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A Control System For Autonomous Vehicle Valet Parking

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Abstract: The autonomous vehicle valet parking service (AVP) enables a vehicle to drive and park without any human interaction. The driverless vehicle has to follow the scheduled route and be parked in a parking lot automatically. Most fundamental technologies for autonomous vehicle valet parking service are controlling vehicle driving and parking. For autonomous driving, the path to near goal parking lot has to be generated and control commands to follow the path have to be generated continuously. For autonomous parking, the controlling vehicle steer value has to be found to park the vehicle at a parking lot well. We have used two turning radius circles to find vehicle steering control value about perpendicular and parallel parking method basically. These two vehicle turning radius circles are minimum radius circles in initial and are updated in real time as vehicle stop location in parking mode. In this paper, we have developed the control system for autonomous vehicle valet parking service in parking area with low speed limited.

Keywords: unmanned ground vehicle, autonomous driving, autonomous parking, parking assistance, auto-valet parking

1. INTRODUCTION

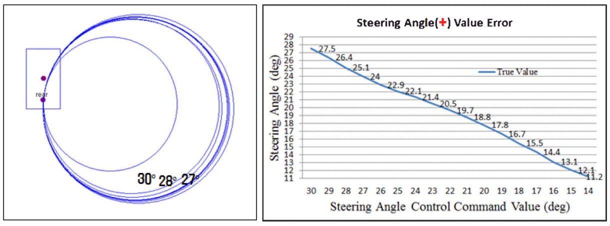
An automatic valet parking service enables a vehicle to drive and park without any human interactions [1]. Parking task is recognized as the most difficult among the driving tasks since it includes finding free parking space and moving backward in large probabilities of collision [2]. To alleviate the aforementioned driver's burden, two different types of systems are studied and commercialized. The first is smart parking system [3] and the second is automatic parking assistance system [4]. Although these two types of systems give some degree of comfort and safety to the driver, they assume drivers presence in the car, and still need driver's much attention and constrained environment. In this dissertation, we have developed the control system to provide the full autonomous vehicle valet parking service in a parking area with low speed limited. In our system framework, there are AVP server system, AVP mobile system and AVP vehicle controller system for this service. AVP server system provides vehicle driving path which is generated as considering the vehicle kinematics to target parking lot as most important role. If static obstacles are detected in parking area by infra-sensor server, the path avoiding these obstacles has to be generated. We have developed the AVP server system already in [5]. AVP mobile system provides the driver assistance service in a mobile device. A driver can request the AVP service and monitor the state of the vehicle moving using this system remotely. It provides user interface for the driver to choose the parking lot using parking area map data which is updated and managed in mobile spatial DBMS [6]. Also we have developed the AVP mobile system in [7]. The AVP controller system is able to follow the path which is transmitted from AVP server system in driving mode and control the driverless vehicle to park in a destination parking lot well in parking mode. And also it can control the vehicle to stop and resume as detecting the forward moving obstacle such as pedestrians or other vehicles using a laser scanner sensor in driving mode. So, goal of this research is developing the AVP control system for autonomous vehicle valet parking service. It is organized as follows. In section 2, vehicle parking control algorithms are described in detail. Section 3 explains the driving path following and perception of forward obstacles algorithm in driving mode. Section 4 our system experiment will be described. Finally, section 5 offers some concluding remarks regarding this research and future work.

2. CONTROL ALGORITHM FOR AUTONOMOUS VEHICLE PARKING

As vehicle model with Ackerman steering, the vehicle turning radius r is determined as the value of steer angle and vehicle wheelbase in (1) [8]. When θ_l and θ_r are maximum steer angle value, the θ_{steer} is the maximum and r is the minimum radius value.

$$r = \frac{wheelbase}{\tan\theta_{steer}}, \quad \theta_{steer} = \frac{\theta_l + \theta_r}{2} \tag{1}$$

In our study, we use two minimum turning radius circles to find vehicle steering control value about perpendicular and parallel parking method initially. In this algorithm, it is important to find exact vehicle steering control value to locate the vehicle to center of parking lot well. That is to say, it is more important to correct vehicle lateral error in parking mode than in driving mode. But it is inaccurate value providing by mechanical measurement at the steering actuator. To adjust the steering angle control command value error, we have been able to gather the log points by steering angle control command value $\theta_n \sim \theta_m$ with forward and backward direction by simple experiment. So, we have found the error values by extracting the steer angle value from the circumscribed circle using log points like in Fig. 1. The different value which is θ_{error} with command value and extracted the steer angle value is 2 ~ 2.9 deg.



