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LOW COST DESIGN OF PARALLEL PARKING ASSIST SYSTEM BASED ON AN ULTRASONIC SENSOR

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ABSTRACT−This paper presents a low cost design and implementation of a parallel parking assist system (PPAS) based on ultrasonic sensors. Generally, a PPAS requires several types of sensors, such as an ultrasonic sensor, camera sensor, radar sensor and laser sensor for parking space detection. However, our proposed PPAS only requires two ultrasonic sensors on the front and lateral sides for parking space detection. Moreover, a steering angle sensor and wheel speed sensor installed in the vehicle are used to obtain vehicle position information for localization in ultrasonic range data. The hardware architecture of the PPAS based on an electronic control unit (ECU) module, sensor modules and a human machine interface (HMI) module was proposed. Moreover, the software architecture of the PPAS is based on system initialization, scheduling, recognition and a control algorithm. In particular, a novel sensor algorithm was proposed to minimize the vehicle corner error of the ultrasonic sensor. A prototype of the PPAS based on the proposed architecture was constructed. The experimental results demonstrate that the implemented prototype is robust and successfully performs parking space detection and automatic steering control. Finally, the low cost design and implementation of the PPAS was possible due to the cheap ultrasonic sensors, simple hardware design and low computational complexity of the proposed algorithm.

KEY WORDS : Parallel parking assist, Ultrasonic sensor, Parking space detection, Parking control

1. INTRODUCTION

Recently, the production and sales of vehicles have rapidly increased compared to the expansion of roads and parking spaces. Narrow parking spaces along with these latest trends can cause inconvenience to many drivers. Therefore, intelligent parking assist systems (IPASs) can be helpful to drivers because the IPAS provides information about the parking space, the ideal parking path and automatic steering control. According to J. D. Power's "2001 Emerging Technology Study", 66% of consumers indicated that they were likely to purchase intelligent parking assist products (Frank, 2004).

Until now, the development of IPAS has used several types of range and vision sensors. For example, there are IPASs based on camera sensors (Vestri *et al*., 2005; Jung *et al*., 2006), ultrasonic sensors (Santonaka *et al*., 2006), radar sensors (Stefan and Hermann, 2006) and laser sensors (Hirahara and Ikeuchi, 2003). Among these sensors, IPAS development based on ultrasonic sensors is an important issue to reduce the cost of the system. Moreover, it is also important that an IPAS be constructed using ultrasonic sensors as few as possible in a vehicle.

Generally, the IPASs can be classified into parallel parking assist systems (PPASs) and cross parking assist systems (CPASs), which are called *garage parking assist systems* or *perpendicular parking assist systems*. In Europe, VALEO's PPAS, which is called Park4U, uses 10 ultrasonic sensors: 2 side sensors for parking space detection and 4 rear and 4 front sensors for parking assistance (John, 2006).

In this paper, we propose a low cost PPAS using 2 side ultrasonic sensors. After the proposed PPAS finishes detecting the parking space, it can guide the vehicle to the parking destination without the assistance of additional rear or front sensors.

Our proposed PPAS is shown in Figure 1. First, the scanning process for measuring a parking space is performed when the driver gives the start command. In this process, the PPAS provides information about the surroundings to drivers in both a graphical and audible format through the human machine interface (HMI) module. In the

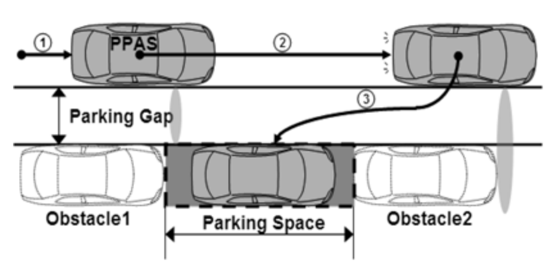

Figure 1. Operation procedure of PPAS.

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second step, the driver can stop the vehicle and change the gear position into reverse. In the last step, if the scanned space is large enough for parking, the PPAS guides drivers to the parking destination with the EPS control command. Moreover, the PPAS can provide feedback instructions and emergency stop warnings to drivers through the HMI module until the parking procedure is over.

