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DEVELOPMENT OF THE CONTRIBUTION

This paper presents an a solution of remote control for parallel parking using multiple-turn control and sensor fusion, including ultrasonic scanning, steering control and self-positioning. The proposed system has the advantage of easily operation, 1.25 slot length in relation to the length of the car and obstacle detection within 1.1 m; moreover, it helps driver have an active-safety vehicle parking using field sensing of ultrasonic. Using an inertial sensor to enhance its availability, this paper provided s robust

Verification of Multi-Turn Control and Inertial/Vehicular Data in Advanced Parking Guidance System

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Abstract

Parking a vehicle is always a troublesome problem to beginners because it's hard to know the turning time. This paper presents a solution to decrease parking space for parallel parking using ultrasonic sensors, intelligent control embedded developed algorithm. The developed system integrates ultrasonic sensors, gyro, electric power steering driver, steering angle sensor and hall sensor with microcontroller into an advanced parking guidance system. The tracking model is scanned by ultrasonic sensor, and then fuzzy-PID control method is adapted to control steering motion. An inertial sensor, gyro, is used to compensate vehicular parallelism relative to parking lines. Besides, torque sensor of electrical power steering system is taken into consideration for disable parking guidance system when system is under failure mode. The discrete kalman filter is used to filter measured data of torque sensor and estimate true state which is affected by white noise. The proposed system is carried out with theoretical algorithm and hardware integration, and the implementation result shows vehicle control applicability.

Introduction

In the recent two decades, many assist driving devices are developed and designed for comfortable life. Nowadays, the parking assistant system is one of the popular active-safety driving devices with the objectives of increasing the capacity and improving the safety of existing metropolitan problems. There are also many auxiliary devices which are used to detect blind area, assist driving or help driver judgment, like rear parking trajectory, around view system and so forth [1-2]. 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.

In some parking system, they have shortcomings about parking speed and the angle of vehicle relative to parking lines. The tracking path and vehicular maybe has limited under small speed result of odometry uncertainty. Besides, the length of parking slot is always discussed and implemented with different control methods. An automatically parking system is the most interested device under statically data; however, the marketable vehicles which have parking guidance system always need large parking space about 6 meters or 20 ft length. Taking intelligent parking assist system (IPA) as example, the Toyota motor has devoted it into commercial product on Prius/Lexus models. It can help drivers automatically drive the car in constrained environments where much attention and experience is required. But it needs about 1.5 times slot length.

This paper presents a solution to decrease parking space for parallel parking using ultrasonic sensors, intelligent control embedded developed algorithm [3]. The developed system integrates ultrasonic sensors, electric power steering driver, steering angle sensor and hall sensor with microcontroller into an advanced parking guidance system (APGS). The system adopted a microcontroller to construct an independent navigation platform using data fusion integration for parking. The developed algorithm is derived to satisfy the requirement of parking space scanning and tracking control, moreover, it is carried out some experiments to implement and verify the proposed idea of APGS system. The hardware has been implemented on microcontrollers and carried out verification tests. The following sections will be focused on integrated design and its verification.

System integration

A data fusion of APGS platform is built of four mainly components, including scanning unit, steering control unit and vehicular date unit in demonstrated vehicle. The architecture of the proposed system is shown in Figure 1 below. 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. The range sensing information may be display the image and warning to show the driving appearance in remote operation via buzzer. The fabricated circuit board has two local networks. One network is used to transmit self-scheduled data, and the other function utilizes this interface to get required data from vehicular network.

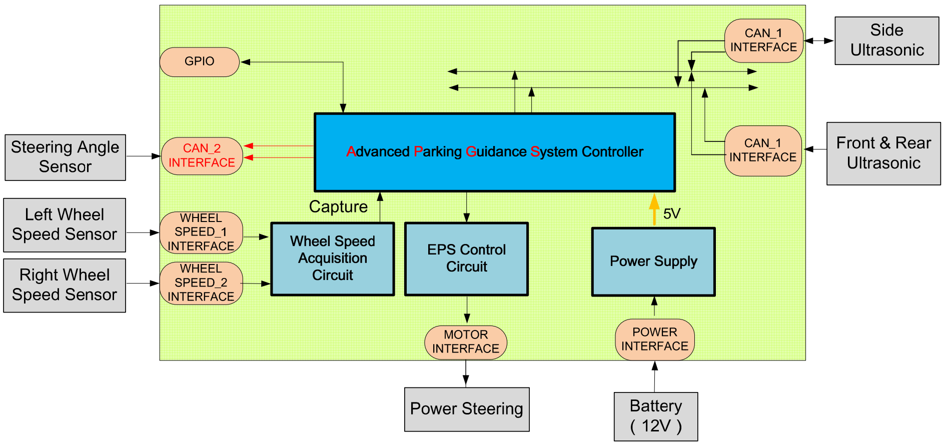

Figure 1: The architecture of advanced parking guidance system.

