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A Car Parking Monitoring System Using Wireless Sensor Networks

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***Abstract*—**This paper presents a car parking monitoring system using wireless sensor networks. Multiple sensor nodes and a sink node, a gateway, and a server constitute a wireless network for monitoring a parking lot. Each of the sensor nodes is equipped with a 3-axis AMR sensor and deployed in the center of a parking space. Each sensor node reads its sensor values periodically and transmits the data to the sink node if the current and immediate past sensor values show a difference exceeding a threshold value. The sensor nodes and sink node use the 448 MHz band for wireless communication. Since RF transmission only occurs when sensor values show abrupt changes, the number of RF transmission operations is reduced and battery power can be conserved. The data from the sensor nodes reach the server via the sink node and gateway. The server determines which parking spaces are taken by cars based upon the received sensor data and reference values. The reference values are average sensor values measured by each sensor node when the corresponding parking spot is not occupied by a vehicle. Because the decision making is done by the server, the computational burden of the sensor node is relieved, which helps reduce the duty cycle of the sensor node.

***Keywords*—**Car parking monitoring, magnetometer, sensor node, wireless sensor network.

I. Introduction

WIRELESS sensor networks have recently attracted a great amount of attention and found wide application areas. As sensor nodes are designed to operate on extremely low power, they usually run on battery power, which makes wireless sensor networks especially useful in monitoring applications where AC electricity is not available.

The increasing number of automobiles has resulted in severe parking problems in many cities. It has become increasingly difficult for drivers to find parking spaces available in downtown areas. Big buildings usually have large parking lots. As the size of a parking lot increases, it has become not easy to find available parking spaces even in a single parking lot. Consequently, the demand for intelligent parking services that can provide status information on parking spaces for drivers grows rapidly. Wireless sensor networks are considered to have a great potential in this area and several application solutions have been proposed.

Several different sensors were adopted to obtain information on vehicles. Although image sensors are able to provide the most information for recognizing cars but they are prone to failures when there is not enough ambient light. Moreover, image data require lots of computations, which imposes heavy burden on sensor nodes. Ultrasonic sensors are commonly used in distance measuring applications. Chen and Chang used ultrasonic sensors for detecting the status of parking spaces and proposed a non-standard network protocol [1]. Lee et al. and Tang et al. proposed hybrid approaches using a combination of ultrasonic and magnetic sensors and light and acoustic sensors in [2] and [3], respectively. Active sensors such as ultrasonic sensors, however, consume far more energy than passive ones, which causes rapid battery drain. Since vehicles are usually made of metals, they disturb the magnetic field of surrounding areas, and therefore magnetic sensors are a good candidate for detecting vehicles. Zhang et al. presented a vehicle detection algorithm using a 3-axis AMR sensor and an adaptive sampling mechanism to reduce energy consumption [4]. Benson et al. and Barton et al. proposed wireless sensor networks using magnetic sensors and hardware platforms that run tinyOS [5], [6]. Yoo et al. proposed a wireless sensor network based parking guidance system where magnetic sensors were used to detect the movement of vehicles [7].

In the previous works, each of the sensor nodes determines the occupancy status of a parking space without regard to the types of sensors involved. To this end, the sensor nodes should read sensor data at a relatively high sampling rate to tell whether a car is entering or leaving a parking space. A higher sampling rate inevitably yields more power consumption by the sensor. This paper adopts a different approach in which a sensor node reads sensor data periodically and reports the data only if the measured sensor data differ from the immediate past one more than a predefined threshold value. In other words, the sensor node does not determine whether or not a parking space is occupied, and therefore does not have to execute a complicated decision-making algorithm.