(a) Circles by log points (b) Error values of steering angle control

Fig. 1 Error values of steering angle control command

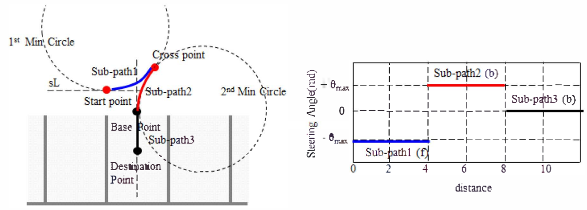
Finally, target steering control value is able to be corrected like in (2) during parking procedure.

$$\theta_{target} = \theta_{control\ command} + \theta_{error} \quad (2)$$

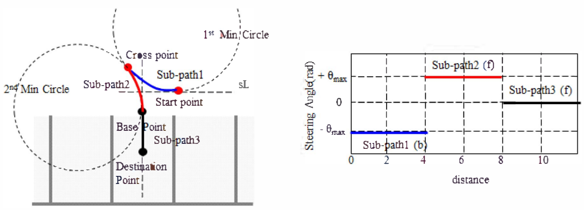
We have developed the three kinds of parking methods: forward / backward perpendicular and backward parallel parking. The vehicle parking mission is executing after driving. The start location of parking mode is destination location of driving one. The change location of the mission can be found using two minimum turning radius circles in initial as mentioned before.

2.1 Parking algorithms at initial state

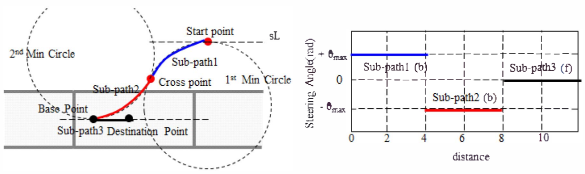
The Fig. 2 shows the algorithm of the vehicle parking at initial state.



(a) Backward perpendicular parking and control command input



(b) Forward perpendicular parking and control command input



(c) Parallel parking and control command input

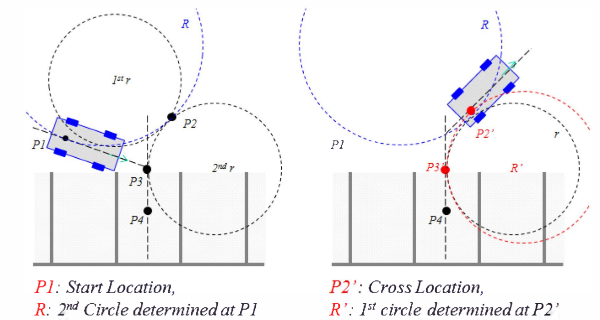
Fig. 2 Vehicle parking two circles at initial state.

In backward perpendicular parking (a), the 2nd minimum radius circle which meets at a base point can be found at first. When the driving final path is sL, the 1st minimum radius circle which meets at the line sL and 2nd minimum radius circle can be calculated. The start point which is intersection of 1st minimum radius circle and sL is driving end location and also parking start location. After then, the parking path is able to be generated which consists of three sub parts. In the (a) of the Fig. 2, sub-path1 is path from start point to cross point, sub-path2 from cross point to base point and last sub-path3 from base point to destination point. The control commands can be generated at the control section of each sub-path like right figure in (a). In the backward perpendicular parking, the control sequence of shift value is forward, backward and backward direction. The forward perpendicular (b) and parallel (c) parking are similar to backward perpendicular (a) parking.

The AVP server system generates the driving path to parking start location initially and the vehicle has to be controlled to stop at the near parking start location with minimum location error.

