Design and Prototype Implementation of A Novel Automatic Vehicle Parking System✝

Li-Der Chou Chun-Cheng Sheu and Home-Way Chen

Department of Computer Science and Information Engineering
National Central University
Jhorngli, Taoyuan, Taiwan, 32001 R.O.C.
Email: cld@csie.ncu.edu.tw

Abstract Unmanned vehicle driving systems are getting interesting for the auto mobile industry. One of the key issues in the unmanned vehicle driving system is how to acquire the current position of the vehicle. In general, it can be achieved by Global Positioning System (GPS). However, if the unmanned vehicle will be parked in the parking garage by itself, GPS can not provide sufficient information to avoid collisions and the accuracy of GPS is not enough for the narrow parking space. An automatic vehicle parking system is proposed in the paper, where wireless sensor networks and infrared technologies are adopted simultaneously to enhance the accuracy of positioning. The prototype of the proposed automatic vehicle parking system is also implemented.

Keywords: *automatic vehicle parking system, infrared, positioning, wireless sensor networks*

1. Introduction

Unmanned vehicle driving systems have been developed by famous auto mobile companies for years. Regardless of the issues of laws and regulations, there still have many technical issues, such as navigation, combination with Geographical Information System (GIS), and real-time monitoring of surrounding environment. One of the key technical issues is how to acquire the current position of the vehicle accurately.

There are many up-to-date positioning techniques, such as Global Positioning System (GPS) [1][2], wireless local area networks (WLAN) [3][4], wireless sensor networks (WSN) [5], bluetooth and infrared technologies [6][7], depending on the transmission distance, the accuracy of the measured position and the cost of deployment. In general, the positioning of the unmanned vehicle driving system can be achieved by GPS which is really one of the most popular positioning technologies today. However, GPS has several major drawbacks. Its receiver is not cheap enough, and the GPS signals cannot be received in the indoor environment and may be affected by harsh climate. Besides, the position reported by GPS receivers may have an error of 5 to 15 meters [2]. If the unmanned vehicle will be parked in the parking garage by itself, GPS can not provide sufficient information to avoid collisions and the accuracy of GPS is not enough for the narrow parking space. Moreover, it is not suitable to be adopted in an indoor parking garage.

Wireless sensor networks have risen sharply. The wireless sensor network has low-cost, low-power, smart size, multi-functional miniature sensor devices and wireless communication function. No matter in the indoor, outdoor or harsh climate environment, wireless sensor networks can work very well. Positioning and tracking for mobile devices by wireless sensor networks are one of important research topics and applications, but its accuracy depends on the density of the deployed sensors and their transmission power.

In the paper a novel automatic vehicle parking system is designed, where two different positioning technologies, wireless sensor networks and infrared, are adopted simultaneously to enhance the accuracy of positioning. The positioning and error correction procedures are calculated by vehicles, and are forwarded to the server by wireless sensor networks. The prototype of the proposed automatic vehicle parking system is also implemented, where the toy vehicle can go forward and backward, and turn right and left, according to the measured position. The success in the automatic vehicle parking demonstrates the feasibility of the proposed system. The rest of the paper is organized as follows. Related positioning technologies are described in Section 2. In Section 3, the architecture of the automatic vehicle parking system and its positioning algorithm are proposed. In Section 4, the prototype of the designed is demonstrated. Finally, conclusions are given in Section 5.

✝ This research was sponsored in part by National Science Council, R.O.C. under the grants NSC 95-2221-E-008-031 and NSC 95-2627-E-008-002, and Department of Industrial Technology, Ministry of Economic Affairs, R.O.C. under the grant 94-EC-17-A-02-S1-029.