In vehicle dynamic information, vehicle information is collected and processed with four segments. Hence, the delicate timing scheme is well-done before system operation. Vehicular data from on-board diagnostic is captured by the scheduled timing.

A. The proposed system architecture

The system technology for APGS system is designed with an integration of control technique and environment sensing through ultrasonic sensors. The range sensing information may use beep to alarm the driving appearance in remote operation. In vehicle dynamic information, vehicle speed is captured by calculating wheel displacement relative to controller trigger time. 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 odometry 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 odometry [4].

A dsPIC30F6010A chip is the mainly adopted APGS 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 ultrasonic sensors is 2.5 m and 1.1 m which is separately mounted in front, back and side area.

The dsPIC30F6014 is Microchip product for signal processing. This chip are designed to perform as supervisor core, where GPS message and inertial analog signals are on-lined captured, sampled and processed, back to the DSRC application; while the vehicular data is determined as the calibrated information. This INS core has the communication interface to a personal computer/IXP to downlink messages and broadcast to adjacent vehicles in real time. As the needs for the system, the specification and requirement of dsPIC30F6014 are listed in the following Table 1.

B. Parking slot detection

Several kinds of parking guidance system usually adopt camera base operation, and the driver can select the parking space which he wants. However, this kind of system usually takes a lot of time to process and operate. The full-ultrasonic APGS system has an ability of prompt operating, and it use ultrasonic sensor instead of camera device. The front & rear ultrasonic has the detection ability about 1.1 m with fixed interval. The side ultrasonic has highly detection about 2.5m ability. In APGS system, the parking space is identified and finished by the scanning unit. This unit applied an edge positioning method and also calculated vehicle position to get relative distance in world coordinate. The side sensor is separated from ground about 55 cm in Figure 2.

C. Power steering control unit with disable ability

The control unit is mainly implemented by steering angle sensor and original EPS device. The steering angle is used to detect on-line angle and feedback to APGS controller in order to do remote control. The interface of steering sensor is outputted on CAN bus and its ID is 0x0c0. The data length is 16 bits in Intel mode, and the resolution is 1 degree. Besides, a good design always contain failure mode in order to have higher safety for user. In this paper, system failure or disable is applied and implemented.

D. Vehicular information from On-Board Diagnostic System II (OBD II)

The amount of electronic devices in vehicles is connected and diagnosed by CAN bus. In APGS platform, data is transmitted or received by CAN bus. CAN is a serial, asynchronous, multi-master communication protocol for connecting electronic control modules, sensors and actuators in automotive and industrial applications. The CAN-based system is based on the broadcast communication mechanism which is achieved by using a message oriented transmission protocol. The bit rate of CAN bus is up to 1 Mbps and is possibly operated at network lengths below 40 meter. In this study, the data rate is 500 kbps and its sampling point is held in 75%. Each unit is implemented by CAN circuit board, and the APGS ECU is embedded CAN controller and it adopts NXP TJA 1040 as the transceiver. The CAN transceiver is the interface between the CAN controller and the physical transmission line and it is one of the key factors influencing the capability of network system.

Vehicular information usually is packet with scheduled timing in OBD II connector after 1995 [5], and the demonstrated vehicle provides many kinds of signals, such as ESP information, ABS signals, and brake states and so on. This paper adopts paddle, ABS signals to detect forward & backward and calculate vehicle position. The OBD II connector usually locates near brake/throttle under steering, and the connector is D-type and 16 pins with CAN interface, as shown in Figure 3.

Figure 2: Parking slot detection sensor.