2.2 Parking algorithms at initial state

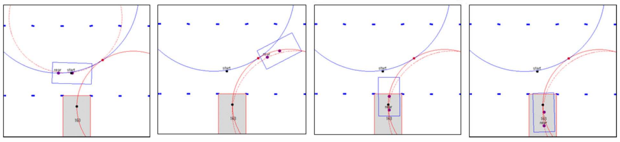
The control commands of each control sections are *{θ, S, G}*. The *θ* is target steering control value, *S* is target speed value and *G* is target gear-shift value. The S is 3 ~ 4 km/hr and *θ* is max steering value in initial state. But the minimum turning radius circles have to be changed as the location and heading value of the vehicle stop at the start point and cross point. That is to say, the steering control values are determined at the vehicle stop location. The Fig. 3 shows the dynamic update of the vehicle turning radius circles at the start location and cross location. The control commands of three control sections are $\{\theta_1, S_1, G_1\}$, $\{\theta_2, S_2, G_2\}$ and $\{\theta_3, S_3, G_3\}$. At the start location *p1*, the θ_1 value is updated to $\theta_1{}'$ and cross point is updated to *p2*. And at the cross location *p2'*, the θ_2 value is updated to $\theta_2{}'$ and base point is updated to *p3'*.



(a) Update 2nd circle at the start location (b) Update 1st circle at the cross location

Fig. 3 Dynamic update turning radius circle.

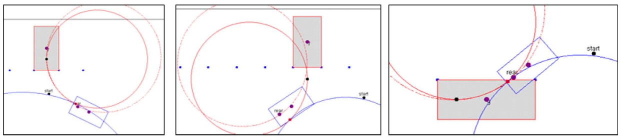
The Fig. 4 shows the backward perpendicular parking control step at each control section. It is screen capture of playing logs of real autonomous vehicle parking execution. In figure (a), the 1st circle is recalculated at the start point and the 2nd circle is re-generated at the cross point in (b). The vehicle stop screen is shown at the base point in (c) and final parking state is in (d). We can get the steering control value from geometrical 1st and 2nd circle at first. And then correct value is calculated like in (2).



(a) At start point (b) At cross point (c) At base point (d) At final point

Fig. 4 Backward perpendicular parking control step.

The Fig. 5 shows backward, forward perpendicular and parallel parking execution. All figures show the regenerated 2nd circle at the cross point during each parking procedure.

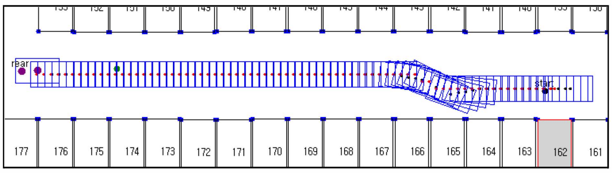


(a) Backward parking (b) Forward parking (c) Parallel parking

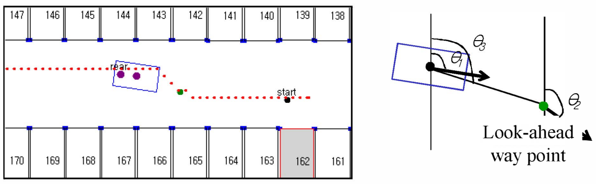
Fig. 5 Three kinds of parking algorithm execution.

3. CONTROL ALGORITHM FOR AUTONOMOUS VEHICLE DRIVING

The form of the driving path generated in the AVP server system is a way point which consists of vehicle location and heading angle value. The AVP controller system can follow the way points which are generated at intervals of 50 cm resolution, with low speed about 7 km/hr in a parking area with low speed limited. The Fig. 6 (a) shows the generated path from AVP server system and the (b) shows it's following by the AVP vehicle controller system. It is important to find the steering angle control value to correct vehicle lateral error while following driving path. The steering angle control value is calculated using current vehicle location/heading and look-ahead way point information like in the figure 7 and (3).



(a) Generated Driving path



(b) Driving path (way points) following

Fig. 6 Generated driving path and it's following

$$\theta_{steering} = \frac{\theta_3 - \theta_2}{2} - \theta_1 \qquad (3)$$

The θ_1 is vehicle heading angle, θ_2 is look-ahead way point heading angle and θ_3 is lateral error angle of vehicle location and look-ahead way point.

In driving mode, AVP vehicle controller system can detect forward moving obstacles and control vehicle to stop and resume without collision obstacles. We have used the LMS511 of SICK Corporation as sensor to detect the forward moving obstacle. This sensor is able to detect the object distance maximum 80 m within 0° ~ 190° angular range with 0.5° resolution and provides raw data as 500k baud-rate. The perception algorithm is executing as follow. At first AVP vehicle controller system acquires the raw data from LMS (Laser Management System) and filters raw data by spatial map data. And next, it extracts the object as clustering raw data using the spatial approximation. The filtering area is all of vehicle non-movable area including parking lots. And the 3.5 x 15 m rectangle of vehicle forward direction is also filtering area. The Fig. 7 shows the executing of forward moving obstacle detection.