2. Related Positioning Techniques

In this section, many kinds of positioning technologies will be described. The Angle-of-Arrival (AoA) [8] technique combines the angle at which signals are received and simple geometric relationships to estimate the position. The Time-of-Arrival (ToA) technique [9] estimates the position based on at least three devices with known positions, say landmark devices, where one-way time, and round-trip time between the landmark devices and the device whose position is to be determined are measured. The Time-Difference-of-Arrival (TDoA) technique [10] is like ToA, except two differences. First, the TDoA technique only needs two landmark devices and their timers are synchronized. Secondly, the differences of received time for the two signals between the landmark devices and the device with unknown position are calculated. The Received Signal Strength Indicator (RSSI) technique [11][12] has been used mainly for RF signals and measures the power of the signal at the receiver, based on the known transmission power and the effective propagation loss. Theoretical and empirical models are used to translate this loss into an estimated distance, according to the signal strength and geometrical triangulation methods.

Especially, three types of RSSI-based positioning algorithms in wireless sensor networks will be explained. The Ad-Hoc Positioning System (AhPS) [13] is conceptual hybrid from distance vector routing and beacon based positioning. The Multidimensional Scaling (MDS) [14] method only makes use of connectivity to provide position in network. In the Ad-Hoc Localization System (AhLOS) [15], the density of landmark devices has to be high enough, so that a node has enough neighbors to apply basic trilateration.

3. Design of the Automatic Vehicle Parking System

For the scenario in real life, the vehicle has to be driven to the gate of the parking garage. The driver draws a parking ticket, and then drives the vehicle to search an available parking space for parking. The automatic vehicle parking system has to be designed to be smart and easily managed. Vehicles can search parking space and park themselves in correct spaces automatically.

The architecture of the proposed automatic vehicle parking system consisting of three subsystems is illustrated in Figure 1. The major work of the parking management subsystem is to supply user interface, and to display system status and information. The control and positioning subsystem is embedded on the vehicle, and is able to control the behavior of the mobile vehicle and compute its current position according to the received signals. The WSN network and management subsystem is deployed in the parking garage. It is responsible for monitoring the status of the vehicle, and transmitting commands and data between the parking management subsystem and the control and positioning subsystem.

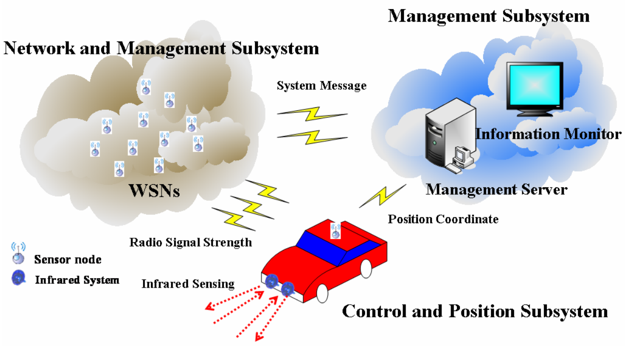

Fig. 1. Architecture of the automatic vehicle parking system

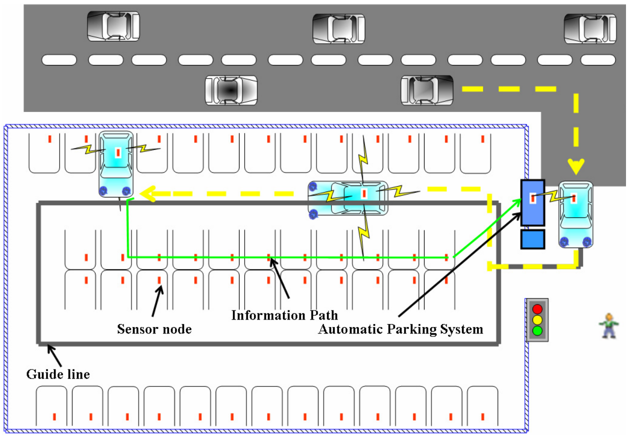

Fig. 2. Environment and operation procedure of the automatic vehicle parking system

Figure 2 shows the environment and operation procedure of the automatic vehicle parking system. Sensor nodes are equipped with the parking spaces for the purposes of positioning and communications. A guide line is painted on the road surface. The infrared detector embedded on the vehicle can detect the guide line and report to the control and positioning subsystem. The vehicle thus can avoid deviation from the guide line, due to the inaccuracy of the position estimated. In the automatic vehicle parking system, the driver just takes a parking ticket and leaves the vehicle on the gate. The parking management system will communicate with the control and positioning subsystem on vehicle, and command the vehicle to move to and park on an assigned available parking space. The WSN management system will keep monitoring the parking space for the reason of security. As long as the driver wants to take back the vehicle, he just pays the parking fees and the vehicle will automatically move to the exit gate.

