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Wirelessly Sensing Open Parking Spaces : Accounting and Management of Parking Facility

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ABSTRACT

Driving into a parking lot only to find that all of the parking spaces are taken is frustrating. It would be very beneficial to implement a system that tracks the number of spaces left. Wireless sensors are well-fitted to do this task. Existing systems perform this task in various ways, discussed at the beginning of the paper. Taking the shortcomings of these systems into account, a new system based on signal strength is proposed and tested in a virtual environment.

Keywords

Sensor network, parking, wireless networks.

INTRODUCTION

Monitoring the number of available parking spaces in a large parking lot is a difficult task. Many methods designed for this task have been explored and implemented, each with various strengths and weaknesses. The most basic of these which is commonly employed in parking structures is to simply count the number of vehicles passing in and out of the garage or lot and if the number of cars determined to be in the lot is less than the capacity, one may determine that the lot has open spaces. This, however, provides a vague analysis of the situation and leaves the monitor with no indication of where these spaces might be. Further information is desirable, especially the knowledge of exactly which spaces are open. Wireless sensors are the key to providing this information. They require no new cables or wires to be installed and are low maintenance. The remainder of this document discusses existing sensor systems of this type, proposes a newly designed system which is deemed more reliable and relays data and results from an experiment on this new system.

RELATED WORK

Optical Sensing: Optical sensing involves a less traditional "sensor" when it comes to wireless sensor networks – a camera. An immediate benefit to this is that one camera can cover a wide area of spaces, saving on the cost of other solutions which require the placement of a sensor in every single parking space, and pre-existing security cameras can be used [1]. A variety of ways exist to process an image and detect cars, ranging from analyzing color histograms [2] to car feature detection [3]. Regardless, these systems analyze images and extract regions of interest (ROI) which correspond to a labeled parking space [1]. It [1] describes a system which uses the "K nearest neighbor" (k-NN) approach to finding ROI's which are likely to contain vehicles. The system then uses machine-learning techniques to identify vehicle features and empty space features.

Disadvantages to optical sensing mainly involve the fact that a camera position must be available – that is, areas in which an overhead view is hard to produce, such as an indoor parking structure, are incapable of using such techniques. Additionally, spaces which are blocked by larger vehicles in adjacent spaces are unable to be analyzed, introducing the requirement for redundant cameras covering the same spaces from different angles to ensure that each space is always visible.

Magnetic Field Detection: This method involves placing a sensor capable of detecting the magnetic field generated by a car in each parking space [4][7]. The problems that such systems have and difficulties in operating such a system are outlined by Benson et al. They use a Speake FGM-3 magnetic sensor which outputs pulses to detect magnetic flux in the surrounding field. These sensors were found to be difficult to calibrate and were known to behave erratically in the presence of a vehicle [4]. Manual placement of the nodes in west-east or east-west orientation was found necessary. This could be overcome by a more sophisticated, self-calibrating sensor.

The sensor was tested with two vehicles – one representing a mid-size car and the other a Super Utility Vehicle (SUV). Sensors were calibrated to trigger an alert when the percent change in the magnetic field surpassed a certain threshold. Though a downside to the system was that the two vehicles required different thresholds, 10% and 15%, respectively, placing a vehicle within .75 meters of the sensor (but not directly on top of it) failed to generate a false positive. The largest obstacle reported in using the sensors, aside from their erratic behavior, was the required complexity in routing and poor link quality when a vehicle parked on top of a sensor [4].

Other Methods: Many other methods exist to detect open parking spaces. A system dubbed SPARK [5] uses sensors mounted on the vehicles themselves to create a vehicular ad-hoc network (VANET). The idea of putting sensors on the vehicles is largely impractical, however. Others use laser or sonar sensors above each space to detect a vehicle underneath. A patent exists from 1996 for a system which reads some sort of RFID transmitted by tickets issued at the entrance of a garage [6]. When a car parks in a space, an overhead sensor reads the ID. Another idea is given by Sangwon Lee et al. for using ultrasonic sensor detection measuring the distance from a node to a target using ultrasonic waves.[8] If the distance is less than a certain threshold then an object (expectedly a vehicle) is passing by. If the duration it takes for the object to pass is over a certain threshold then it is determined to be a vehicle and not something smaller such as a person walking by. Huong-Zhong et al. discuss their algorithm for dealing with interference caused by noise from cars passing by [9]. Issues arise in these systems, also, such as power consumption or the complexity of the sensors themselves, making them sub-optimal solutions.