In this paper, the design process and implementation of this PPAS based on ultrasonic sensors are meant for a low cost design. The proposed PPAS prototype was constructed using only two ultrasonic sensors to reduce the cost. We improved the error rate of vehicle corner detection with the proposed novel sensor design and algorithm. Moreover, the simple hardware and software architecture of the PPAS were implemented. The experimental results demonstrate that the proposed prototype is robust and successfully performs parking space detection and automatic steering control. In the conclusion section, we discuss potential improvements and the direction of our future research.

2. SYSTEM DESCRIPTION

In this section, the configuration and state diagram of the proposed PPAS is described. Figure 2 shows the configuration of the PPAS. The PPAS consists of 2 ultrasonic sensors, electric power steering (EPS), electronic stability control (ESC), an electronic control unit (ECU), a HMI, a steering angle sensor (SAS), and a wheel speed sensor (WSS).

The ultrasonic sensor, which is connected to ECU by LIN, performs the search operation for parking space detection. The EPS transfers the steering angle information from the SAS to the ECU and receives the control command from ECU by CAN, and then, it performs steering control operation as an actuator. The ESC, which is connected to the WSS, provides wheel pulse data to the ECU to estimate the position of the vehicle. The HMI allows communication between the driver and the PPAS. The ECU, which is connected to the EPS, ESC and HMI, can initialize and communicate with these connected devices and operate the algorithm for parking space detection and parking control.

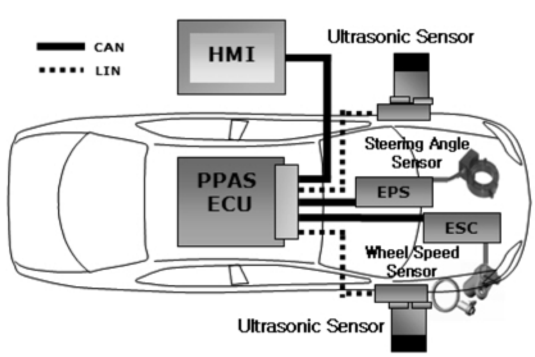


Figure 2. Configuration of PPAS.

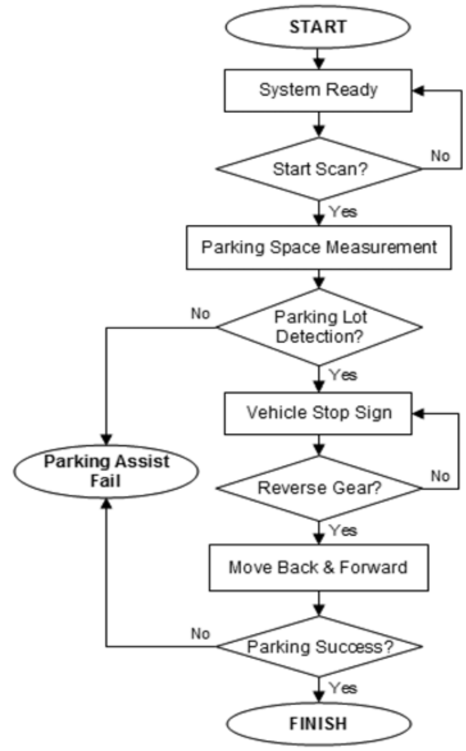


Figure 3. Operation state diagram of PPAS.

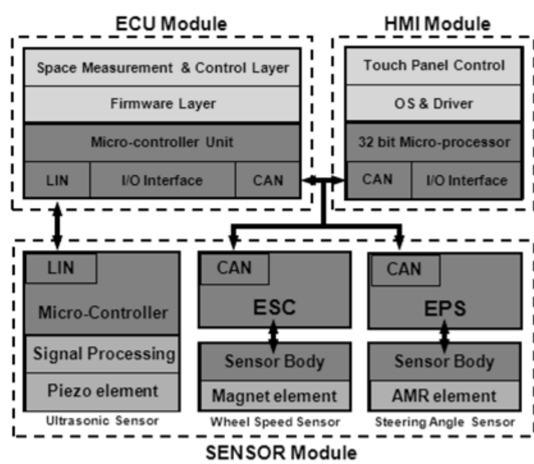


Figure 4. Hardware and software architecture of PPAS.