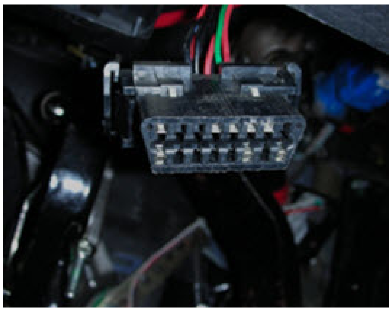

Figure 3: OBD II connector.

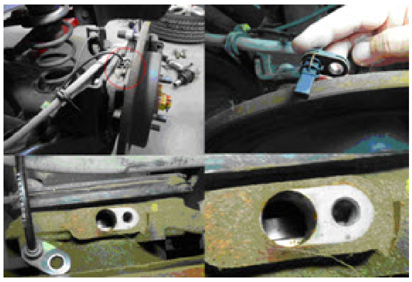

Figure 4: Odometry.

E. Positioning calculation by odometry sensor

This system needs to have self-positioning function in order to know where the vehicle is. The positioning technique utilizes wheel speed sensor to calculate vehicle moving distance in Figure 4. The sensing technology used two interrupts. One interrupt is a counter to get the numbers of wheel perforation. Compared with the trigger time, the other interrupt is used to read the counter value and calculate the speed. When the hall sensor detects the perforation, the output signal will be pulse one. In the demonstrated vehicle, each wheel has about 47 perforations. Relative to wheel circumference, each pulse indicates about 4.17 cm. When the vehicle turns or drives straight, there will be heading and speed variation. From right and left difference, the variation angle can be calculated and the average is vehicle speed. Hence, the reference point which is located in the middle of rear wheels can be taken as vehicular moving center from odometry information.

Principle of system algorithm

From user push on system power, the side ultrasonic starts to scan environment space and show the available parking slot. At the same time, odometry provides on-line signals to do position positioning. 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. When user wants to disable this system, user can hold or pull steering device. Using discrete kalman filter (DKF) to process torque data [6], the disable point is controlled by APGS controller.

The multi-turn 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 in Figure 5. 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. 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 Figure 6, the following step is to do multiple-turn control after geometry relation.

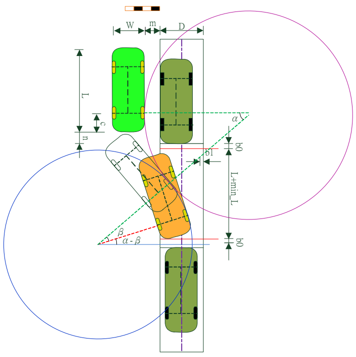

Figure 5: Two-turn geometry model.

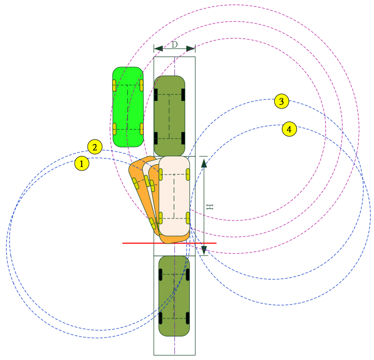

Figure 6: Multi-turn geometry model.

A. Multi-turn control method

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 Equation (1). The first radius will be constrained and considered in Figure 5. *s* is steering angle, and N is the gear ratio. Hence, the constrained relations in longitudinal and lateral condition are concluded into Equation (2)-(3). From Equation (2)-(3), the minimum length (H) is simplified in Equation (4). The demonstrated vehicle length is showed as "L". The anti-collision distance is preserved as buffer (b_1).

From the original position and first turn relation, the geometry can give two relations in Equation (4). By integrating Equation (3)-(4), the first radius will be calculated. 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 Equation (5). Although the two-turn can solve parking space problem, this kind of method will need about 1.3~1.5 times vehicle length or over 20 feet. This paper studies a delicate method to reduce parking space by improving two-turn method, as shown in Figure 6. 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 constrained by lateral relation, and the second turn in multiple-turn will has smaller angle variation and its lateral motion is constrained

$$R_{\min\_out} = l \cdot \cot\left(\frac{\varphi_s}{N}\right) + \frac{W}{2} \tag{1}$$

$$(\mathrm{R}_{\min\_out} - \mathrm{R}_{\min\_out}\cos\theta) + (L-c)\sin\theta = (D-b_1) \tag{2}$$