SYSTEM ARCHITECTURE

Overview

The proposed system is designed to approach the shortcomings of systems mentioned above. It is designed with multiple layers – a sensing layer, a communications layer, a data processing layer, and a data storage layer. The sensor nodes are Crossbow MICAz motes running TinyOS version 2.x along with software utilizing the light sensor and radio hardware to sense the amount of light reaching the sensor and the strength of incoming signals when it reaches the sensors. This information will be used in determining whether a car is parked in a space or not. While the previously mentioned systems find poor link quality as a hindrance, it will be used as an indicator that a car is likely in the path of the signal. Additionally, a drop in the periodic light reading is likely to indicate that a shadow has fallen on the sensor, potentially due to a vehicle in the surrounding space. More information on this is covered in the *Methods* section.

Mote Placement

Sensing motes will be placed in each parking space. These motes will be equipped with sensor boards and communication modules. Additional motes will be placed above the ground in an area with a significantly wide line of sight (LOS), such as on the ceiling of a parking garage or on a light pole in an outdoor lot. Figure 1 illustrates this.

Server

Since communication is expensive in terms of power, the logical detection of potentially occupied spaces will be done in-network to the greatest extent possible (see *Methods*). A PC base-station exists for storing data concerning the current state of each node in the network and consequently displaying the parking spaces which are available. The base station will also act as a moderator for any un-resolvable conflicts arising during the logic of determining whether a given space is occupied or not, and it will monitor the health of the network overall. The base station software will be written in Java. A database stored locally on the PC will be used to store all data. If in the future it is deemed necessary or desirable for the database to be remotely accessible, the addition of such a feature may be considered

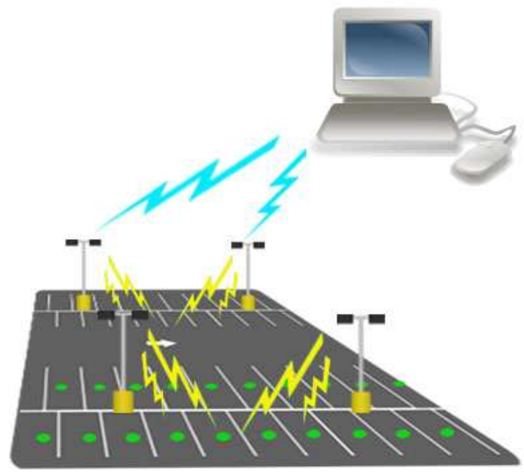

Figure 1. System Architecture

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The Crossbow MICAz mote uses the MPR2400 processor board which is based on the ATmega128L low-power microcontroller with a MICAz IEEE 802.15.4 radio module. An MTS400 sensor board with light sensing capabilities is attached to each sensing mote via the 51-pin connector. Motes responsible solely for collecting and analyzing data from other motes (communication motes) need not be equipped with sensor boards. The MIB520 board creates a serial interface with the base station PC.

METHODS

The main method for determining whether a parking space is vacant or occupied will be statistical analysis of various data from the light sensor and radio. Systems in the *Related Work* section complain of poor link quality when a vehicle is parked over a sensor; this clearly works quite well, then, in considering whether a parking space is occupied. When a mote suspects that the space in which it is located is occupied, it will attempt to send packets to a nearby communication node. This node, mounted above the sensing nodes, will have a clear LOS and is expected to periodically measure the received signal strength indicator (RSSI) of messages transmitted from sensing nodes. If the strength of the signal drops below a certain threshold, it may be assumed that an obstruction is blocking the signal. The issue may also arise that a low signal is due to hardware failure. To address this, nodes will periodically send health updates on their current status to the communication nodes.