The functional structure of the proposed automatic vehicle parking system is shown in Figure 3. Each subsystem has several modules and will be detailed as follows.

In the control and positioning subsystem, the positioning mechanism proposed in the paper adopts WSN and infrared/guideline technologies simultaneously. Figure 4 shows the concept of the positioning mechanism.

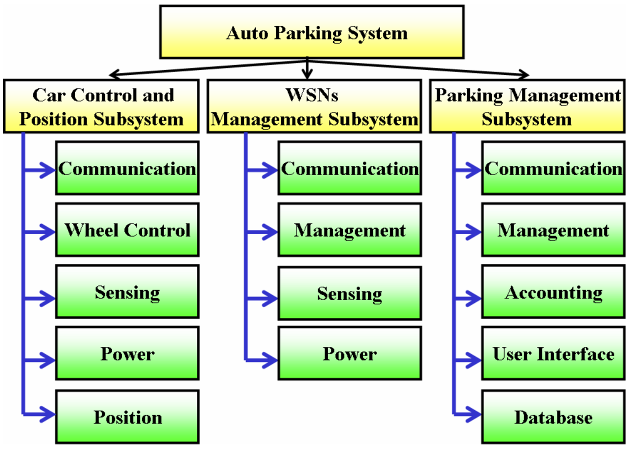

Fig. 3. Functional structure of the automatic vehicle parking system

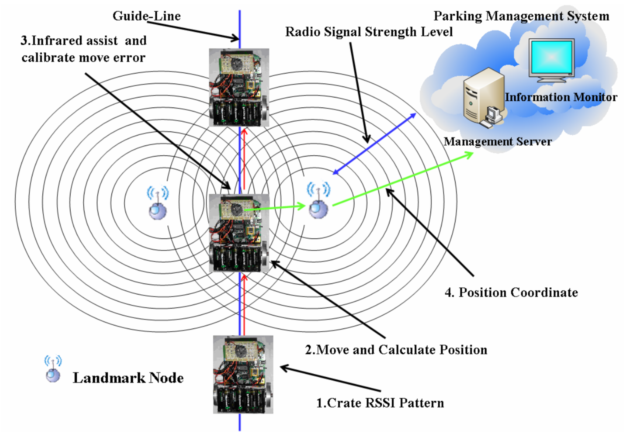

Fig. 4. Procedure of the proposed positioning mechanism

The positioning algorithm adopted in WSN is based on Ad-hoc Positioning System. The strength of the radio signals received from the landmark sensor nodes will be detected by this module, and then the position of the vehicle in the parking garage will be calculated according to the AhPS algorithm. Because the vehicle is movable, the estimated position may be inaccurate. In the paper, this inaccuracy is corrected by the infrared/guideline technology, so the vehicle can keep moving along the guide line. Thus the infrared/guideline technology plays the role of complement of WSN AhPS. The final corrected position information will be sent to the control module for further wheel control. Besides, the position information will be delivered to and stored in the parking management system. The control module decides how to control wheel speed and direction of the vehicle, according to the position estimated by the position module. The wheel control activities include progress, back, stop, turn right and turn left.