$$\mathrm{R}_{\min\_out}\sin\theta + (L-c)\cos\theta = H - c \tag{3}$$

$$(R_{\min\_out} + R_s)^2 = (H+n+b_0)^2 + (R_{\min\_out} - U)^2 \tag{4}$$

$$(R_{\min\_out} + R_s)^2 - (H+n+b_0)^2 \geq 0 \tag{5}$$

B. Parking slot scanning method

Before the driver start to park his/her vehicle, the proposed must be power on and the ultrasonic will scan the around space. In the developed system, the ultrasonic sonic will integrate with vehicle position from odometry. The algorithm uses a multiple points positioning method, and it is derived from 2nd order recursive regression. When a vehicle passes through a series of vehicle and scans a free space, the microcontroller system will calculate the edge of parking space. The edge position is computed by Equation (6). The argument "$\hat{x}$" is predicted position in x direction, and the argument "$\hat{\rho}$" is the measured distance. From predicted distance and measured distance, the right term of error vector can be obtained. The computed procedure usually needs three times to get a right position within 5ms.

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

C. System disable method via discrete Kalman filter

Filtering is desirable in many situations, and a good filtering algorithm can remove the noise from electromagnetic signals while retaining the useful information. The Kalman filter is a tool that can estimate the variables of a wide range of processes. In this study, it uses a linear system to simply the process of torque signal. The processing flow chart is described in Figure 7. The first procedure is used to guess initial ($\hat{X}_0^-$) and observation covariance values (P_0^-) of torque sensor; moreover the Kalman gain (K_k) is estimated. The 2nd procedure utilizes measured data to get system true state ($\hat{X}_k$), and this value is the filtering value of torque sensor. The third step will use K_k and P_k to update newer P_k. At the fourth procedure, it will estimate system state and observation covariance value using system error covariance value (Q_k). These initial values will decide system performance in this paper, and these values will be trained with many cases and scenarios.

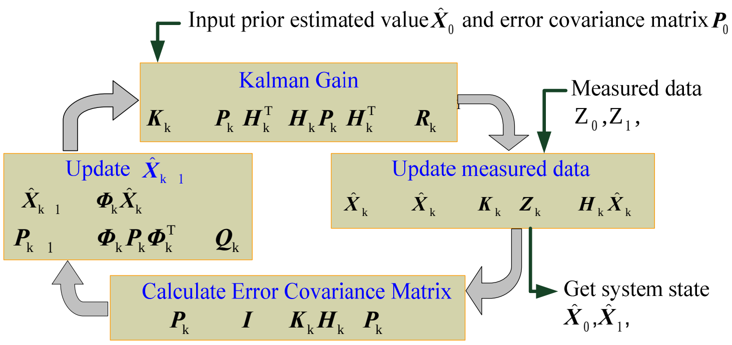

Figure 7: The flow chart of discrete Kalman filter.

D. Control Tracking Method

Path tracking is the process concerned with how to determine speed and steering settings at each instant of time in order for the vehicle to follow a certain path. From point to point path tracking, pure pursuit is applied in this work. It calculates the curvature that will take the vehicle from its current position to a goal position. A circle is then defined in such a way that it passes through both the goal point and the current vehicle position. Finally a multiple turn algorithm chooses a steering angle in relation to this circle [7].

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. The steering control is based on steering angle error and accumulated error to form control law. 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 K_p={6/NB,10/NS,15/ZR,20/PS,25/PB} and K_I={0.3/NB,0.4/NS,0.5/ZR,0.8/PS,1.2/PB} and K_D ={3/NB,3/NS,3/ZR,5/PS,5/PB }. Each control gain processes 25 times and does membership summation.

Table 1: Fuzzy-PID control 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

Unit tests and system verification

System software on demonstrated CAN bus is programmed with appropriate protocol. The main CPU is dsPIC30F6010A controller which uses to catch environmental condition and generate tracking points. Through CAN bus and OBDII, the APGS ECU can integrate related parameters from CAN bus auxiliary.

The following unit tests did system function availability. The first test is about positioning error, and the following is tracking angle error of steering with different control parameters. The third test is disable test, and this function test implemented system failure redundancy. It usually uses for changing APGS mode to driving mode.

A. Odometry test

To accomplish the positioning capability, the vehicle position must have a delicate positioning. In Figure 8, the self-positioning trajectory is compared with RTK-GPS locus which 3-sigma standard deviation is about 0.6 cm. The minimum radius difference is within 20 cm after stacking graphs together. The blue line is odometry locus.

