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# Automated Vehicle Mobile Guidance System for Parking Assistance

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***Abstract*— A new concept that a vehicle, which does not have fully automated functions but has partial intelligent functions, is manually or automatically guided to an assigned destination position with a guidance system has been proposed. This paper describes the concept of the system and reports the experimental results of the guidance to a parking space with the proposed system. The experimental study has been conducted to show the feasibility of the system proposed. In the experiments, a vehicle was guided with a mobile guidance system that measures the position and the heading of a guided vehicle to instruct it the steering and the velocity to its goal. The system is featured by that a few intelligent mobile guidance systems will assist many ordinary vehicles in dedicated areas including parking lots.**

## I. Introduction

AUTOMATED vehicles for highways can provide safety and efficiency of the road transportation, but they are not easily introduced to the current road transportation. Instead, those at a low speed or parking assistance have already been introduced to the market. A drawback of the systems is the necessity of the onboard special equipment. This paper proposes a new system for parking assistance, and it is featured by that less onboard equipment is necessary, because another vehicle will cooperatively guide a vehicle to be parked.

There are some researches about cooperative driving system[1]-[4]. This paper proposes a new concept of a vehicle guidance system, which is an extension of the driver assistance by the cooperation between two vehicles [5],[6], and the system will have some variations. In a typical system, a highly intelligent vehicle, which has a complete set of the sensing systems including obstacle detection and localization, and also has an automated driving function, will assist and guide an ordinary vehicle by exchanging the driving data over the communications. The function that a guided vehicle must have is the communication function. One of the applications of the guidance system will be the tight maneuvering like parking.

There are a lot of interesting researches about parking assistance systems which include the study on path planning, control algorithms, obstacle detection and human machine interface (HMI)[7]-[13]. Most parking assistance systems are on-board systems. One of the drawbacks of these systems is the cost. Drivers who really need the assistance like elderly drivers less experienced young drivers, thus, cannot afford these systems. In order to provide a solution to the drawbacks, this paper proposes use of a mobile guidance system operating in a dedicated site like a parking lot, which has a sensing function and a communication function for a guided vehicle, which does not have any intelligent functions except for a communication function.

This paper describes the concept of the system, and the measurement and control algorithms, and reports the experimental results of the guidance to parking with the system proposed.

## II. Concept of Proposed System

Figure 1 shows the general concept of the guidance system proposed here. The system consists of the guidance or assistance system, and a guided or assisted vehicle. The guidance system is usually mobile or the infrastructure. In this study, we propose the mobile guidance system as shown in Fig.2. The communications between the guidance system and a guided vehicle play an essential role. Inter-vehicle communications can be used for the communications between the guidance system and a guided vehicle.

