A Novel Design for Full Automatic Parking System

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***Abstract*—This paper proposed an obstacle orientation algorithm and a path planning of multi-turn mode to apply in automatic parking systems. The vehicle parks at a low velocity by developing a braking strategy. In addition to the design of controllers, a speed trajectory consisting of acceleration, constant speed, and deceleration is planned in order to provide the driver more comfortable feeling. According to the result of the verification tests, the obstacle orientation algorithm could accurately identify the 2D coordinate. And the proposed path planning of multi-turn mode saves one meter than the traditional two-turn mode. It makes the parking space only need 1.28 times the vehicle length. The vehicle control is implemented using Fuzzy-PID tracking control. System performance and tracking ability are verified in hardware and software implementations with very low cost.**

Keywords-Obstacle Orientation Algorithm, Path Planning of Multi-turn Mode, Brake Control

I. INTRODUCTION

The recent advances in intelligent vehicle electronics technologies have generally made active safety systems applied in driving aid systems. To eliminate the collision accidents, many car factories aim at promoting the safety and convenience by using various sensors or actuators embedded in vehicles. The parking system is one of the popular assistant driving devices since the Toyota motor has devoted it into commercial product on Prius/Lexus models. Parking a vehicle is always a problem to beginners because it's hard to know the turning point. The parking guidance system also has been researched and developed by many research institutes or manufacturers because the advanced parking guidance system is one of the growing topics that aim to enhance the comfort and safety of driving.

The earliest concept of parking assistance is Parking Assistance System (PAS) [1, 2]. The parking assistance system can calculate the reversing trajectory by using the signal from the steering angle sensor in real time. For back-in parking and parallel parking applications, this system provides a series of parking guidance lines and assists the driver to determine the initial rotation angle of the steering wheel as well as the returning point. The second stage is Advanced Parking Guidance System (APGS). APGS can assist a driver to find a suitable parking space and detect obstacles by ultrasonic sensing and image recognition technologies, and to steer the host vehicle automatically to the expected parking space by path tracking control with an Electric Power Steering (EPS). It can assist driver to park their car safely and conveniently [3-5]. However, the driver still needs to operate the brake pedal. On the basis of the technique of APGS, the system combine brake control, gear shift, remote control with EPS. Automatic parking system (APS) is proposed. The key techniques are environmental mapping, Path Planning, trajectory tracking control and gear shift and brake control as the following statements:

(1) Environmental Mapping

The parking space can be detected by sensors to ensure collision-free motion within the available space. To scan the parking space and estimate availability of parking space, the scanning technology of ultrasonic sensor is adopt as scanning unit. The techniques contain the following items:

(a) Graphic User Interface

User Interface displays image of rear parking space or results of detecting parking space. It helps drivers to judge whether the parking space is enough.

(b) Parking Space Detection

It is mainly to detect the length and width of parking space by ultrasonic sensors installed on the side of the vehicle.

(2) Path Planning

The process is concerned with how to determine speed and steering settings at each instant of time in order for the vehicle to follow a certain path. Many researches were proposed such as Simple Continuous Curve, Rapidly-Exploring Random Tree, nonholonomic and fuzzy control [6-8]. Although the above mention methods are feasible, lowering parking space is not considerable. From the position data, vision and vehicular information, this paper provided a multiple turn control algorithm to do forward-back motion [9]. The algorithm is derived from two-turn model which describe how to park using two different radiuses. The two-turn methodology based on geometry relation is developed below. The turning radius in the first turn is computed from present location, and the second turn is constrained by minimum turning radius. After the algorithm computes the turning radius, the controlled method uses pure pursuit to track target path by utilizing steering control. It makes the parking space only need 1.28 times the vehicle length by examinations.

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(3) Trajectory Tracking Control

These vehicular signals are held and processed by circuit board in operation platform, and then the steering control unit will be operated through path tracking. In steering control, an electric power steering (EPS) composed of a motor, steering angle sensor and a power module is equipped into the steering wheel for implementation of automatic parking in this study.

(4) Brake Control

It is important to note that in the process of path tracking, the speed control has the influence on the tracking stability and precision. And the vehicle speed is relative directly to brake control during parking. Therefore, this paper will focus on developing a brake control strategy of the automatic parking system and planning a proper speed trajectory to make the parking process smooth and stable. In the following sections, there will be a description about the design of brake controller and system validation in our experimental platform.