The operation state diagram of the PPAS is shown in Figure 3. If the driver pushes the system start button on the HMI, the ECU receives the initialization command flag from HMI by CAN, which changes the system into the ready state. The system ready state means that the ECU is turned on and finishes preparing to communicate with each module. After the system reaches the ready state, the parking space is measured when the driver indicates that the scan should begin. If there is enough parking space, the PPAS informs drivers about the possible parking space and the best parking path. The starting position and destination for parallel parking is shown to drivers on the display panel of HMI.

Currently, the driver drives the vehicle to the start position, until the vehicle stop sign appears on the screen of the HMI, and then puts the vehicle into reverse. After this step, if the driver puts his foot down, the vehicle automatically moves to the parking destination according to the EPS control command of the ECU. If the vehicle arrives at the destination, the PPAS informs the driver that parking is complete and a stop sign appears on the screen of the HMI.

3. SYTEM DESIGN AND IMPLEMENTATION

In this section, the architecture and design process of the proposed PPAS is described. As shown in Figure 4, the PPAS is separated into three parts: the ECU module, SENSOR module and HMI module. The SENSOR module consists of three types of sensors: ultrasonic sensors, WSS connected to ESC and SAS connected to EPS. Ultrasonic sensors are used to classify obstacles and empty space between vehicles after scanning parking space. Then, the WSS and SAS data are used to estimate the vehicle position and range. Lastly, the EPS receives the steering angle command from the ECU module and operates as a controller for steering actuation. The ECU module was designed using a low power 16-bit micro-controller and a simple I/O interface for communication with several peripherals. Furthermore, the ECU software consists of the firmware that initializes and schedules the system, the parking space detection algorithm for vehicle position estimation and localization and the parking control algorithm for path planning, target profiling and EPS control. The HMI module includes a touch panel controller with a graphic user interface (GUI). To realize the GUI environment, the touch panel control driver was ported on the QNX operating system of the HMI module. A touch driver can easily control the PPAS with the GUI.

3.1. Sensor Module

The SENSOR module consists of 2 ultrasonic sensors, the SAS connected to EPS and WSS connected to ESC. Especially, the ultrasonic sensor in SENSOR module was designed to enhance the recognition ratio and reduce noise at the corner of the vehicle.

3.1.1. Ultrasonic sensor design

Ultrasonic sensors for the passive parking assist system have been developed because the sensor was introduced to the market many years ago. The main function of the sensor is to warn about possible rear or front obstacle warnings. However, the ultrasonic sensor for PPAS focuses on classifying obstacles and parking spaces between vehicles. To achieve this purpose, our proposed ultrasonic sensor was designed to recognize the vehicle corner exactly. There are two types of methods that minimize the vehicle corner detection error. The first modifies the transducer of the

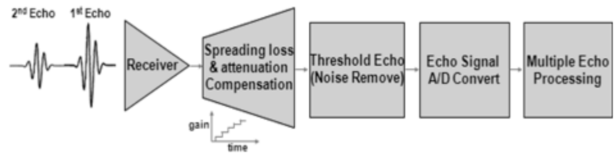


Figure 5. Proposed architecture of ultrasonic sensor.

ultrasonic sensor to minimize the beam width (Bank, 2002), and the second uses the multiple echo signal processing method (Park *et al*., 2008).

For the first method, the beam width can be adjusted based on the excitation frequency and the transducer's radius of the ultrasonic sensor (Kuc, 1990), as shown in equation (1). If the sensor is designed to raise the excitation frequency, the beam width can be narrower. However, this adjustment causes the sensor circuit to be more complex. The beam width of the vertical axis is also narrower; as a result, the ultrasonic sensor may not detect obstacles such as low guardrails, crash barriers and small stones. Moreover, adjusting the excitation frequency changes the sensitivity of the sensor transducer and reduces the obstacle detection accuracy. On the other hand, the horizontal and vertical beam widths can be adjusted separately by modifying the transducer's radius. It can generate a reliable and stable beam pattern, such as an oval (Bank, 2002).

$$\theta_0 = \sin^{-1}\frac{0.61\lambda}{a} \tag{1}$$

where θ_0 is the half beam width, a is the radius of the transducer and λ is the excitation wavelength of the ultrasound:

$$\begin{aligned} &R_{2nd} - R_{1st} > \text{Threshold : Corner} \\ &R_{2nd} - R_{1st} \leq \text{Threshold : Plane} \end{aligned} \tag{2}$$

where R_{1st} is the calculated distance by the 1st Echo TOF and R_{2nd} is the calculated distance by the 2nd Echo TOF.

