An Intelligent Car Park Management System based on Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) have attracted increasing attentions from both academic and industrial communities. It can be deployed in various kinds of environments to monitor and collect information. In this paper, we describe a WSN-based intelligent car parking system. In the system, low-cost wireless sensors are deployed into a car park field, with each parking lot equipped with one sensor node, which detects and monitors the occupation of the parking lot. The status of the parking field detected by sensor nodes is reported periodically to a database via the deployed wireless sensor network and its gateway. The database can be accessed by the upper layer management system to perform various management functions, such as finding vacant parking lots, auto-toll, security management, and statistic report. We have implemented a prototype of the system using crossbow motes. The system evaluation demonstrates the effectiveness of our design and implementation of the car parking system.

Keywords: Pervasive Computing, Wireless Sensor Network, intelligent car parking system.

1. Introduction

In recent years, wireless sensor networks have attracted a great amount of attention [1]. A wireless sensor network consists of a large number of low-cost sensor nodes which can be self-organized to establish an ad hoc network via the wireless communication module equipped on the nodes. Each sensor node is also equipped with various kinds of sensors, computation units, and storage devices. These functional parts enable sensor nodes to be easily and rapidly deployed to cooperatively collect, process, and transmit information. WSNs have a great potential to be used in future pervasive computing systems as they can be embedded into our daily living environment and provide sensory data for localization and surveillance.

Taking the advantages of sensing and wireless communication, wireless sensor networks have already found many civil and military applications, such as smart home[2], intelligent buildings[3], health-care[4], wild environmental monitoring[5], battle surveillance[1], etc. In this paper, we describe the design and implementation of an intelligent car park management system based on low-cost wireless sensor networks. With the approaching of the automobile epoch, the demand on intelligent parking service is expected to grow rapidly in the near future. This emerging service will provide automatic management and high security measures, as well as convenience to the customers.

A few existing studies focused on the applications of car parking system using sensor technologies [6][7]. The system in [6][7] adopts cameras to collect the information in car parking field. However, video sensors have two disadvantages; one is that a video sensor is energetically expensive, and the other is that a video sensor can generate a very large amount of data which can be very difficult to transmit in a wireless network. These greatly limit the application of video sensors.

In our WSN-based car part management system, the nodes are equipped with light, sound and acoustic sensors. Wireless sensor nodes are deployed to the parking lots to monitor and detect the occupation status of the parking lots, and to cooperatively process and transmit the information to a management system. By using the management system, the managers and administrators will be able to get the information about the parking field, including statistics and real-time information. In addition, the management system can alert the illegal mobility of the car parking in the field. The system can also record the duration of a car parking and perform auto payment of parking fee. We have built a prototype of the system using the crossbow motes products and the extended Crossbow XMesh networks architecture [8].

The remaining part of this paper is organized as follows. Section 2 briefly describes the related works.

Section 3 presents the analysis on the requirements of an intelligent car parking management system. Section 4 overviews the design of our system. Section 5 describes the implementation of a prototype system. Section 6 reports the system testing results. Finally, Section 7 concludes the paper with a discussion of our future works.

2. Related Work

In this section, we will review some studies on the application systems of automobile management based on wireless sensor networks. Developing applications for the management of automobiles have some specific difficulties, such as high speed mobility detection and prediction, mobile object identification and tracking, etc.

Irisnet [6][7] proposed a wide-area architecture for pervasive sensing networks which enables users on their ways to retrieve the information about available car parking space via distributed accessing methods. In this system, the video cameras (Webcams), microphones, and motion detectors are employed to detect and recognize the automobiles. The sensory data, for example parking field images captured by Webcams, will be processed in a networking environment. The processed data will be published on the web. Then, the user can acquire the interesting information by using the web access technologies. However, as we have mentioned in the first section, the video cameras will generate a large amount of data. The transmission and process of these data will consume a great deal of resources, including communication bandwidth, processing cycles, and energy, which are very limited in a wireless sensor network.

Traffic Plus Technology [9] and MIT Intelligent Transportation System [10][11] are also transportation applications based on wireless sensor networks. They deploy the automobile sensors on both sides of a road and into a road bed to detect the relevant information about automobiles. Although both systems can be effective for traffic and road condition monitoring, they are not designed for car parking management. In addition, the hardware used in the systems are quite expensive and complicated.