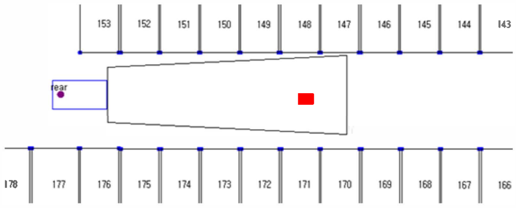


Fig. 7 Perception of the forward moving obstacles.

The control system controls to stop the vehicle if any obstacle is within the 7 m forward and resumes if there is no obstacle or 12 m away from the vehicle.

4. EXPERIMENT

We have carried out the autonomous driving and parking experiments in real test area. We have remodeled steer, brake, accelerator and shift of the electric vehicle named "CHANGE" and normal car named "MORNING" to control the lateral position, speed and gear shift. These have three motors for steer, brake and accelerator and lower controller. The lower controllers can control the vehicle using the input values of steering, speed and shift. We have developed the vehicle driving and parking control system using interface provided by the lower controller. The Fig. 8 shows our experiments.

(a) Unmanned vehicles driving and parking (b) Parking area

Fig. 8 Experiments in test-bed area.

In the figure (a), the ② is the electric vehicle CHANGE which has a laser scanner sensor for forward obstacle detection and has three small cameras for vehicle positioning. The ③ is the vehicle MORNING which has a laser scanner sensor and GPS for positioning. In figure (b) shows our test-bed area which has about 300 parking lots. We have carried out the experiment that the unmanned two vehicles were driving start at the same time to the destination parking lot 2, 3. The vehicle ① was already parked at the parking lot # 1. The vehicle ② was scheduled to park at the parking lot # 2 which located next to the lot # 1 as backward perpendicular parking method. And the vehicle ③ was scheduled to park at the parking lot # 3 which located next to the lot # 2 as forward perpendicular parking method. In the figure (a), the still cut shows the vehicle ③ stopped while the vehicle ② was executing backward perpendicular parking because the vehicle ② was detected as moving obstacle. After finishing the vehicle ② parking mission, the vehicle ③ has resumed and executed forward perpendicular parking.

5. RESULT AND FUTURE WORK

We have developed the control system for autonomous vehicle valet parking service. The unmanned vehicle is able to follow the driving path generated from AVP server system with low speed in parking area. And also it is able to be parked at the target parking lot as backward/forward perpendicular and parallel parking method by carrying out experiments in real parking area.

As the future work, when the obstacles are detected by sensors such as ultrasonic or vision camera during parking procedure, multi-stage parking path generation and following algorithm have to be added in our system.

6. ACKNOWLEGEMENT

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REFERENCES

[1] J. D. Choi, "An Automatic Valet parking Platform for Neighborhood EV," Proc. Of VCT 2011, Dec, 2011.

[2] M. Wada, K. S. Yoon, and H. Hashimoto, "Development of Advanced Parking Assistance System," IEEE Transactions on Industrial Electronics, vol. 50, No. 1, pp.4-17, Feb. 2003.

[3] M. Y.I. Idris, et al., "Car Park System: A Review of Smart Parking System and its Technology," Information Technology Journal 8 (2), pp.101-113, 2009.

[4] Automatic Parking. http://en.wikipedia.org/wiki/Automatic_parking

[5] K. W. Min and J. D. Choi, "Design and Implementation of Path Generation Algorithm for Controlling Autonomous Driving and Parking," Proc. Of the 12th international conference on Control, Automation and Systems, pp.956-959, Oct, 2012.

[6] K. W. Min, K. W. An, I. S. Jang, and S. I. Jin, "A System Framework for Map Air Update Navigation Service", ETRI Journal, Vol. 33, No. 4, pp.476-486.

[7] K. W. Min, and J. D. Choi, "Design and Implementation of Mobile Assistance System for Auto-Valet Parking Service," Proc. Of International Conference on Mechanical, Industrial, and Manufacturing Engineering, Jan, 2011.

[8] M. Hsieh and U. Ozgner, "A Parking Algorithm for an Autonomous Vehicle," Proc. Of IEEE Int. Conf. on Intelligent Vehicles, June 2008, pp 1155-1160.

[9] SICK LMS291, http://www.sick.com