The second method to reduce the vehicle corner error is to use the multiple echo signal processing method. In this paper, a new transducer for the PPAS was designed, and a novel sensor algorithm was implemented, as shown in Figure 5. The transducer frequency is 50 kHz, and it generates 16 pulses for transmission. The transmitted pulse

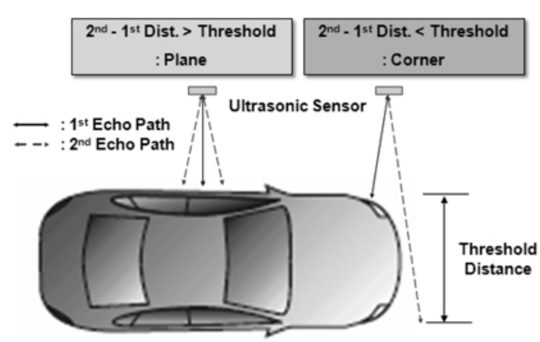


Figure 6. Multiple echoes for vehicle corner detection.

through the transducer is reflected from obstacles, and the pulse subsequently returns to the transducer as several echo signals. The received echo signals are modified to account for spreading loss and attenuation in air (Polaroid Corporation, 1984). In the next step, the received noise is removed by the threshold process, and multiple echo signal processing for the vehicle corner recognition is performed (Park *et al*., 2008). In the multiple echo signal processing, we applied a time enable function to the received echo signal because the complex structure of the vehicle body causes the echo signals to travel multiple paths. The stable and reliable performance of this multiple path problem was achieved when the threshold distance of the time enable function was 1 m. Figure 6 shows that the vehicle corner shape can be discriminated by multiple echo function. According to equation (2), we adopted the distance threshold as 1.2 m because the lateral width of the vehicle body is about between 1.2 m and 1.8 m in the situation of parallel parking. In this paper, we designed a new ultrasonic sensor with a frequency of 50 kHz, a radius of 1.5 cm, beam width of $\pm 16^{o}$ and the signal processing algorithm shown in Figure 5.

3.1.2. Wheel speed sensor (WSS) interface

The proposed PPAS ECU receives wheel pulse information from the vehicle in CAN communication with ESC. The hardware interface of ESC was designed to receive the analog pulse signal from the WSS. Moreover, the ESC counts the wheel pulse signal and calculates the speed of the vehicle. Then, it is transmitted to the PPAS ECU by CAN communication.

3.1.3. Steering angle sensor (SAS) interface

The proposed PPAS ECU can also receive steering angle information of the vehicle by CAN communicationwith EPS. The ECU transmits the steering command to control the EPS by CAN communication. Then, the ECU accurately performs the steering operation with high steering angle resolution because the EPS is connected to the SAS, which can recognize zero points with the absolute angle.

3.2. Electronic Control Unit (ECU) Module

In this section, the hardware and software design process of ECU module is described. The ECU module acquires data from each sensor, controls the steering angle through EPS and communicates with drivers via the HMI. Moreover, the hardware was designed with simple and cheap ICs, and the software was also implemented with a simple computational algorithm.

3.2.1. ECU hardware design

The hardware of the ECU module consists of network drivers (CAN and LIN), power FETs, a voltage regulator and a 16-bit MCU, as shown in Figure 7. The proposed ECU module has an inexpensive and simple circuit, only has a few I/O ICs and a 16-bit processor to communicate

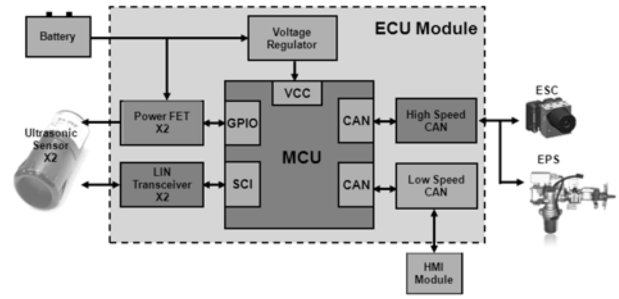


Figure 7. Block diagram of ECU hardware.

peripheral devices.