An important problem in designing a car parking and transportation system is how to accurately detect the mobility of automobiles, especially when the vehicles move in a high speed. There are some studies using magnetic sensors [12]. However, these sensors can be energy intensive [13]. The widespread deployment of these sensors is still a challenging problem in the wireless sensor networks with the constraint on energy.

3. Requirement Analysis

In this section, we discuss the requirements of designing a WSN-based intelligent car park management system. Although the conventional requirements of a car park management system can be easily satisfied, we still need to address more challenging issues by taking advantages of wireless sensor networks. In the following, we list some important requirements of a car parking management system and then analyze the feasibility from the viewpoint of wireless sensor networks.

The common goal for all car parks is to attract more drivers to use their facilities from the business aspect. Thus, their basic facilities are required to fulfill the following conventional requirements:

(a) The location of the car park should be easy to find in the street network.
(b) The entrance of the car park should be easy to discover.
(c) The number of parking lots should be abundance and a parking lot should obtain a large space enough to park a car in.
(d) Easy to exit and to re-enter on foot.

However, an intelligent car parking system should provide more convenience and automation to both the business and customers. It should also satisfy the following requirements:

(a) The system should provide plenty of informative instructions or guidelines to help drivers to find a available parking lot
(b) The system should provide effective security measures to prevent the cars from being broken, stolen, etc.
(c) The system should provide suitable auto toll methods to drivers.
(d) The system should provide powerful functions to facilitate administrators and managers to manage a car park.

In accordance with the above requirements, an automatic and smart car park management system should minimize human operations and supervisions, so as to reduce the cost of manpower and the lost from human mistake and to enhance the security and efficiency. Also, the car park system is required to provide higher accuracy, security, robustness, and flexibility in operations, more convenience to customers, lower cost of operating and maintaining overall system.

4. An Overview of Our System

In this section, we describe the design of our intelligent car park management system. First, we will introduce the hardware components employed in our wireless sensor network. Second, we will discuss the infrastructure of the application system based on the wireless sensor network. Finally, we will describe architecture of the intelligent car park management system.

4.1. Hardware Components

The wireless sensor nodes and gateway used as the underlying hardware platform are from Crossbow Technology Inc., which is one of the suppliers of wireless sensor networks. Crossbow serials of wireless sensor networks are based on Berkeley Motes. The products used in our system are listed as below.

(a) ***Motes.*** The devices consisting of a processor and a radio chip are commonly referred as Motes Processor Radio boards (MPR). Each of these battery-powered devices are pre-loaded the open-source TinyOS [14] operating system which provides low-level event and task management services and the Crossbow's XMesh networking stack. In our system, the mote of MPR2400 (Figure 1(a)) is selected. The motes operate compatibly with IEEE802.15.4 and can be extended to connect for different sensor boards and used to wireless communicate with other nodes as router capability.

(a) MPR2400 (b) MTS310 (c) MIB510

Figure 1. Crossbow Mote products[7]

(b) ***Sensors borads.*** Sensor and data acquisition boards (MTS and MDA) mate directly to the Mote Processor Radio board (MPR). The sensor board, MTS310 (Figure 1(b)), is equipped with the sensors of light, temperature, and acoustic and a sounder.

(c) ***Gateways.*** The Mote Interface Board (MIB), MIB510 (Figure 1(c)), provides a gateway for the motes and allows the acquisition of sensory data on a PC as well as other standard computer platforms via a RS232 serial interface. Beside data transferring, the MIB broad allows the Motes to accept control command from the upper layer application systems.

4.2. Architecture of application systems based on WSNs

An application system based on wireless sensor networks typically adopts a 3-layer of framework for deployment, as shown in Figure 2. The first layer is the Mote layer which is a wireless sensor mesh network. The motes are programmed as TinyOS firmware to perform some tasks, for example environment monitoring. The second layer is Server layer which provides data logging and database services for sensory data transferred to the base station and stored on the server. Finally, the software at Client layer provides visualizing, monitoring, and analyzing tools to display and interpret sensory data. MOTE-VIEW,is a free software tool developed by Crossbow and can be used to perform the above manipulations of sensory data.