The paper proposes a car parking monitoring system based on wireless sensor networks. Each parking space has a sensor node equipped with a 3-axis AMR sensor installed in its center. The sensor node is powered by batteries. The sensor node in a parking space measures the values of the AMR sensor periodically (e.g., 3 seconds) and wirelessly transmits the sensor values only when they show abrupt variations. A server receives the data from all sensor nodes via a sink node and a gateway and determines whether each parking space is occupied based on the received sensor values and reference values maintained by the server. This approach results in a low

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duty cycle of sensor nodes by decreasing computations performed by the sensor nodes and in turn longer battery life of the sensor nodes

II. System Architecture

The car parking monitoring system is composed of a server, a gateway, a sink node, and multiple sensor nodes, as shown in Fig. 1. Each of the sensor nodes is equipped with a 3-axis AMR sensor and installed in the center of a parking space to detect the availability of the parking space. The sink node forms a star-shaped wireless network along with the sensor nodes and collects information from the sensor nodes. The sink node is connected to the gateway and the information collected by the sink node is relayed to the server via the gateway. The server determines which parking space is available based on the received information and provides the availability information for drivers (e.g., using an LED display board).

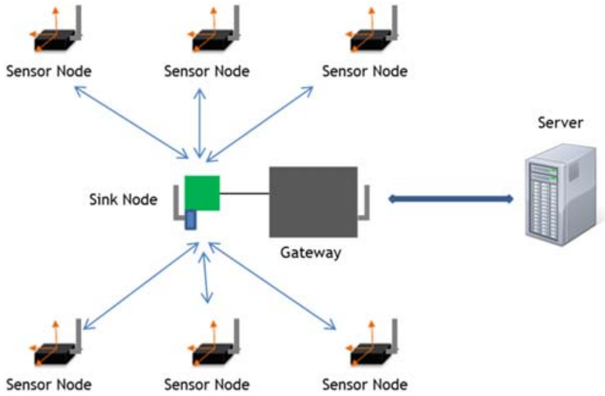

Fig. 1 Configuration of the car parking monitoring system

Each parking space has a sensor node equipped with an AMR sensor deployed in the center. Fig. 2 and Table I show a picture of the sensor node with casing and the hardware specifications of the sensor node, respectively. Motor vehicles create disturbances on the magnetic field of the earth, which affects the output of the AMR sensor. The sensor outputs show significant differences when the parking spot is occupied and not. The presence of a motor vehicle in a parking spot, therefore, can be detected based upon changes in the output of the AMR sensor mounted on the sensor node deployed in the parking spot.

Fig. 2 The sensor node in enclosure (lid not shown)

TABLE I
Specifications of the Sensor Node

MCU	ATMega128A
Sensor	HMC5883L
RF transceiver	CC1120
Frequency	447.9875 MHz
Data rate	4 kbps
Antenna	Coil antenna (0 dBi)
Battery	3.6 V Li-ion battery

The sensor node remains in a sleep mode during most of the operation time to conserve battery power and wakes up at a predetermined time interval to read the AMR sensor data. Since the status of a parking spot does not change very frequently, the wake-up interval of the sensor node may be set to a few seconds. When initially installed, the sensor node measures the sensor outputs along the 3 axes, x, y, and z while there is no vehicle in the parking spot and stores the average values of the sensor outputs in its internal nonvolatile memory like EEPROM. After the sink node joins the sensor network, it transmits the average values to the sink node. As a result, the server has the average sensor values of each of the sensor nodes existing in the network and uses the values when determining the availability of parking spots.

After wakeup from the sleep mode, the sensor node reads the x, y, z values of the AMR sensor and compares the measured x, y, z values with the immediate past values. If the sum of the absolute values of the differences along the 3 axes exceeds a predefined threshold level, the sensor node transmits the current sensor data to the sink node. Large changes in the magnetic field in a parking space are observed only while a vehicle is entering or leaving the parking space, which usually takes less than a minute. If the occupancy status of the parking spot remains unchanged, the sensor node does not observe meaningful changes in the sensor data and as a result does not transmit any data. In other words, RF transmission, which consumes the most power in the sensor node, occurs only when noticeable changes in the sensor outputs are detected, and therefore battery life can be extended.

Multiple sensor nodes are wirelessly connected to the sink node, forming a star-shaped network. The basic role of the sink node is to relay the data from the sensor nodes to the gateway and to relay commands issued by the server to the sensor nodes. Because sensor nodes may send data at any time, the sink node maintains its radio in the receive mode until a data packet is detected. Once a packet is received, the sink node acknowledges the data receipt to the sending node and sends the received data to the gateway. The sink node has similar hardware specifications with the sensor node except that it does not have a sensor on it. The sink node is connected to the gateway through UART interface.