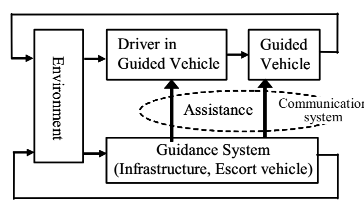


Fig.1: Concept of vehicle guidance system

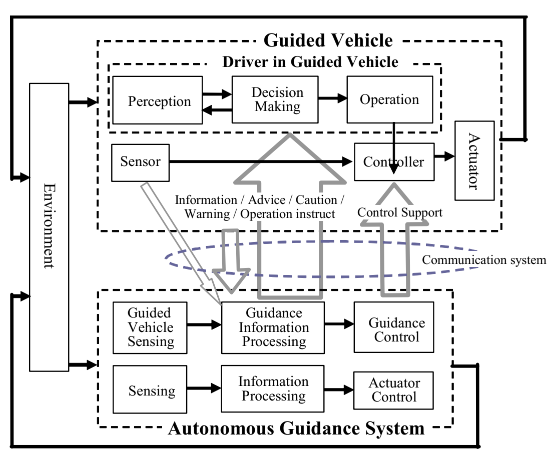


Fig.2: Configuration of the parking assistance

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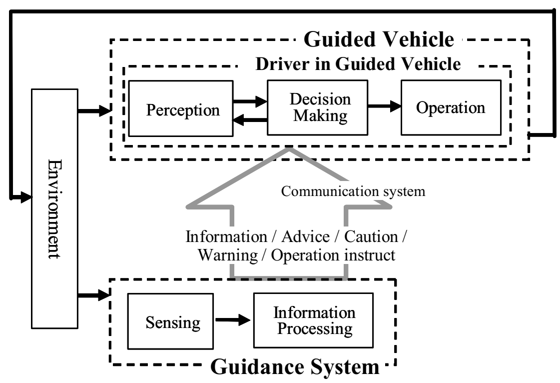
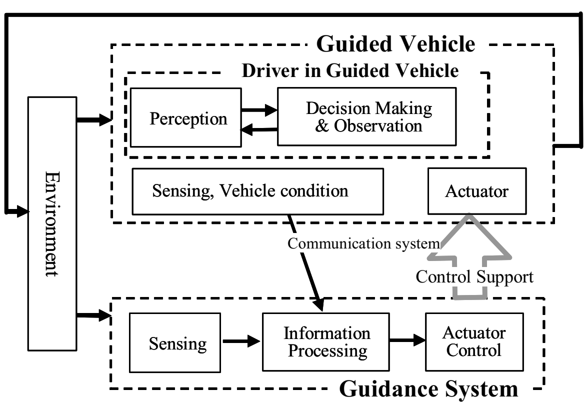
The system proposed here can have some levels of guidance, and variations of the configuration, depending on the kinds of sensing and communications. Figure 3 illustrates two configurations: one at the top of Fig.3 is a driver assistance system, where a driver drives a vehicle with assistance from the mobile guidance system, and the other at the bottom of Fig. 3 is an automated guidance system, where the guided vehicle is automated and is guided to its goal with the information from the mobile guidance system. The system proposed has some applications including parking assistance, driving guidance on lane changing, and right turning at an intersection. The communications technology is essential in the guidance system, and it can be either data transmission or audio/visual transmission.



(a) Manual guidance



(b) Automated guidance

Fig. 3: Two configurations of the parking assistance

## III. Necessary Functions for Application to Parking Assistance

### A. Overview

The functions of the system proposed here include the sensing of objects in the neighborhood, the localization of the mobile guidance system and a guided vehicle, the communications between the guidance system and a guided vehicle, and the guidance control algorithm. The measurement of the relative distance between the guidance system and a guided vehicle is also critical. In addition, the prediction of the behavior of a guided vehicle will be necessary, depending on an application.

The advantages of use of the mobile guidance system over an infrastructure based system are as follows:

1. The sensing system does not have blind spots.
2. The guidance system can be easily upgraded.
3. The system has the flexibility in comparison with a stationary guidance system.
4. The mobile guidance system is not only for parking guidance but also for administration of parking like security, vacant space detection, pedestrian guidance, or broadcasting. As the results, the proposed system contributes to improve the service level in parking lots.
5. The guidance system can be employed under environment, where an on-board parking assistance hardly works, by the customization of the system.
6. A driver in a guided vehicle can share the information with system about obstacles including pedestrians.
7. An external system like the proposed system can provide much relief than an on-board system.

### B. Parking Ways

There are several types of parking ways like parallel parking and garage parking, and this paper deal with the garage parking as shown in Fig.4. When the mobile guidance system assists parking, it can be positioned around a guided vehicle at four positions as shown in Fig.5. Since the position #4 in Fig.5 can provide a large view on the parking space, the control algorithm will be designed for a guidance system positioned at #4.

The assistance will be performed by transmitting guidance information from the mobile guidance system to a guided vehicle. The assistance starts when a vehicle to be guided arrives at a predetermined location. During the assistance, the mobile guidance system measures the state variables of the guided vehicle, and calculates an appropriate steering and velocity for the guided vehicle to reach a goal or a planned parking space. The calculated steering and velocity are transmitted over the communications. The guidance system is supposed to have the information on the geometry of the parking lots and the vacant space.

This guidance requires the followings: the measurement of the state variables of the guided vehicle for control, the guided vehicle control algorithm that allows the delay of communications, and control algorithm for the mobile guidance system.