B. Control parameters test

In the control strategy description, the segment introduced intelligent control method in this paper. Owing to system model uncertainly and hardly identify, artificial control technique is adopted in this study. To meet an optimal or better performance, many tests are operated and summarized in related parameter training. The Figure9 shows P and I gains in different characteristics; besides, it can find a proper gain refer to demo tests. Taking I gain for example, higher value will have fast tracking characteristics, but it will have higher overshoot.

C. System disable test

A good design always contain failure mode in order to have higher safety for user. In this paper, system failure or disable is applied and implemented. The key point is torque sensor, and the initial designed is to measure its static voltage about 1.72 volts. The Figure 10 shows two scenarios tests and its tests. The blue line shows original signal of torque sensor. Sometimes these ripples may human operation or reactive force from road. The difference feature is on the duration time, and human operation has continuous curve and long time.

The first scenario is that driver uses hand to hold steering. It will result in high torque and long time ripple in Figure 10(a). In second scenario, the driver uses his hand to hit steering slightly in Figure 10(b). This test is simulated a low attention condition when driver wants to get something. But it may have a little danger to let driver hurt. Hence, it will also disable to prevent driver out of danger. In Kalman filter application, the system error covariance value (Q_k) is about 0.1 and the observation error covariance value (R_k) is about 1 [8]. The processing data and test information are showed in Figure 10(c).

D. Gyro tests

To meet higher performance, an inertial sensor (ADXRS614) is added into enhancing its availability [9]. The ADXRS614 operates on the principle of a resonator gyroscope. The output signal of ADXRS614 is

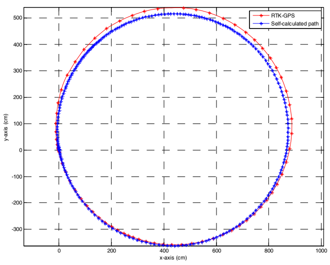

Figure 8: Self-Positioning Test.

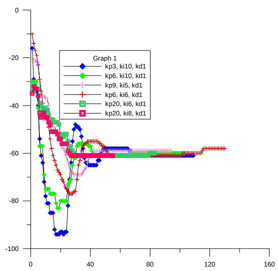

Figure 9: Fuzzy-PID control performance.

Figure 10(a): Use hand to hold steering.

Figure 10(b): Use Hand to hit slightly.

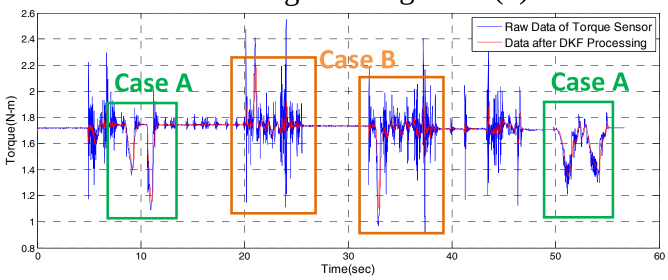

Figure 10(c): System disable tests.

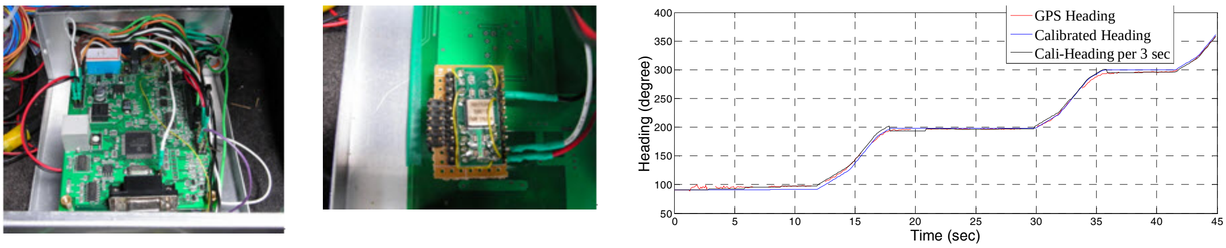

Figure 11: Gyro mounted under system hardware and its calibration test.

a voltage proportional to angular rate about the axis normal to the top surface of the package. With the increase of the rotation rate, the output voltage leaves the neutral point [ADXRS614 Datasheet, Analog Devices Products Inc., UK, web: http://www.analog.com/]. An external capacitor is used to set the bandwidth. Use external capacitors in combination with on-chip resistors to create two low-pass filters to limit the bandwidth of the ADXRS614's rate response.