II. APS SYSTEM

The system technology for APS system is designed with an integration of tracking control through electrical steering system and environment sensing through ultrasonic sensors. The range sensing information may be display the image and warning to show the driving appearance in remote operation via buzzer. In vehicle dynamic information, vehicle speed is captured with variable timer by calculating wheel displacement relative to controller trigger time. Hence, the delicate timing scheme is well-done before system operation. The architecture of the proposed system is shown in Fig. 1 below.

A data fusion of APS platform is built of four mainly components, including scanning unit, steering control unit and vehicular date unit in demonstrated vehicle. The parking strategy is completed by means of coordinated control of the steering angle and taking into account the actual situation in the environment to ensure collision-free motion within the available space. To scan the parking space and estimate availability of parking space, the scanning technology of ultrasonic sensor is adopt as scanning unit. The following procedure is to generate a delicate parking trajectory by developed multi-turn algorithm. The vehicular position is computed by world coordinate relative to the nearest edge of parking space and done self-positioning from odometer data. The third unit, vehicular unit, is used to provide wheel speed and location positioning from hall sensor; furthermore the vehicular unit is also used to receive the wheel signals via controller area network (CAN) interface connected to odometer [10].

The CAN-based interface is based on the broadcast communication mechanism which is achieved by using a message oriented transmission protocol [11]. These vehicular signals are held and processed by circuit board in operation platform, and then the steering control unit will be operated through path tracking. In steering control, an electric power steering (EPS) composed of a motor, steering angle sensor and a power module is equipped into the steering wheel for implementation of automatic parking in this study. Since the EPS is equipped in the experimental vehicle, the steering control with a developed Fuzzy-PID can be utilized to automatically control the vehicle longitudinal and lateral motion.

A dsPIC30F6010A chip is the mainly adopted APS ECU, where the control law to access data input and output is programmed. To fulfill the proposed vehicle control application, steering angle data as well as positioning data are processed in specific logic, digital formats and sent through CAN bus in controlled intervals. Each data packet is less than 8 bytes using standard ID (11 bit); moreover, the refresh time of packets is about 20ms. The detecting ability of slide ultrasonic sensors is 5 m and 2.5 m which is separately mounted in front, back and side area.

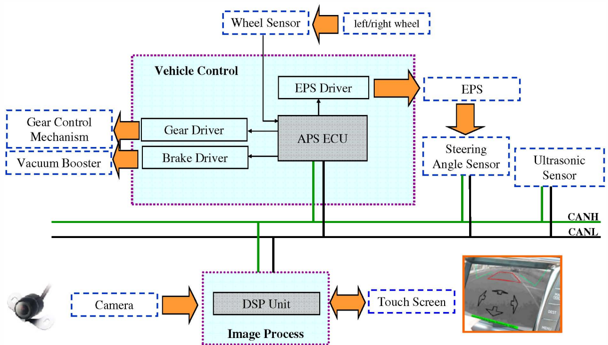

Fig. 1 Architecture of APS

A. *VEHICLE SPEED CONTROL*

A vehicle longitudinal model is necessary to build up before starting to design a brake controller. In this paper, the vehicle longitudinal model developed by You-Hua Shiu in 2006 [12] will be applied in our simulation. This model links the engine, torque converter, automatic transmission, tire, brake, and vehicle dynamic model. Compared the simulated result in this model, this model also has a quite similar performance. In overall, it is clear to see that the system depends on the acceleration and deceleration command decided by throttle and brake control to determine the vehicle speed. When the engine receives these input parameters, the engine will deliver the engine speed to the torque converter, which converts it into the turbine torque. And then the torque will be passed to automatic transmission part. As a result, the automatic transmission block will determine the driving torque to the tire model that outputs the longitudinal driving force of tire. Finally, the force combines the vehicle dynamic model to obtain the final vehicle speed.

There have been many methods to plan a suitable speed trajectory during the process of braking. The goal of the automatic parking system is to provide the driver a comfortable feeling, and the process of automatic parking should be smooth and stable. According P. Seiler's research [13], human passengers feel comfortable as the automotive acceleration or deceleration is under 2.5 m/s2. Therefore, the parking speed trajectory will be planned as three states, consisting of proper acceleration, constant speed, and deceleration. Due to the reason that the brake pedal control is limited from 0% to 100%, it could cause the control action stays saturated for a while in the initial period of acceleration. In order to avoid this condition, Peng-Syu Liang [14] presents that a smooth trajectory can be designed as:

$$v(t) = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + c_4 t^4 + c_5 t^5 \tag{1}$$