The power source of the PPAS is the vehicle battery. The voltage and current sources through the battery have a strong surge current, voltage and ripple noise. Therefore, the ECU was designed to account for load dump, reverse voltage and current protection, and a real time battery check using the MCU's ADC (Analog to Digital Conversion) port. Ultrasonic sensors also use the unstable battery source in the PPAS. Therefore, we designed an MCU that can control the sensor power with the FET enable or disable function. Even, MCU can block the battery power from entering the ultrasonic sensor.

For example, if the ultrasonic sensors receive 0-V or 12-V biased data via LIN, then either a ground short or battery short exists. At this time, the power source connected to the ultrasonic sensor is blocked by the MCU.

The communication between the ECU and the ultrasonic sensor operates via LIN. In this LIN connection, the MCU takes the role of master, and the ultrasonic sensors operate as slaves. The MCU was designed to transmit start, stop and measurement command IDs to the ultrasonic sensor. After the ultrasonic sensors receive MCU's command IDs, the sensors execute the command such that if the sensor power is on or off, the measurements start or stop. According to the operation status of the PPAS, the MCU can control the connected ultrasonic sensors to enhance the reliability of the range data.

The MCU was also designed to communicate with the HMI, EPS and ESC through the CAN driver. To communicate with the ESC and EPS, the ECU was designed with a high-speed CAN driver because ESC and EPS require a heavy communication load. On the other hand, the communication interface with the HMI module was designed with a low-speed CAN driver.

3.2.2. ECU firmware design

If the PPAS starts, the firmware layer was designed to initialize the ECU module. Then, it prepares to communicate with other devices and to operate EPS control. Moreover, it is important that the scheduling function of the firmware layer cause the PPAS to operate efficiently, accurately and reliably.

Figure 8 shows the firmware operation sequence for

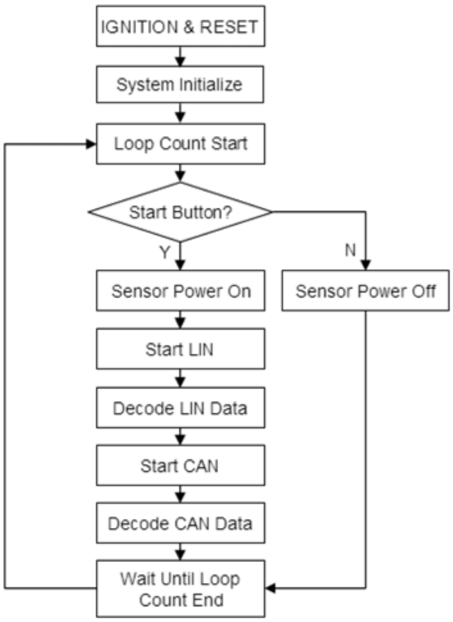


Figure 8. State diagram of the firmware.

system initialization and scheduling. As soon as the regulator supplies 5-V power to the MCU, the 8-MHz clock of the external crystal oscillator is stabilized by PLL in MCU. After this operation, the MCU performs system initialization, that is, it initializes overall control and data registers, such as GPIO (General Purpose Input Output), ADC (Analog Digital Converter), clock frequency, period scaling and communication controllers of CAN and LIN. For system scheduling, we used a timer counter in the MCU and set a specific count number for the loop time. When we set the loop time, it is very important that the loop time synchronizes with the common cycle time of external devices, such as sensors and actuators. In the PPAS, the system loop time was designed to synchronize with the common cycle time while considering the ultrasonic sensor's transmission-reception period, the acquisition time of the wheel pulse data and the EPS command period. Moreover, this synchronization loop time ensures the reliability of system functions, such as parking space measurement with the ultrasonic sensors and control operation with ESC and EPS. If the scheduling time period is designed to be shorter, its performance is better than a longer scheduling time period to ensure the reliability of the system. However, to achieve this performance, a higher speed MCU and computing power consumption are needed. Therefore, setting the optimized loop time is a very important process to reduce the cost of the PPAS. As shown in Figure 6, if the system enters the loop, the PPAS measures the parking space with LIN and operates the parking control with CAN.