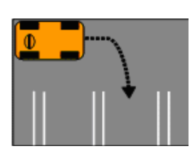


Fig.4 Way of parking

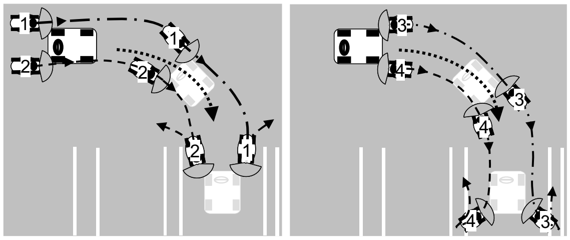


Fig.5 Ways of guiding by guidance mobile system (left: pushing type, right: pulling type)

## C. Measurement Algorithm

The state variables of the guided vehicle are the position, the heading, the velocity, and the yaw rate, and all the state variables are measured with a laser range finder in this study. The laser range finder detects the existence of an object ant measures the distances to the object. The processing of the data from the laser range finder is as follows:

1) The measurement system searches the data from the laser range finder and finds straight lines from the data.

2) The system selects two lines that cross each other with a right angle among the lines found.

3) The vehicle heading is calculated with the gradients of the two lines.

4) The point at the intersection of two lines is regarded as the vehicle's corner.

5) The center position of the vehicle is found by use of the heading and the corner of the vehicle.

We deal with the center position instead of the center of gravity of a vehicle. The measurement of the state variables with a laser range finder has enough accuracy for the control.

## D. Guided Vehicle Control Algorithm

The requirement of the proposed system is that the system calculates optimal or feasible control for a guided vehicle, and that the system transmits the control to the vehicle. The algorithm can be applied to two kinds of guidance: one is assistance, and the other is automated control. The algorithm is based on the automated parking control algorithm [14] and modified to accommodate the communication delay. The algorithm has characteristics that it does not depend on the parameters of the vehicle dynamics like the cornering power, the wheelbase or the tread. The algorithm, thus, is applicable to any vehicle. Figure 6 shows the steering control algorithm, and it is divided into 3 parts depending on the position and heading of the vehicle. The flow of the steering control algorithm is as follows:

*If* $(P_y - V \cdot \sin\theta_V \cdot T_{dp}) > D_{th}$, then

$$\delta_V = K_1[\theta_V - 0.5 \cdot \pi + \gamma_V \cdot (T_{PP} + T_{dp})] \quad (1)$$

*If* $(P_y - V \cdot \sin\theta_V \cdot T_{dp}) \le D_{th}$, then

$$\delta_V = K_2[\theta_V + \gamma_V \cdot (T_{PP} + T_{dp})] \quad (2)$$

*If* $(P_y - V \cdot \sin\theta_V \cdot T_{dp}) \le D_{th} \cap [\theta_V + \gamma_V \cdot (T_{pp} + T_{dp})] < A_{th}$, then

$$\delta_V = K_2[\theta_V + \gamma_V \cdot (T_{PP} + T_{dp})] + K_3[P_y - V \cdot (T_{pp} + T_{dp}) \cdot \sin\theta_V] \quad (3)$$

where,
$D_{th}$: threshold of the starting yaw angle control [m],
$A_{th}$: threshold of the starting lateral control [rad],
$T_{pp}$: delay time of the control [s],
$T_{dp}$: delay time of the communication [s],
$K_1, K_2, K_3$: control gains ,
$\delta_V$ : target steering angle [rad].

In the velocity control method, the system keeps the vehicle at very slow speed during the guidance, and brakes the vehicle after the vehicle is in the vicinity of the target parking space.

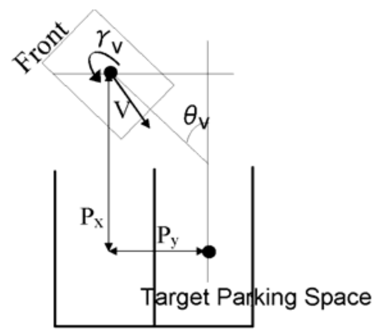



Fig.6 Guidance control algorithm

## E. Mobile Guidance Control Algorithm

The steering control of the mobile guidance system is programmed in advance in principle, and is modified while guidance with the localization data. On the other hand, the velocity control of the mobile guidance system is based on the gap between it and the guided vehicle. The velocity is controlled to keep the gap of 2[m].