where

$$\begin{aligned}
c_0 &= v_0 \\
c_1 &= \dot{v}_0 \\
c_2 &= \frac{1}{2}\ddot{v}_0 \\
c_3 &= \frac{1}{2t_f^{\,3}}\left[20v_f - 20v_0 - (8\dot{v}_f + 12\dot{v}_0)t_f - 3(\ddot{v}_0 - \ddot{v}_f)t_f^{\,2}\right] \\
c_4 &= \frac{1}{2t_f^{\,4}}\left[30v_0 - 30v_f + (14\dot{v}_f + 16\dot{v}_0)t_f + 3(\ddot{v}_0 - 2\ddot{v}_f)t_f^{\,2}\right] \\
c_5 &= \frac{1}{2t_f^{\,5}}\left[12v_f - 12v_0 - (6\dot{v}_f + 6\dot{v}_0)t_f - (\ddot{v}_0 - \ddot{v}_f)t_f^{\,2}\right]
\end{aligned} \tag{2}$$

v_0 , $\dot{v}_0$, $\ddot{v}_0$ present the initial speed, acceleration, and jerk respectively at t =0. v_f , $\dot{v}_f$, $\ddot{v}_f$ present the final speed, acceleration and jerk respectively at t = t_f .

B. OBSTACLE ORIENTATION ALGORITHM

To avoid the collision with obstacle at the rear of the vehicle, this paper provided the obstacle orientation algorithm to detect the coordinate of the obstacle. Suppose the positions of the four ultrasonics installed in the rear bumper are (x_1, y_1, z_1) , (x_2, y_2, z_2) , (x_3, y_3, z_3) and (x_4, y_4, z_4) . If the obstacle at the rear of the vehicle, is scanned by three ultrasonics simultaneously can be denoted as:

$$\begin{cases}
\rho_1 = \sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2} \\
\rho_2 = \sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2} \\
\rho_3 = \sqrt{(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2}
\end{cases} \tag{3}$$

Equation (3) can be concluded as (4), where ρ_i is the distance measured by ultrasonic.

$$\rho_i = \sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} \tag{4}$$

Utilize the equilibrium point $(\hat{x}, \hat{y}, \hat{z})$. If the slight variation is occurred, the position of the obstacle is

$$x = \hat{x} + \delta x, \quad y = \hat{y} + \delta y, \quad z = \hat{z} + \delta z \tag{5}$$

The position of the obstacle can be calculated as (6). The obstacle is scanned by at least two ultrasonic sensors.

$$\begin{bmatrix} \rho_1 - \hat{\rho}_1 \\ \rho_2 - \hat{\rho}_2 \\ \vdots \\ \rho_n - \hat{\rho}_n \end{bmatrix} = \begin{bmatrix} \frac{(\hat{x}-x_1)}{\hat{\rho}_1} & \frac{(\hat{y}-y_1)}{\hat{\rho}_i} \\ \frac{(\hat{x}-x_2)}{\hat{\rho}_1} & \frac{(\hat{y}-y_2)}{\hat{\rho}_i} \\ \vdots & \vdots \\ \frac{(\hat{x}-x_n)}{\hat{\rho}_n} & \frac{(\hat{y}-y_n)}{\hat{\rho}_n} \end{bmatrix} \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} \tag{6}$$

If the obstacle is scanned by only one ultrasonic, the displacement of the vehicle will be considered. The matrix will be transferred as (7).

$$\underbrace{\begin{bmatrix} \rho_1 - \hat{\rho}_1 \\ \rho_2 - \hat{\rho}_2 \\ \rho_3 - \hat{\rho}_3 \end{bmatrix}}_{\delta\rho} = \underbrace{\begin{bmatrix} \frac{(\hat{x}-x_1)}{\hat{\rho}_1^{'}} & \frac{(\hat{y}-y_1)}{\hat{\rho}_i^{'}} & \frac{(\hat{z}-z_1)}{\hat{\rho}_i^{'}} \\ \frac{(\hat{x}-x_1^{'})}{\hat{\rho}_1^{''}} & \frac{(\hat{y}-y_1^{'})}{\hat{\rho}_i^{''}} & \frac{(\hat{z}-z_1^{'})}{\hat{\rho}_i^{''}} \\ \frac{(\hat{x}-x_1^{''})}{\hat{\rho}_n^{'''}} & \frac{(\hat{y}-y_1^{''})}{\hat{\rho}_n^{'''}} & \frac{(\hat{z}-z_1^{''})}{\hat{\rho}_n^{'''}} \end{bmatrix}}_{H} \underbrace{\begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix}}_{\delta p} \tag{7}$$

III. MULT-TURN ALGORITHM

From the position data and vehicular information in CAN bus, this paper provided a multiple-turn control and parking space scanning algorithm to do forward-back motion. The developed algorithm is derived from two-turn model which describe how to park using two different radiuses in larger parking slot. The two-turn methodology based on geometry relation is developed below. The turning radius in the first turn is computed from present location, and the second turn is constrained by minimum turning radius. After the algorithm computes the turning radius, the controlled method uses pure pursuit to track target path by utilizing steering control.