3.2.3. Recognition and control algorithm design

After the firmware design was completed, the application algorithm for the PPAS was designed and ported in the MCU. In this section, we discuss the recognition algorithm for parking space detection and the control algorithm for the EPS angle control in detail. To design the application algorithm, we used the kinematic model (Li *et al*., 2003) shown in Figure 9. The parameters of the vehicle model are also defined in Figure 9. The parameter (x_f, y_f) is the center position of the vehicle front wheel, (x_r, y_r) is the center position of the vehicle rear wheel, ϕ is the direction angle of the steering wheels, θ is the angle between the vehicle frame direction and X axis, and l is the wheel base length of the vehicle. The kinematic equation (3) (Laumond *et al*., 1994) of the proposed vehicle model is as follows.

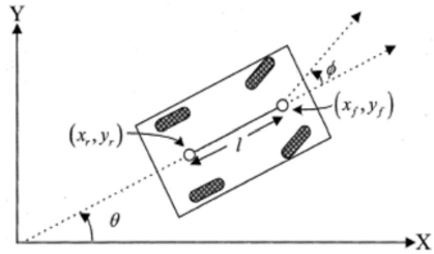


Figure 9. Kinematic model of PPAS.

$$\begin{aligned} \dot{x}_r &= v\cos\theta\cos\phi \\ \dot{y}_r &= v\sin\theta\cos\phi \\ \theta &= v\frac{\sin\phi}{l} \end{aligned} \tag{3}$$

The parameter v is the wheel speed. Equation (3) presents the backward movement of the vehicle. Based on this kinematic model, the parking recognition and parking control algorithm was proposed as shown in Figure 10.

For the recognition portion of the algorithm, the PPAS estimates the position of the vehicle itself from wheel pulse data and steering angle data because the system calculates the direction and trajectory of the vehicle over time. Then, the PPAS calculates the absolute coordinates from the installed position data of the ultrasonic sensor. That is, the localization process is performed. In the next stage, we implemented two classes of parking spaces using real-time adaptive distance threshold algorithm. One is an obstacle class, which means that a parked vehicle exists, and the other is a free-space class, which means that there is vacant space. With a real time adaptive distance threshold, the proposed system can classify range data into two-classes efficiently and recognize free space in real time. The corner points of the target parking lot can be detected by extracting the border between target vehicles and the target parking space based on a simple template. In this recognition process, the final result is the corner point coordinate; the value is transferred to the control algorithm.

In the control algorithm, the PPAS calculates the path profile from the present vehicle position and the acquired corner point coordinate. That is, path planning process is

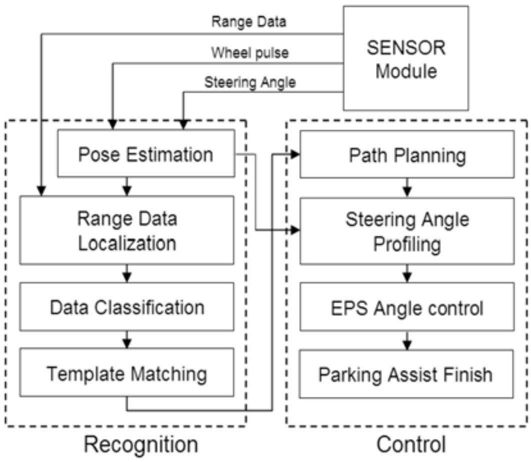


Figure 10. Recognition and control algorithm.

performed. In the next step, the PPAS calculates and generates steering angle profile data and performs EPS angle control with these profile data and the feedback position estimation data. When the vehicle enters the parking destination, the PPAS informs drivers that the parking assist process is finished through the HMI.

3.3. Human Machine Interface (HMI) Module

In this section, we introduce the configuration and operation of the proposed HMI module. As shown in Figure 11, the HMI module was designed based on a graphic user interface (GUI). To make this type of HMI module, we used a 32-bit CPU based on the PowerPC core, touch screen controller and TFT-LCD. Then, the real time operating system is ported in the PowerPC processor for the GUI driver.

