.

5. Conclusion

This article described the overall AVP system, the control technology, what we learned from the evaluation results of the field operational tests, and future activities. The system and control specifications of the devised vehicle infrastructure cooperative type allowed four vehicles to operate AVP.

The issue of the controlling the AVP system is to increase the calculation accuracy of the parking time that is different for each vehicle in order to improve the accuracy of calculation time for entering/leaving.

We would like to continue to develop technologies aimed at spreading the use of the AVP system from now on.

Finally, the research introduced in this article was implemented in cooperation with JARI and other related companies, we would like to take this opportunity to express our deepest appreciation to everyone for their cooperation in this research.

Reference

1) Accomplishment report of FY2016 Smart Mobility System Research, Development and Demonstration Project (research & development necessary for demonstration of Automated Valet Parking and realization of advanced automatic driving system)
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