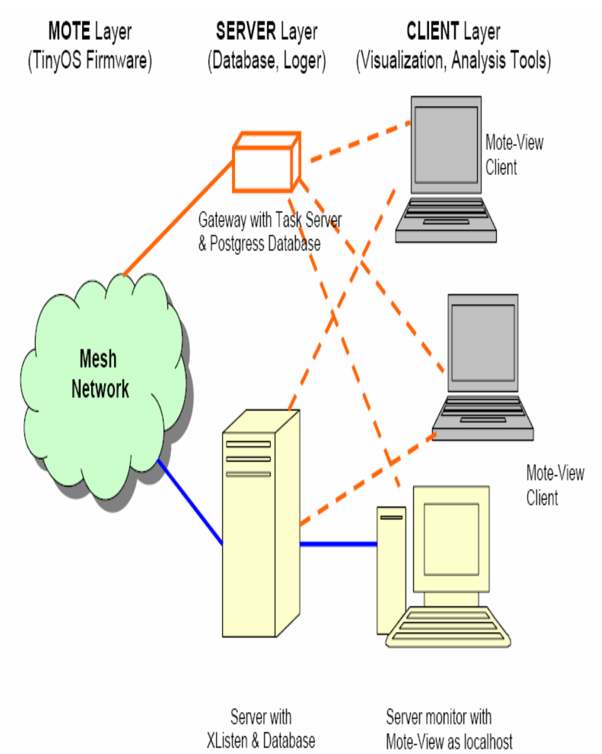

Figure 2. 3-layer framework of WSN-based system

4.3. Intelligent car park management system

The architecture of our system, as shown in Figure 3, illustrates the relationship between the sensor network, MOTE-VIEW, PosgreSQL database[15], TinyOS, CarRecord database, and the car park application. The sensor nodes can be deployed to a car parking field and collect the real-time occupation information and vehicle information. The collected information can be transmitted to a gateway via wireless communication among the sensor nodes. The gateway is connected to a database server via Internet. The collected information will be acquired and installed into a database by a database server. The car park management application operates on top of the database. This architecture can effectively decouple the upper layer application from the underlying wireless sensor networks. The variation of the underlying wireless sensor networks will not lead to the change of the upper layer application system.

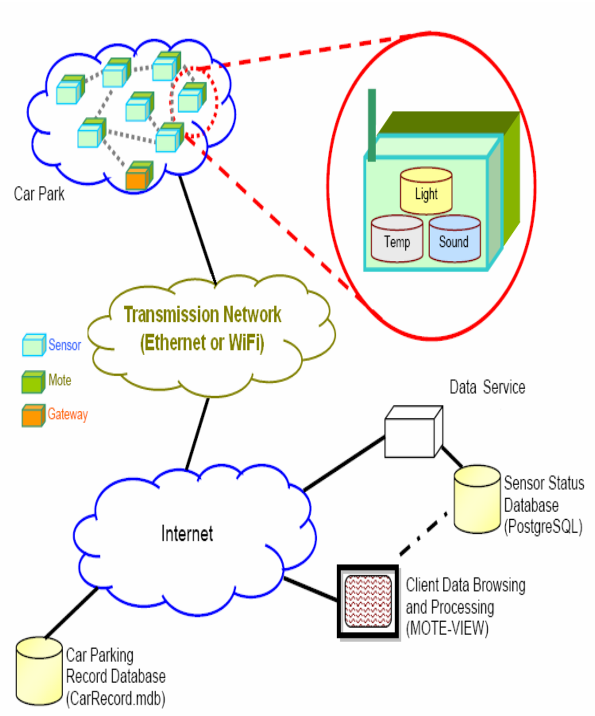

Figure 3. the architecture of our system

5. System Implementation

In this section, we will first give a brief introduction of the main functional parts of the intelligent car parking management system, and then describe the event-driven processing and interactions of these modules.

5.1. Funcational components of the system

The software system of our application can be divided into three parts, including the bottom part of motes and the network, the middle part of the database system, and the top part of application system. The interaction between the bottom part and top part is via the middle part of the database system, so the application layer can be decoupled from the underlying wireless sensor networks and need not to concern the low-level details of wireless sensor nodes. Thus, the application layer can focus on the business logic of the car park administration and the processing of the collected information stored in the database system. The three parts of our software system will be described as follows.

The bottom part of the software system supports the operations of Mote and the wireless sensor networks composed of motes. A Mote is loaded with TinyOS which is a light-weight operating system specified for wireless sensor nodes. The network protocol adopted by the mote in our system is XMesh which is developed specifically for Mote networks.

The middle part is implemented using the Postgres [15] database system. The data stored in the database is updated by the underlying wireless sensor networks. The sensory report generated by the mote will be transmitted to the database system and used by the upper layer applications.