In the WSN management subsystem, all sensor nodes are responsible for relaying the position information from the control and positioning subsystem to the parking management subsystem. Moreover, the subsystem has to monitor the availability of the parking spaces, and to relay the system commands issued by the parking management

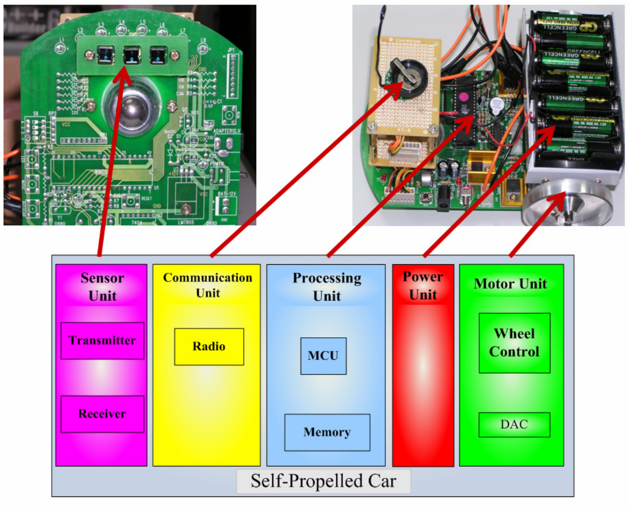

Fig. 5. Hardware of the control and positioning subsystem on the self-propelled car

subsystem to the control and positioning subsystem. The management module on the sink node not only has the same jobs on sensor nodes, but plays the role of gateway between WSN and Wi-Fi networks. The Wi-Fi network is adopted for data transmissions between the sink node and the parking management subsystem.

In the parking management subsystem built on a PC, the management module can receive and store the system information, such as position, and perform the commands received from the user interface module. The management module also has to monitor the status of all subsystems, such as the availability of sensor nodes and the position of the vehicle, and displays them on the user interface module. The system manager can remote control the vehicle through the user interface module. The user interface module also supplies identification for security issue. The database module stores the availability status of the parking spaces. The accounting module counts the required parking time.

4. Prototype Implementation

Figure 5 shows hardware of the control and positioning subsystem on the self-propelled car, where the photograph on the right-upper side is the self-propelled car, and the photograph on the left-upper side is the bottom view of the self-propelled car. Note that the sensor unit on the bottom of the car is an infrared module. We adopt the self-propelled car with a micro controller 8051 and a DC-motor system to emulate the vehicle. All modules of the control and positioning subsystem are integrated on the car, where a MICA2Dot sensor node is installed as the communication module. Figure 6 shows hardware of the WSN management subsystem. The sensor nodes adopted in WSN are MICA2 and MICA2Dot developed by Crossbow Tech. [16] and U.C Berkeley [17]. In the system, the sink node includes not only the MICA2Dot sensor node module, but also the STARGATE platform, as shown in Figure 7. They are connected by