It should be noted here that each sensing node will have one designated communication node (CN) with which it communicates. Each CN will have multiple assigned sensing nodes for which it is responsible. To allow for the insertion of new nodes without hard-coding designated CN's for each node, sensing nodes will be allowed to discover CN's when they are introduced to the network. They will broadcast a packet with a request for CN's to respond. Whichever CN sends a response will then be the designated CN for that node. If multiple CN's are in range, the CN with a higher link quality will be chosen.

The communication nodes will be responsible for determining what level of RSSI is deemed significant through statistical analysis. Statistics will be kept on RSSI values for each node (individually). When a certain node transmits a packet to the CN, the CN will first determine if the signal strength is significantly different by performing an outlier check on the data. An outlier will simply be defined as any value lying below the 25^{th} percentile (Q1). If the value is deemed an outlier, then the CN will discard the data and send a request to the original node to send additional packets for further measurement. If a vehicle is parked on top of the sending sensor, it is expected that all of the packets sent in response to the CN's request will have an attenuated RSSI.

Once it is determined by the CN that a parking space is occupied, the CN will send this information to the base station PC via other CN's or direct link if it is located close enough to the base station. The base station will keep an up-to-date record of which spaces are vacant or occupied.

Two main issues arise in executing the above method: 1) Sending messages to measure the signal strength may be very costly with regard to power consumption and 2) a low RSSI measurement might indicate a physical failure of a node rather, causing a false positive. These issues are addressed below.

Each sensing mote (those in the parking spaces) will have a sensing application installed. The motes will take a reading of ambient light at a set time interval. Data from several readings will be stored and statistics for central tendency and variation will be calculated. Due to memory constraints, the data will be represented in a moving frame such that when a new reading is taken, the first reading in the frame is dropped and the new data is appended. This will maintain a constant number of data points while having a sufficiently large data set for statistical calculation. When a significant difference in the light reading is discovered with a large enough confidence, the mote will begin the process to determine whether a vehicle is parked in the space or not by initiating contact with a CN. In this way, a node will have additional input (aside from just a timer) as to when it should communicate with the CN. This allows for the time interval at which it will automatically speak with the CN (regardless of the light reading) to be increased and save on power consumption – we trust that (for the most part) if a car is parked in the space, the light reading will initiate the detection procedure. While light is not reliable as a sole indicator of when a vehicle might be parked over a sensor, a sudden drop in light could indicate a higher probability of this being the case. However, in dark areas or at night, light readings might not change significantly when a vehicle is parked on top of the sensor. In this case, the timer will be sufficient in letting the node know when to communicate with its CN. The side effect of the added light constraint is only to increase the real-time feel of the network by forcing a node to communicate if it thinks it is covered by a vehicle, even when the timer does not dictate that it needs to do so.

To deal with false positives given by hardware failures, a communication system will be implemented in which nodes are aware of their neighbors. This gives CN's an alternate route to a given node if the direct link is too greatly diminished. It may be assumed that another node under the supervision of the CN will be a neighbor of the node which has dropped its link, and a packet may be routed via its neighbors to check on its status. If neighbors fail to deliver a message to the node, then it is fairly probable that the node has failed (since neighbors still have a LOS even when cars interfere with the LOS to the CN).

EXPERIMENTAL EVALUATIONS

Our experiment was to attempt to simulate an occupied parking space and a vacant parking space (used as the control) to determine whether the vacancy status of the space could be assessed merely by examining light readings and how often signals were successfully being transmitted to a receiver. We created a virtual environment in the lab attempting to simulate the scenario of a car parked over one node and a control node in an empty space. One node was used for each position and a third node was placed unobstructed near the receiver to ensure that things were running correctly. In this virtual environment, instead of the nodes transmitting to a CN they were transmitting directly to the base station. The sensors were then left running, broadcasting readings approximately every three seconds, for just over two hours. NodeView, the software analyzing the signal readings, is a program developed by my coworkers and I for the purpose of taking in signal readings and converting them to understandable and organized data tables. It then checks them against user generated alert levels, notifying the user of an alert in the case the requirements were met. In the case the light reading was low enough an alert would be triggered.