The top part, the application system, is divided into four main modules: 1) Parking lot management module which monitors and detects the occupation of parking lots, 2) Auto toll module which manage the payment of parking fee, 3) Security management module which alerts the illegal leaving of cars previously parked in a parking lot, and 4) statistic and reporting module which generates various reports to help managers or administrators to understand the running status of the car parking field.

The software structure of the implemented system is shown in the below figure.

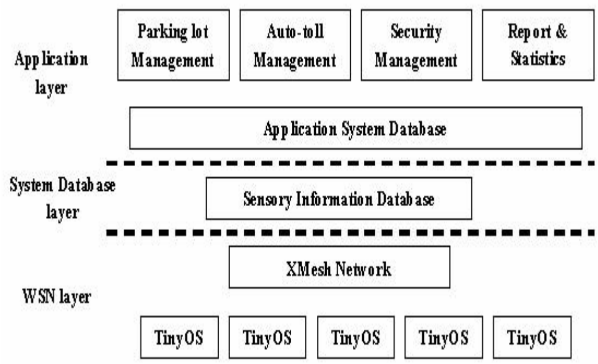

Figure 4. the software structure of our system

5.2. Event-driven processing in the system

The prototype system is implemented using the object-oriented programming approach and is event-driven for processing. In the system operations, there are 5 major types of events, namely *timer*, *car-in*, *driving status*, *car-out*, and *field management*.

(a) ***Timer event.*** The system timer will generate this kind of events which can be used to refresh the sensor status stored in the PostgreSQL database.

(b) ***Car-In Events.*** This kind of event indicates that a can that has just checked in to the system.

(c) ***Driving status.*** This kind of event indicates the moving path of the car and its parking status sensed by wireless sensor.

(d) ***Car-Out Events.*** This kind of events indicates that a car has just checked out from the system.

(e) ***Field Management Events***. This kind of events described that a manager performs the management task of the car parking field.

These events trigger the interactions between and the operations to be performed by the various function modules described above. For example, Figure 5 shows the operations triggered by the car-in and car-out events.

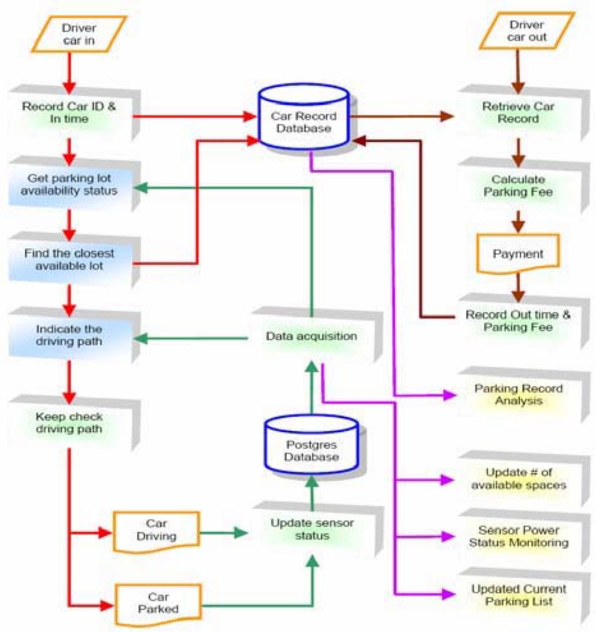

Figure 5. the flowchart for car in and car out

6. System Evaluation

The intelligent car parking system is built for real applications required to be of good quality and consistency. We have carried out some testing experiments using the prototype system. Figure 6 shows the application interface with various functions specified in the requirements. We used remote-controlled toy cars to evaluate the functions of our system, as shown in (Figure 7). The testing cases used to evaluate the functionalities of the system and the testing results are listed in the table shown in Figure 8.