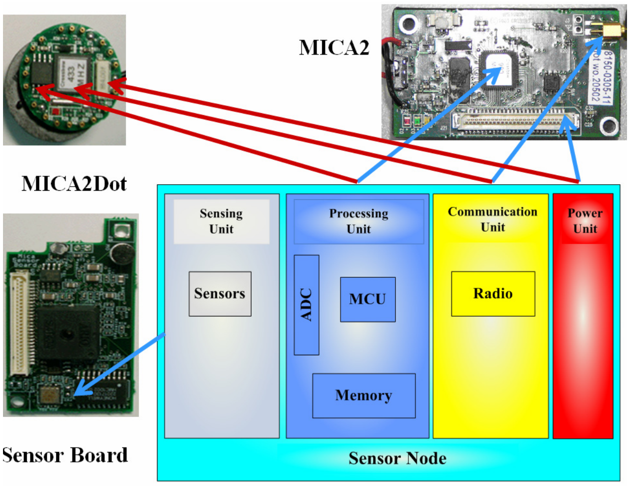

Fig. 6. Hardware of the WSN management subsystem

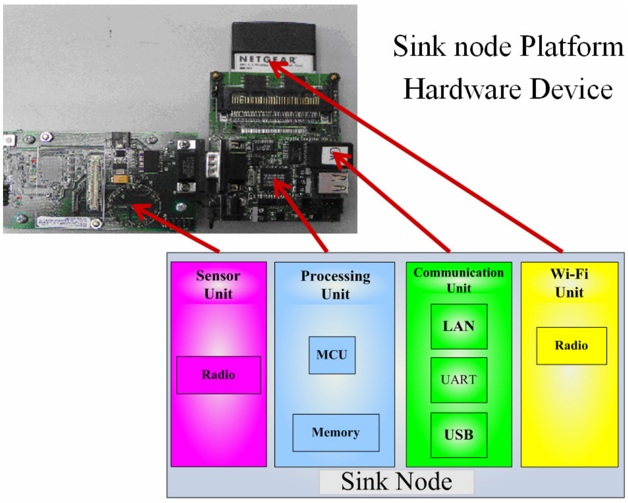

Fig. 7. Hardware of the sink node

UART transmission module. The communication module on STARGATE platform is based on Wi-Fi, and thus it is the gateway between WSN and Wi-Fi networks. The PC adopted as the platform of the parking management subsystem is an IBM R40 notebook running Windows XP.

Figure 8 shows the prototype of the system, including the planned parking garage, the self-propelled car, sensor nodes and the sink node. The area of the parking garage is 88 cm * 88 cm, and the white lines are guide lines. There are nine wireless sensor nodes deployed in this area, where each parking space is equipped with one sensor node. Figure 9 shows the layout of the implemented system, where the red line indicates the guideline. The user interface of the parking management subsystem is shown in Figure 10.

The experiment on the accuracy of the positioning mechanism for the implemented prototype is performed. Figure 11 shows the probability of correction of the positioning mechanism versus the error distance, where the error distance is the tolerant distance between the actual position of the self-propelled car and the estimated position in unit of centimeters. The probability of

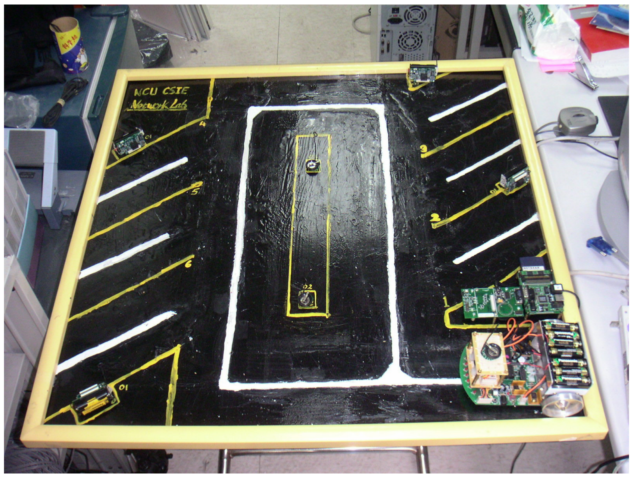

Fig. 8. Prototype of the system including parking garage vehicle, sensor nodes and the sink

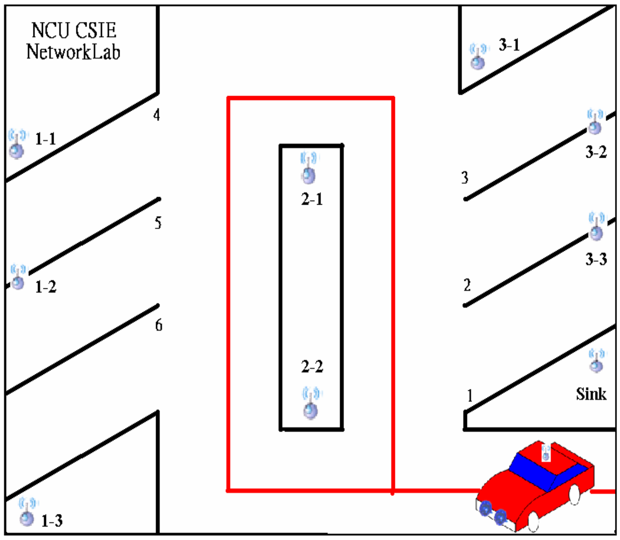

Fig. 9. Corresponding layout of the implemented prototype system shown in Figure 8