The steering control program consists of four steps. Firstly, the mobile guidance system is moved to be perpendicular to the road and parallel to the guided vehicle as indicated with 'i' as shown in Fig.7. The following rule (4) is applied: Secondly, before the guided vehicle starts turning automated or manually, the mobile guidance system is driven to the first target point as indicated with 'ii' as shown in Fig.7. The following rule (5) is applied: In this case, the mobile guidance system is controlled not to go into other parking space. Thirdly, the mobile guidance system is controlled to back side of a target parking place and parallel to that as indicated with 'iii' as shown in Fig.7. The following rule (6) is applied: Finally, the guidance mobile system is controlled to the final target position and stopped there in order to improve the measurement of the stables of the vehicle as indicated with 'iv' as shown in Fig.7. The following rule (7) is applied: Because the above mentioned control algorithm of the guidance mobile system needs to cooperate with the guided vehicle, it not only coordinates the position and target velocity of the guidance mobile system but also instructs the guided vehicle if needed. The guidance mobile system, thus, can lead a guided vehicle, even if the guided vehicle does not drive smoothly. The flow of the steering algorithm is as follows:

*If* $(P_y - V \cdot \sin\theta_V \cdot T_{dp} - B_{th}) > D_{th}$,

then $\delta_R = K_{R1}(\theta_R - \theta_v + \gamma_R \cdot T_{pp})$ (4)

*If* $(P_y - V \cdot \sin\theta_V \cdot T_{dp} - B_{th}) \le D_{th}$,

then $\delta_R = K_{R2}(\theta_R + \gamma_R \cdot T_{PP}) + K_{R3}(R_x + W_P - W_R)$ (5)

*If* $(P_y - V \cdot \sin\theta_V \cdot T_{dp}) \le D_{th} \cap [\theta_V + \gamma_V \cdot (T_{pp} + T_{dp})] < A_{th}$,

then $\delta_R = K_{R2}(\theta_R + \gamma_R \cdot T_{PP}) + K_{R3}(R_x + W_P - W_R)$ (5)

*If* $(P_y - V \cdot \sin\theta_V \cdot T_{dp}) \le D_{th} \cap [\theta_V + \gamma_V \cdot (T_{pp} + T_{dp})] < A_{th}$
$\cap (R_y < C_{th})$,

then $\delta_R = K_{R2}(\theta_R + 0.5 \cdot \pi + \gamma_R \cdot T_{PP}) + K_{R3}(R_y + L_P)$ (6)

where,
$B_{th}$: threshold of the position [m]
$C_{th}$: threshold of the position [m]
$R_x$: $X$ position of the mobile system [m],
$R_y$: $Y$ position of the mobile system [m],
$T_{pp}$: delay time of the control [s],
$K_{R1}$, $K_{R2}$, $K_{R3}$: control gains,
$\delta_R$: target steering angle of the mobile system [rad].

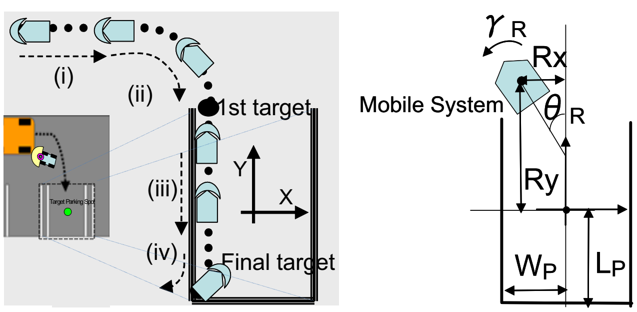



Fig.7 Target points, control step and control algorithm of mobile system

## F. Simulation Study on the Assistance

Figure 8 shows a simulation result, and the trajectories of the mobile guidance system and the guided vehicle are illustrated. The communication delay of 2 [s] is included in the simulation. They show the feasibility of the control algorithms of the guidance system and the vehicle.

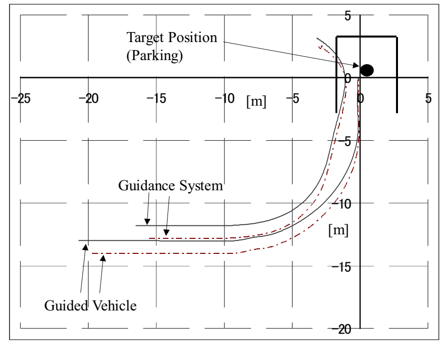



Fig.8 Trajectories by the simulation studies

# IV. EXPERIMENTS

## A. Configuration of Experiments

We conducted two kinds of experiments on the parking assistance: one is assistance as shown in Fig.3 top when a driver in a guided vehicle operates with the instruction from the mobile guidance system (manual guidance), and the other is automation as shown in Fig.3 bottom when a driver in a guided vehicle does not operate at all (automated guidance ). The former configuration of the experiment is shown in Fig.9, and the latter is shown in Fig.10. We employ three vehicles: a subcompact car as shown in Fig.11 left as a guided vehicle on manual guidance, which has HMI for the instruction to a driver [15], an ultra small experimental electric vehicle as shown in Fig.11 center as a guided vehicle an automated guidance. And a wheelchair as shown in Fig.11 right as the mobile guidance system.