The server is the destination of all the information transmitted by the sensor nodes. Though each of the sensor nodes reads the sensor values indicative of the occupancy status of a related parking space, it does not know whether or not the space is actually taken. A sensor node simply compares two consecutive sensor data and transmits it the server when there are changes exceeding the threshold value. It is the server that determines whether or not the corresponding parking space is occupied based upon the measured data from the sensor node and the initial average values of the AMR sensor, thereby reducing the computational burden of the sensor nodes. The server manages the occupancy status of all areas of the parking lot and provides drivers with the status information. The status information may be provides in several different ways including displaying the information on an LED board located at the entrance of the parking lot.

III. Network Protocol Implementation

The RF frequency is an important factor that determines the communication range and data rate in a wireless network. In many of the previous works, the 2.4 GHz band was used. Higher frequencies allow higher data rates but have shorter range. The size of the data transmitted by a sensor node is small and data transmission frequency is quite low because data transmission only occurs when changes in the sensor data are detected. This is the reason that the proposed system adopted the 448 MHz ISM band, as shown in Table I. The frequency band provides a data rate of 4 kbps sufficiently high for the parking monitoring application and allows a good range. In most cases, an entire parking lot can be covered by a single sink node and multi-hop communications are not required.

The proposed system assumes that each sensor node wakes up from a sleep mode at an interval of 3 seconds. Fig. 3 shows the timing information related to the sensor node.

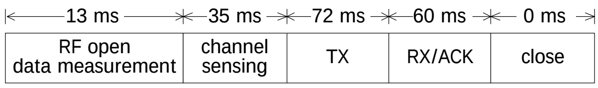

Fig. 3 Timing information related to the sensor node

After wakeup, a sensor node immediately powers up the RF module because it takes a few milliseconds for the RF module to stabilize and gets ready for communication. Then, the sensor node starts data measurement. Unless the measured data differ from the previous data by the threshold value, it quits the current session by powering off the RF module and entering the sleep mode again, in which case the sensor node runs only for 48ms. If data transmission is required, the sensor node listens on the chosen channel to check whether it is clear. If so, the sensor node starts transmitting the measured data during the next time slot, TX, which takes 72ms. If the channel is busy, the sensor node delays the transmission for a random amount of time and listens again. The number of retries is set to 5. After completing the transmission operation, the sensor node switches the RF module to the receive mode and waits for an acknowledgment from the sink node. The acknowledgment interval may be used when the sink node relays a server command to the sensor node. In this case, the sink node transmits a command received from the server to the sensor node as an acknowledgment.

If the RF channel is idle, there is no repeated listening and the whole process takes 120ms. Suppose that there is no collision on the RF channel and a sensor node transmits its sensor data at every measurement. In this case, the duty cycle of the senor node is only 4% because the transmission process takes 120ms and the wakeup period of the sensor node is 3 seconds. In real situations, sensor nodes do not transmit sensor data at every measurement, and therefore the duty cycle of the sensor node may be much lower than 4%. As the number of sensor nodes in the network increases, the RF channel becomes more crowded and the sensor nodes may find the channel busy more frequently. Nonetheless, it is highly unlikely that the duty cycle increases in that the occupancy status of a parking space does not change very frequently.

As briefly described in Section II, the sink node always keeps its RF module in the receive mode without entering a power saving mode. The sink node consumes much more energy than the sensor nodes, and therefore may not be powered by batteries. This is not a problem with the sink node because unlike the sensor nodes, the sink node can be installed in a place where electricity is available. If a data packet is received, the sink node sends an acknowledgment without checking if the channel is idle and transmits the received data to the server via the UART interface. After completing the acknowledgment, the sink node sets the RF module to the receive mode again and repeats the procedure.

IV. Concluding Remarks

A car parking monitoring system based on wireless sensor networks was proposed. The system architecture and the basic network protocol were described. In the proposed system, the sensor nodes simply transmit measured data only when the data show meaningful changes so the number of RF transmissions by a sensor node decreases accordingly. Moreover, the sensor node does not need to perform computations for determining whether or not corresponding parking spaces are occupied. It is the server that determines the status of parking spaces based on the received data. Owing to the features, the duty cycle and the power consumption of the sensor nodes decrease, and therefore the battery life can be extended.

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