Drivers can communicate with the PPAS through the touch panel. As shown in Figure 11, the GUI has a button region, instruction message region and progress bar region. In the button region, drivers start the parking and scanning process in the button region of GUI. In the instruction message region, the PPAS gives maneuvering instructions to the driver, such as “Go forward”, “Stop”, “Go backward” and “Reverse gear”. Lastly, the bar region contains an error margin bar and progressive bar. The error margin bar shows the parking guide error and the progress bar informs drivers of the status of the current parking operation.

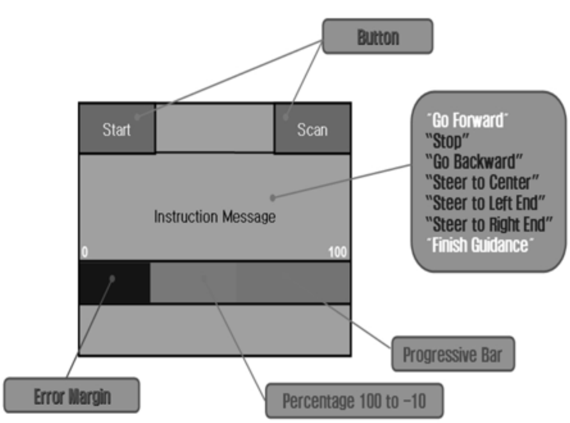


Figure 11. Graphic user interface of the HMI module.

4. EXPERIMENTAL RESULTS

A prototype of the PPAS based on the proposed architecture was constructed. As shown in Figure 12, the PPAS was installed in a test vehicle, a Grandeur TG, which is produced by the Hyundai Motor Company.

The parking experiment was performed on dry and flat ground at 25°C, as shown in Figure 13. Two vehicles for obstacles and one target vehicle with the proposed PPAS were used for the parallel parking experiment. In this experimental environment, we conducted two experiments: corner detection by the ultrasonic sensor and parking performance of the PPAS.

These experiments were performed for 30 consecutive runs. Then, each experiment is performed with a speed limit of 30 kph without a fixed vehicle speed. If the vehicle speed exceeds 30 kph, the ECU blocks the power of ultrasonic sensors and stops the PPAS operation because the PPAS can increase the danger of collision between the vehicle and target vehicles and increase the error rate of the corner detection and parking control. These experiments were also conducted within 4 m of the left and right sides of the target vehicles because the ultrasonic sensor’s detection range is between 30 cm and 4 m.

First, the corner detection experiment was performed with the proposed ultrasonic sensor. In this experiment, we

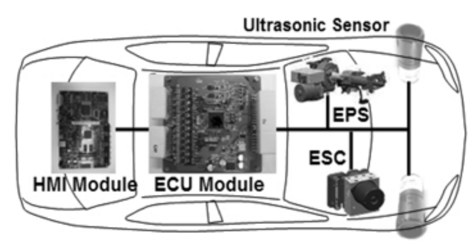
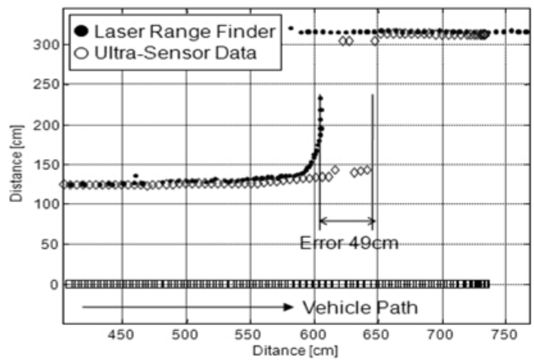
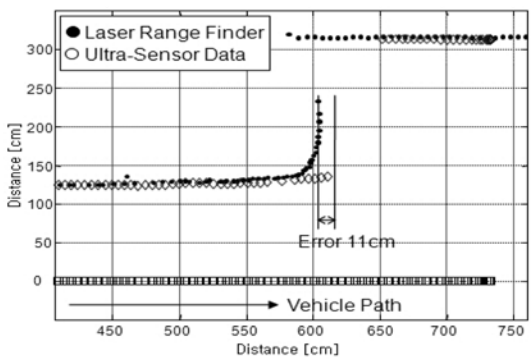


Figure 12. Vehicle installation of the proposed PPAS.

Figure 13. Vehicle test environment of the PPAS.