A laser range finder has been employed for the measurement, and it provides distance data to an object within 180 [deg] with a resolution of 0.5 [deg]. In this experiment, the system employed the RTK-GPS for the localization, but other localization methods can be employed. A laptop on the mobile guidance system was used as an on-board computer. The guidance mobile system has the position and direction data of the target parking space in advance. The parking space, where the vehicle is guided to, is about 2.8 [m] wide and 5.2 [m] long. It was assumed that any obstacles do not exist on the left side of the parking space and there is no blind area for the sensor. In this experiment, in order to evaluate the measurement algorithm, the RTK-GPS system (Novatel OEM4-G2) whose localization accuracy is within ±0.02 [m] is loaded on the guided vehicle. Since the measurement by RTK-GPS includes the delay of the communication and saving, it is not completely accurate, and the data from the RTK-GPS were used for comparison. The wireless-LAN (2.4[GHz]) system is used for the communications between the guided vehicle and the mobile guidance system with a period of 50 [ms].

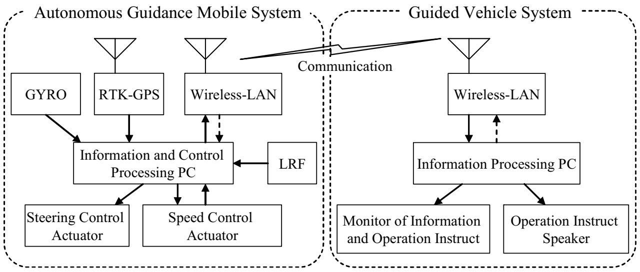



Fig.9 Configuration of guidance mobile system for manual driving

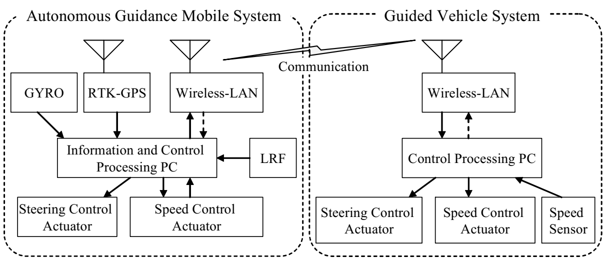



Fig.10 Configuration of guidance mobile system for automated driving

Fig.11 Left: Guided vehicle (that has HMI), Center: Guided vehicle (that has automated functions), Right: Guidance mobile system

## B. Experimental results and discussion

Figure 12 shows scenes of the experiments. In all experiments, the parking assistance worked successfully.

Some experimental results of automated guidance are shown in Figs.13, 14 and 15. Figure 13 shows the three kinds of trajectories; the first one is the center of the guided vehicle estimated by the proposed system, the second one is the center of the guided vehicle measured by the RTK-GPS as the reference, and the third one is position of the mobile system. Figure 14 shows the error between the estimated position by the system and the RTK-GPS. These results show the proposed system can consecutively estimate the position of the vehicle with high accuracy. Each error of the result is within about 0.2[m] and, thus, the result suggests that the measurement algorithm can provide the localization data without any discontinuity with enough accuracy for the vehicle guidance. The error of the estimated position is relatively large when the vehicle is far from the guidance system, but it becomes smaller as the vehicle approaches the system. When a system estimates the position of an object with a sensor like a laser range finder, the further an object is far from the system, the larger the estimation error becomes large. As long as the mobile guidance system drives within 2 [m] from a guided vehicle, the system provides precise measurement of the location of a guided vehicle.

Figure 15 shows the control command from the guidance system to a guided vehicle, and the minus target velocity means a brake trigger from the system. As the experiments show, equipment that the guided vehicle must have is the communication unit, and it is not necessary to have any sensing unit, because the mobile guidance system has the sensing system.