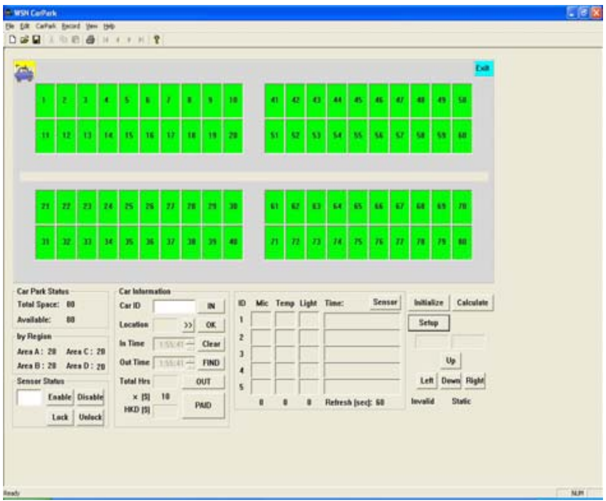

Figure 6. user interface of our prototype system

Figure 7. the testing scenario of our prototype system

Test Scenario Item	Result
MOTE-VIEW get sensor signals via Mote Interface Gateway board	PASSED
PostgreSQL database update records according to sensor status change	PASSED
Number of available parking lot is real time update?	PASSED
Create New Car Record in CarRecord.mdb when incoming car check in?	PASSED
The Car Record noted down the correct information?	PASSED
Allow driver to have 2 options on parking location?	PASSED
After confirm parking, path guideline provided for driver?	PASSED
Can the system trace the moving car drive along the path?	PASSED
Did the system can trace the car if parked in the unregistered parking lot?	PASSED
Did the car record update the parking location according to the actual parking?	PASSED
Did Light sensor signal can reflect the region parking status? - No car Parked ⇒ No cover on sensor => sensor with light - Car Parked ⇒ Cover on sensor => sensor without light	PASSED
Did sound signal got from mic is reflecting car rumbled over the ground? - Car nearby the sensor ⇒ Noisy around the sensor ⇒ sensor with noise - No car nearby ⇒ Silent on sensor ⇒ sensor without sound	PASSED
Retrieve correct car record if search function enable?	PASSED
Record correct check out time and calculate suitable charge if car out?	PASSED
Did Region status will update if the car willing / ready to leave the car park?	PASSED
Administrative application protected by login security?	PASSED
Any warning if invalid login?	PASSED
Did the Analysis tool / chart provide accurate information?	PASSED
Can the system provide function to print the updated current parking list for security purpose?	PASSED

Figure 8. The testing cases of our prototype system

7. Conclusions

In this paper, we described an intelligent car park management system based on a wireless sensor network. We analyzed the requirements of real car park management systems. Based on the analysis, we proposed the main system functions and designed the system architecture. We also implemented a prototype system to realize the designed functions using the crossbow products of motes. Our evaluation demonstrated that the prototype system can effectively satisfy the requirements of a WSN-based intelligent car park management system.

We believe that wireless sensor networks can be a very promising technology to be used in future intelligent car parking systems. We will enhance our existing work in the following aspects.

First, we will deploy our wireless sensor networks into a real car park to test its performance and perform further analysis on the optimization of the algorithm and strategy.

Second, we will establish an information disseminating platform for this system to publish the interesting and helpful information to the users of the car parking system.

Third, we will combine the car park management system with our on-going projects of mobile agent-based mobile computing platform and intelligent transportation system to provide the users more effective and efficient transportation services based on pervasive computing technologies.

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References

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci. *A survey on sensor networks*. In IEEE Communication Magazine, 40(8): 102-114, 2002.
[2] http://www.intel.com/pressroom/archive/releases /20040316corp.htm
[3] J. P. Lynch, K. Loh. *A Summary Review of Wireless Sensors and Sensor Networks for Structural Health Monitoring.* Shock and Vibration Digest, Sage Publications, 38(2):91-128, 2005.
[4] http://www.soumu.go.jp
[5] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk, J. Anderson. *Wireless sensor networks for habitat monitoring.* In ACM international workshop on Wireless sensor networks and applications, September 2002
[6] http://www.intel.com/technology/techresearch/research/ rs11031.htm
[7] http://www.xbow.com
[8] P.B.Gibbons, B.Karp, Y.Ke, S.Nath, S.Seshan. IrisNet: an architecture for a worldwide sensor Web. IEEE Pervasive Computing, 2(4):22 - 33, 2003.
[9] http://corporate.traffic.com/ntdc/
[10] http://mtlweb.mit.edu/researchgroups/itrc/
[11] http://www.media.mit.edu/resenv/vehicles.html
[12] S.-Y. Cheung, S. Coleri Ergen and P. Varaiya. *Traffic surveillance with wireless magnetic sensors.* In 12th ITS World Congress, Nov. 2005.
[13] G. Anastasi, M. Conti, E. Gregori, A Falchi, A. Passarella. *Performance Measurements of Mote Sensor Networks.* In ACM/IEEE International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile System (MSWiM), October, 2004.
[14] http://www.tinyos.net
[15] http://www.postgresql.org/