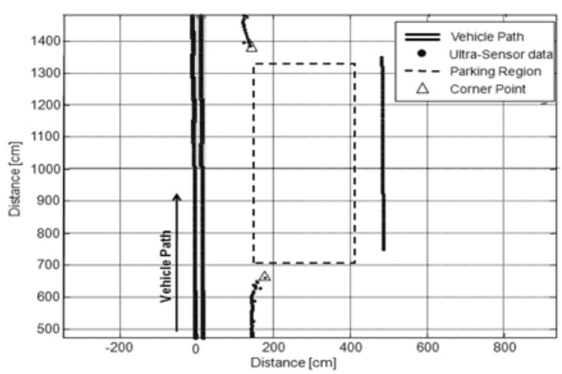


(a) Corner error by single echo

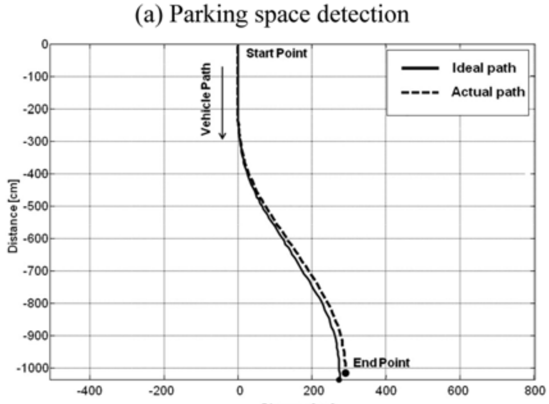


(b) Corner error by multiple echo

Figure 14. Detection performance of multiple echo.



(a) Parking space detection



(b) Parking control

Figure 15. Parking performance of the proposed PPAS.

Table 1. Parking accuracy of the proposed PPAS.

Contents	Recognition error (cm)	Control error (cm)
Average	10.8	13.5
Standard dev.	5.2	3.4
Maximum	20.5	19.8
Minimum	0.3	5.2

used a laser range finder (SICK's LMS200), which has a high resolution within 1 cm, as the reference data to measure the ultrasonic sensor error rate. In the next step, we measured the detection data of the ultrasonic sensor at the front and rear bumper corners of the target vehicles to compare the single echo method with the multiple echo method. Figure 14 shows that the corner error of the single echo method is 49 cm, and the error of the multiple echo method is 11 cm. The corner detection accuracy of the multiple echo method is 38 cm better than that generated by the single echo method. The standard deviation of the detection error of the multiple echo method is 5.2 cm, and maximum error is 20.5 cm, as shown in Table 1. The maximum error was mainly affected by the vehicle's scanning speed and the shape of the bumper corner. If the vehicle's scanning speed was higher and the vehicle's comer bumper was rounder, the error rate of the corner detection was higher. Generally, the front bumper's error rate was worse than that of the rear bumper because the front bumper was rounder than rear bumper.

Secondly, the parking space detection and control experiment of the proposed PPAS was conducted. Figure 15(a) shows that the proposed PPAS extracts the corner coordinates of the target vehicles from range data and successfully detects the parking space. Figure 15(b) shows that the PPAS successfully performs the EPS angle control according to the target profiling data, which means the profile data of the EPS control command matches the trajectories of the wheel pulse data. Further, Figure 15(b) shows that the trajectories of the target profile path follows the actual path of the EPS control. The average parking control error is 13.5 cm; the standard deviation is 3.4 cm; and the maximum error is 19.8 cm, as recorded in Table 1. In this experiment, as the parking speed of the target vehicle increased, the error rate of the parking control also increased.

Therefore, the total accuracy of the proposed PPAS prototype can be calculated as the sum of the recognition and control errors in Table 1. That is, the average error of the PPAS is 24.3 cm; the standard deviation is 8.6 cm; and the maximum error is 40.3 cm.

5. CONCLUSION

In this paper, a PPAS using ultrasonic sensors with a low-cost design and implementation has been presented. In particular, we focused on three aspects of system design and integration issues: functional architecture, hardware module design and software implementation. In the experimental results, our proposed PPAS successfully performed parking space detection and parking control. This performance and low cost design was attained by improving the corner error with the proposed ultrasonic sensor. Future work will include experiments that demonstrate the reliability, stability and robustness of the PPAS. The recognition and control errors must be improved in some parking environments.

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