Fig.12 Scenes of Experiments

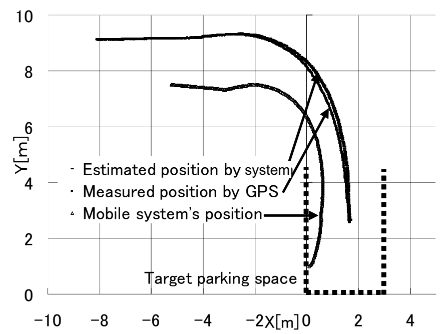



Fig.13 Trajectories of the mobile guidance system and a guided vehicle (automated guidance)

As to the drive of the mobile guidance system, the mobile guidance system is controlled from starting point to the final target point while keeping suitable relative locations among the guided vehicle, the guidance mobile system and the target parking space. The distance between the mobile system and the back of the guided vehicle is kept within about 2.0 [m]

The experimental results in the manual guidance are shown in Fig.16, which shows three kinds of trajectories; the first one is the center of the guided vehicle estimated by proposed system, the second one is the center of the guided vehicle measured by the RTK-GPS as the reference, and the third one is position of the mobile system. These results show the proposed system can consecutively estimate the position of the guided vehicle. The guided vehicle is instructed from the mobile guidance system in a manner to compensate the delay in the human driver on the guided vehicle under the condition that the driver follows the instruction. In comparison with the result in the automated guidance, the result in the manual guidance shows that it takes a long time to guide the guided vehicle. It is because that the driver under manual guidance has to drive slowly. The manual guidance system can finely correct the detailed position and yaw angle of the vehicle, to lead the vehicle to the target parking space. These results show that the mobile guidance system can cooperate with the guided vehicle and the validity of proposed parking assist system by the guidance mobile system.

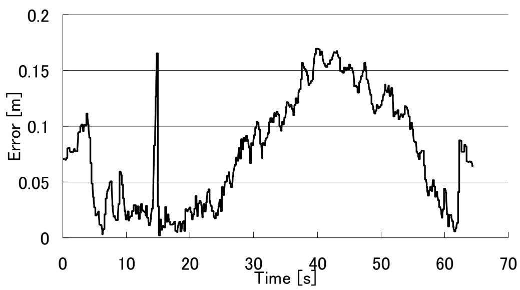



Fig.14 Error between the measurement and the RTK-GPS reference

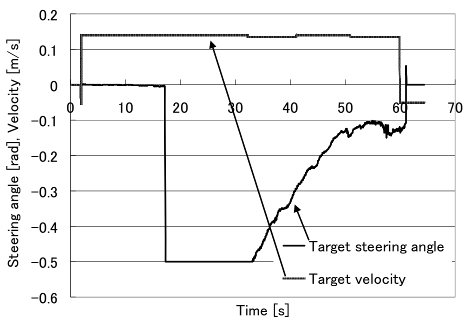



Fig.15 Commands of steering and velocity to a guided vehicle

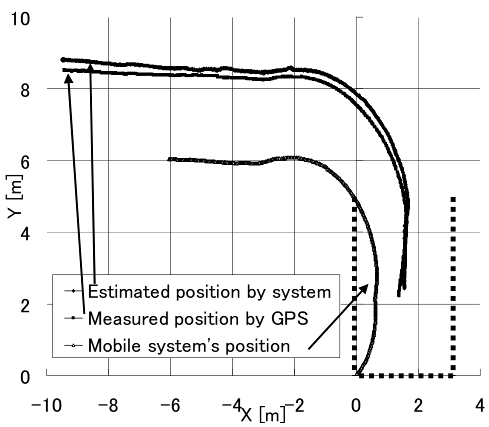



Fig.16 Trajectories of the mobile guidance system and a guided vehicle (manual guidance)

## V. CONCLUSION

A new concept that a vehicle is manually or automatically guided to the target parking space from the mobile guidance system has been proposed and the experiment studies have been conducted to show the feasibility of the mobile guidance system. The system is featured by that a few intelligent systems will assist many ordinary vehicles in parking lots.

We have some future work about human machine interface (HMI) which makes it easy for a driver to follow the instructions from the guidance system. We also need to evaluate the system in other situations such as obstacles existence, other ways of guiding or other types of the guidance mobile system.

## ACKNOWLEDGMENT

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