Example source code for alert detection

```
PRIVATE BOOLEAN PROCESSALERT(ALERT ALERT){
…
rs = server.retrieveNodeHistory(alert.nodeID, cal.getTimeInMillis() - interval[alert.interval]);
calculator.getData(rs, parameter[k]);
calculator.calcMean();
mean[k] = calculator.getMean();
…
if (mean[k] <= value[k])
      CONDITION[K] = FALSE;
```

```
…
alertPanel.displayAlerts(alert);
```

RESULTS

Node beneath car in virtual environment

Mote ID	Parent ID	Voltage	Humidity	HumTemp	PrTemp	Pressure	Accel X	Accel Y	Light
2328	0	2.460417	21.3212	21.93556	21.35352	989.8369	-0.7	-0.24	9.89
2328	0	2.450787	21.3408	21.93682	21.33848	989.5475	-0.7	-0.24	9.89
2328	0	2.46526	21.3212	21.86273	21.35352	989.3919	-0.7	-0.24	9.89
2328	0	2.450787	21.3408	21.93682	21.33096	989.4473	-0.7	-0.22	9.89
2328	0	2.460417	21.3408	21.93682	21.35352	989.5699	-0.7	-0.22	9.89
2328	0	2.450787	21.3408	21.93682	21.33848	989.8145	-0.7	-0.22	9.89

Node unobstructed, empty parking space in virtual environment (control)

Mote ID	Parent ID	Voltage	Humidity	HumTemp	PrTemp	Pressure	Accel X	Accel Y	Light
2508	0	2.340845	21.2134	21.12647	21.54902	989.2789	0.08	0.02	420.67
2508	0	2.332127	21.2134	21.19951	21.52646	989.0689	0.08	0.04	434.93
2508	0	2.336478	21.2036	21.27191	21.54902	989.3689	0.08	0.06	420.67
2508	0	2.332127	21.2232	21.27314	21.5415	989.2689	0.08	0.04	434.93
2508	0	2.340845	21.2232	21.27314	21.5415	989.449	0.08	0.08	420.67
2508	0	2.327792	21.2232	21.27314	21.59414	989.3388	0.08	0.04	434.93

As expected the light readings were easily detectably different for the software and an alert was triggered notifying us of the reading. Also after analyzing all of the data we found that NodeView had received roughly 83% as many messages from the sensor with the obstructed signal path, as from the control sensor. Neither sensor broadcasted at a rate of 100% when checking for a reading sent every three seconds. However this was because much of the time the sensor with the obstructed signal path would hop through the unobstructed sensor, thus taking up some of the broadcasting time of this sensor and delaying its own signals. By setting in a method for checking the ratio of signals received from different sensors, it would therefore be easy to check, based on our results, for sensors whose signals are being interfered with probably by a vehicle parked overhead. By combining this information with the light readings for each sensor we could determine if a vehicle was occupying the space above a particular sensor. This data could be used to display the locations of available parking spaces on a monitor at the entrance to the parking structure. In conclusion this would be a viable solution to parking vacancy detection in any parking structure that is well lit. As it is important to be able to see where you are parking this would account for most public parking structures.

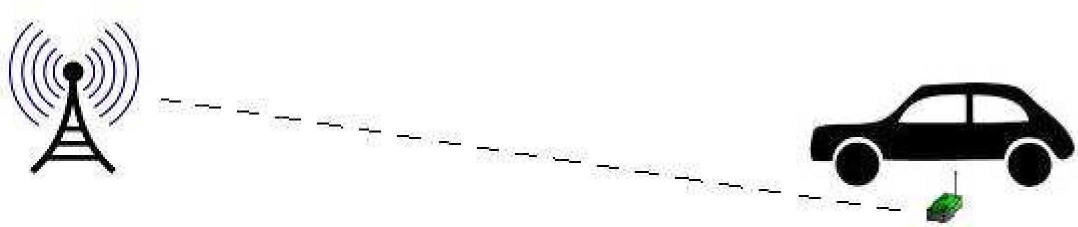

Figure 2. Experimental setup

CONCLUSION

Wireless sensors are well-fitted to implement parking management system. Existing systems perform this task in various ways, discussed at the beginning of the paper. Taking the shortcomings of these systems into account, a new system based on signal strength is proposed and tested in a virtual environment. We intend to further develop NodeView to improve upon existing features and find new ways in which it may more accurately detect scenarios such as the parking one portrayed in this paper, as well as search for other uses for our program.

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