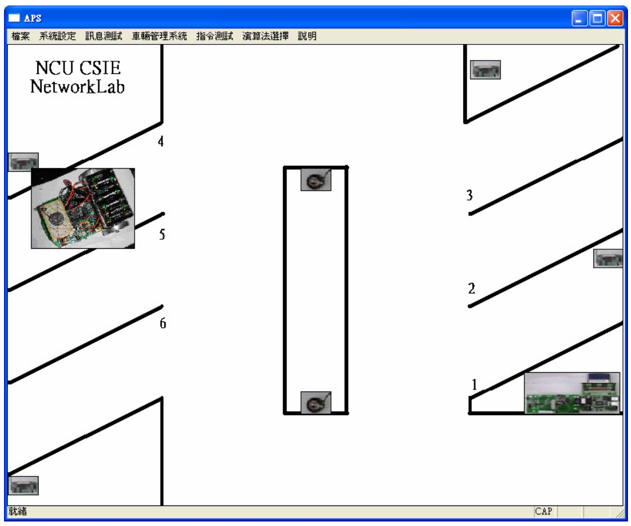

Fig. 10. User interface shown in the parking management subsystem

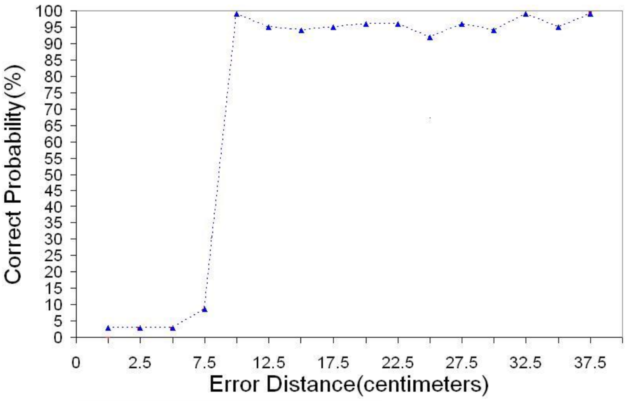

Fig. 11. Probability of correction for the positioning mechanism

correction is over 90% as the error distance is 10 cm.

5. Conclusions

For an unmanned vehicle driving system, the position of the vehicle can be obtained by GPS. However, the GPS signal can not be received in the indoor environment, and the estimated position is not accurate enough for parking by the vehicle itself. In the paper, we adopt the WSN AhPS and the infrared technologies at the same time to enhance the accuracy of the estimated position. The automatic vehicle parking system is proposed and designed, according to the proposed positioning mechanism. The system consists of three subsystems: control and positioning subsystem, WSN management subsystem, and parking management subsystem. The prototype of the automatic vehicle parking system is also implemented. Experiments demonstrate the feasibility of the designed system.

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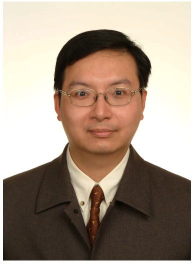
Authors



Li-Der Chou

Received a B.S. in electronic engineering from National Taiwan Ocean University, Taiwan, R.O.C. in 1998, a M.S. and a Ph.D. in electronic engineering from National Taiwan University of Science and Technology, Taiwan, R.O.C. in 1991 and in 1995, respectively. From 1995 to 1997, He was an associate professor with Jin-Wen College of Business and Technology, Chung-Hua Polytechnic Institute, and Central Police University. From 1997 to 1999, he acted as the director of the Multimedia Communications and Services Division, Computer Center, National Central University, Taiwan, R.O.C. From 1997 to 2005, he was an associate professor with the Department of Computer Science and Information Engineering, National Central University, Taiwan, R.O.C. Currently he is a professor with the same department. His current research interests include network management, broadband wireless networks, sensor networks, and Internet applications and services.

Chun-Cheng Sheu

Received a M.S. in computer science and information engineering from National Central University, Taiwan, R.O.C. in 2005.

Home-Way Chen

Received a M.S. in computer science and information engineering from National Central University, Taiwan, R.O.C. in 2005.