With receiving unit information, the remote information is on-line processed. After APS ECU receives data from other units, the mathematical model of parking space will be built a geometry relation in Fig. 2. Vehicular length (L), width (W) and distance from rear-wheel axis to bumper (c) are known from manufacture and the width of parking space usually fixed between 2.2 m and 2.5 m. The key parameter is “m” and “n”, and it can be measured by ultrasonic sensors. In this paper, the ultrasonic operates this task to do world coordinate positioning and obtains unknown parameters. In the Fig. 3, the following step is to do multiple-turn control after geometry relation.

The algorithm derivation has an assumption in second turning and draws back to get first radius using boundary constraint. In two-turn model, the system operation hypothesizes the second radius as minimum one in (8). The first radius will be constrained and considered in Fig. 2. ϕ_s is steering angle, and N is the gear ratio. Hence, the constrained relations in longitudinal and lateral condition are concluded into (9)-(10). The minimum length (H) is simplified in (16). The demonstrated vehicle length is showed as “L”. The anti-collision distance is preserved as buffer (b1).

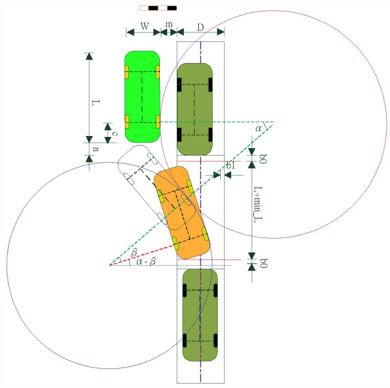

Fig. 2 Geometry Model

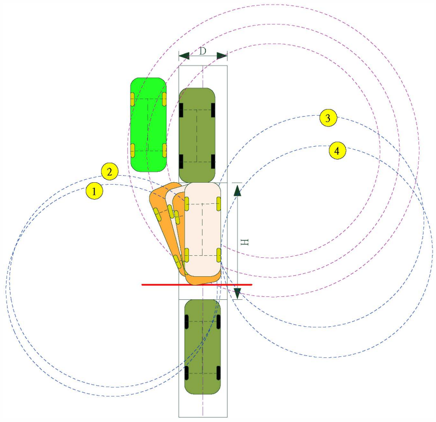

Fig. 3 Multiple Turn Geometry

$$R_{\min\_out} = l \cdot \cot\left(\frac{\varphi_s}{N}\right) + \frac{W}{2} \quad (8)$$

$$(R_{\min\_out} - R_{\min\_out}\cos\theta) + (L-c)\sin\theta = (D-b_1) \quad (9)$$

$$R_{\min\_out}\sin\theta + (L-c)\cos\theta = H - c \quad (10)$$

$$H = \sqrt{(L-c)^2 + 2R_{\min\_out}(D-b_1) - (D-b_1)^2} + c \quad (11)$$

Equation (11) will be rewritten as another input parameter type as a result of steering control. From the original position and first turn relation, the geometry can give two relations in (12) and (13). The first radius will be listed as (14). It means that the controller gives first radius and then the vehicle can do automatically control by sensing relative lateral distance (m) and reference point to bumper distance (c). The first radius will have many solutions depending on boundary condition, as shown in (15).

$$m + (D - U - b_1) = R_s \quad (12)$$

$$(R_{\min\_out} + R_s)^2 = (H + n + b_0)^2 + (R_{\min\_out} - U)^2 \quad (13)$$

$$R_s = \frac{(H+n+b_0)^2 - 2R_{\min\_out}(m+D-b_1) + (m+D-b_1)^2}{2(m+D-b_1)} \quad (14)$$

$$(R_{\min\_out} + R_s)^2 - (H+n+b_0)^2 \geq 0 \quad (15)$$

Although the two-turn can solve parking space problem, this kind of method will need about 1.3~1.5 times vehicle length. This paper studies a delicate method to reduce parking space by improving two-turn method, as shown in Fig. 4. Both of two-turn and multiple-turn have same assumption in second turning, but the second radius will turn and change to another mode by detecting back distance or compared to tracking path. The angle variation of first turn is shown in (16) by lateral relation, and the second turn in multiple-turn will has smaller angle variation and its lateral motion is constrained by (17). Equation (17) can generate tracking points by deciding the first turn angle variation α, and the angle variation of other turns does forward-back depending on residue angle.