The turning test is used to adjust gyro parameters refer to GPS course. Owing to integration error, the result should be calibrated and delicate processed well. The gyro integrated angular rate into heading comparing with GPS course w.r.t North direction in Figure 11.

E. System implementation

The system is integrated until unit tests and interface tests have been finished. In APGS operation, the first step is to scan parking space, as shown in Figure 12. The test uses a 10 m & 2 m parking slot to do test, and the ultrasonic sensor is built in the side of vehicle. The side sensor ID is 0xDD in CAN bus, and the received data whose length is 8 bits needs to multiply 2.2144. In ultrasonic processing, the reflected signal should take vehicle speed to calibrate the length. As a result of cone wave and processing frequency, the actual length usually is bigger than measured length [10]. When vehicle drives straight

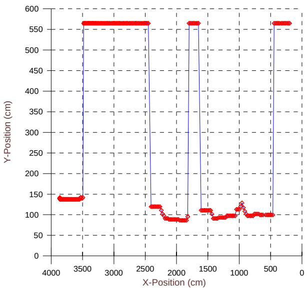

Figure 12: Parking slot scanning.

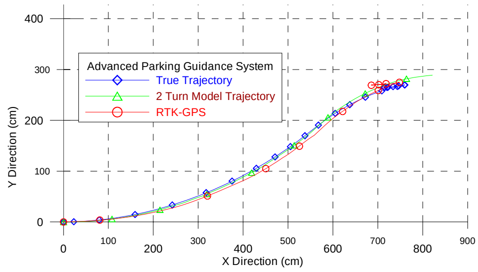

Figure 14: Parallel parking trajectory.

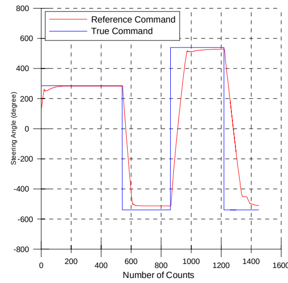

Figure 15: Control Command.

and meets the first corner of parking space, the sensor also can detect the objects due to reflect wave. The other corner still has this drawback, and it is inevitable. The calibrated strategy can reduce this effect and the result closes to actual length.

Figure 13(a) showed on-line operation test, where the demonstrated vehicle was driven on ARTC roadway. The driver drove to a suitable space, and the ultrasonic sensor detected parking slot under 15 kph. If it is enough to park, the auxiliary buzzer has a warning voice and it means available to park. When the vehicle drives over 5 meter reference to edge point, the APGS will be disable. Figure 13(b)-(f) implemented the APGS concept, and the multiple turn is decomposed five figures. When it is available to park, the tracking points are generated by Equation (1) & (5). Figure 14 showed self-estimated trajectory and RTK-GPS positioning data. Figure 15 displayed the control command, and it showed a multiple turn control implementation. Owing to low sensitivity in odometry sensing, the self-positioning data showed a little lag than RTK-GPS trajectory. But the lateral distance error is limited with 20 cm. It doesn't have large effect in parallel parking and can be modified in the later study.


(a).Parking Space Scanning.


(b).First Turn and Back.


(c).Second Turn and Back.


(d).Ready to Forward.


(e).Move Back.


(f).Forward and Stop.

Figure 13(e)-(f): Parallel Parking Test.

Discussion

In this paper, the APGS capability using sensor fusion is verified. The proposed system designed and implemented an integrated technology using microcontroller to accomplish environment detection by adding ultrasonic sensor through data processing. The implementation presented the capability of the sensing information into parking guidance applications in limit parking slot. The developed algorithm is effectively embedded into MCU and generates precise trajectory in accordance with present position.

The speed of demonstrated vehicles is tested under 15kph when it park in very small parking slot. From parking slot detection and tracking characteristics, the demo gave a concept about minimum length parking using multiple turn control. However, the proposed system had verified to have a little lateral distance error under 5 km/hr parking. The APGS offered an important awareness to the driver under test. The APGS can provide high active-safety to enhance parking ability in normal condition.

Acknowledgements

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