$$\alpha = \sin^{-1}\left(\frac{H+n+b_0}{R_{\min\_out} + R_s}\right) \quad (16)$$

$$D_1 + D_2 \geq W + m + b_1 \quad (17)$$

The multiple-turn algorithm can generate optimal tracking position by measuring related parameters. The tracking points are ready to compared to present position, moreover, the steering control method utilizes Fuzzy-PID to get a smoothly control in Table 1 [15]. The steering control is based on steering angle error and accumulated error to form control law. According to the previous discussion, the input parameters are speed error and error summation. Each membership function is composed of three triangular curves in central position, and both sides are trapezoid relations. The fuzzy table is shown in Table 1, where the control gain uses the same as table. In defuzzification step, it uses center of gravity and the control gains are required and showed as Kp={6/NB,10/NS,15/ZR,20/PS,25/PB} and KI ={0.3/NB,0.4/NS,0.5/ZR,0.8/PS,1.2/PB} and KD ={3/NB,3/NS,3/ZR,5/PS,5/PB }.

Table 1 Fuzzy-PID table

K_P/ K_I /K_D		Steering angle error				
		NB	NS	ZR	PS	PB
Error sum	NB	NB	NB	NS	NS	PB
	NS	NS	ZR	NS	ZR	PS
	ZR	NS	NS	ZR	PS	PS
	PS	NS	ZR	PS	ZR	PS
	PB	NB	PS	PS	PB	PB

IV. VERIFICATION TESTS

The result of constant speed tracking test is shown in Fig. 4. The result shows that there is still small oscillation in the figure and the error is about between +0.2 km/h and -0.2 km/h. The reason could be from the difference between the real car and the simulation model, and in the real environment the complexity will increases because of other factors. The following test is to make the vehicle tracking a desired speed trajectory.

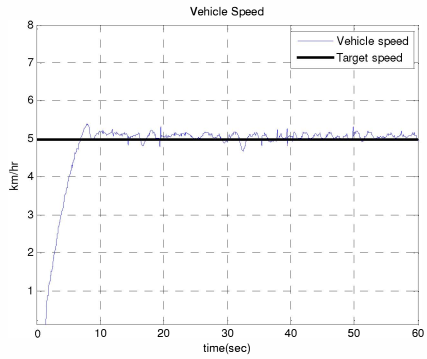

Fig. 4 The result of constant speed tracking test

Fig. 5 shows trajectory of parallel parking test. It shows a multiple turn control implementation. Owing to low sensitivity in odometer sensing, the self-positioning data showed a little lag than RTK-GPS trajectory. The lateral distance error is limited with 20 cm. It doesn't have large effect in parallel parking.

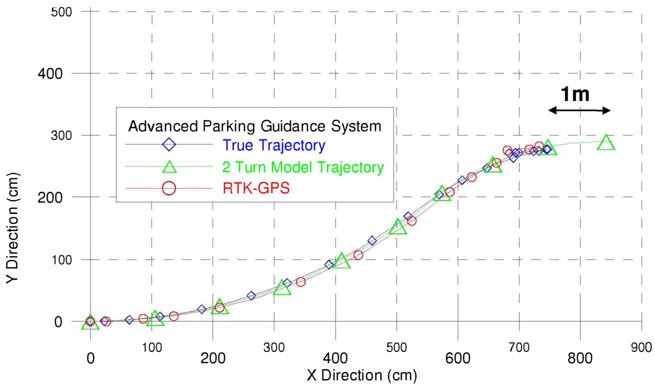

Fig. 5 Trajectory of parallel parking test

V. CONCLUSIONS

In this paper, the capability of automatic parking system using sensor fusion is verified. The proposed system designed and implemented an integrated technology using microcontroller and DSP to accomplish environment map by adding camera module through data processing. The implementation presented the capability of the sensing information into parking applications in sufficient space. The developed algorithm is effectively embedded into DSP and generates precise trajectory in accordance with present position.

The verification tests have proven that the advantages of ultrasonic sensor, odometer, EPS driver and camera integration. The proposed system can assist drivers to have a high active-safety parking with environment awareness capability. The advantage of the automatic parking system has presented with exact awareness of environment map, and the demonstration provides a feasible solution for parking control to enhance parking safety. The developed system only requires about 1.28 times vehicular length. The capability is verified in this study.

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