Intelligent Parking Lot Application Using Wireless Sensor Networks

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ABSTRACT

Wireless sensor networks offer an attractive choice for low-cost and easy-to-deploy solutions for intelligent traffic guidance systems and parking lot applications. In this paper, we propose the use of a combination of magnetic and ultrasonic sensors for accurate and reliable detection of vehicles in a parking lot. We describe a modified version of the min-max algorithm [10] for detection of vehicles using magnetometers, and also an algorithm for ultrasonic sensors. Through extensive real world experiments conducted in a multi-storied university parking space we compare the pros and cons of using different sensing modalities, and show that ultrasonic sensors along with magnetometers is an excellent choice for accurate vehicle detections. We demonstrate the efficacy of our proposed approach by conducting an elaborate car counting experiment lasting over a day, and show promising results using these two sensing modalities.

KEYWORDS: wireless sensor networks, traffic guidance systems, ultrasonic sensors, magnetometers

1. INTRODUCTION

In recent years, wireless sensor networks (WSN) [1] have inspired tremendous research interest in diverse application domains such as structural health monitoring [23], underwater marine life monitoring [2], military and security surveillance, health-care, smart homes, automotive industry, etc. A typical sensor network consists of hundreds to thousands of sensor nodes, each equipped with various kinds of sensors, deployed over a geographical region of interest. A sensor node by itself has severe resource constraints in terms of memory, battery power, computation and communication capabilities; however, a group of sensors collaborating with each other can accomplish a much bigger task efficiently.

With the increasing growth of automotive industry, the demand for intelligent parking service is expected to grow rapidly in the near future. This emerging service will provide automatic management of parking lots by accurate monitoring and making that information available to customers and facility administrators. Wireless sensor networks have a great potential toward providing a cost effective solution to this service for a variety of reasons, such as their ease of deployment in existing parking lots without having to install new, expensive cabling, and the flexibility to couple them with sophisticated but cheap sensors with different modalities that can accurately keep track of vehicles. Moreover, information gathered by each node can be collaboratively processed in a distributed or centralized way to evaluate other meaningful metrics such as duration of parking, automatic billing and payment, etc., to the benefit of users and administrators.

A few existing solutions focus on parking lot applications using sensor technologies, such as magnetometers and video cameras. However, magnetometers are very sensitive on environmental factors, as a result of which their detections are not always accurate. Moreover, since magnetometers measure the change in magnitude and direction of Earth's magnetic field caused by the presence of a vehicle, they need to be placed at close proximity to the vehicle. Although this might be possible near the entrance of a parking lot, it is very difficult to place them in close proximity to vehicles on upper floors simply because there are typically no entrance marked for upper floors and vehicles move at relatively higher speeds than near the entrance. On the other hand, video camera based solutions are energetically expensive and they can generate large amount of data which could be very difficult to transmit over multiple hops in a wireless environment. These disadvantages coupled with the fact that there are other objects moving in a parking lot, such as humans, greatly reduce the applicability of only one type of sensor technology, i.e., only magnetometers or only video cameras for cheap and accurate parking lot manage-

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ment solutions.

In this paper, we propose a hybrid approach for an intelligent parking system using a combination of ultrasonic and magnetic sensors, and demonstrate promising results through real world experiments performed at our multi-storied university parking structure. Because of practical limitations, such as hardware characteristics and localization errors, we show that hybrid solutions using combination of sensing technologies are more practical and accurate. Unlike some of the previous works [20] that propose to place a magnetic sensor at *each* parking space and thereby provide occupancy information for each space at the cost of expensive infrastructure, our goal is to count the number of vehicles only on each floor and provide a cheap but accurate solution.

The rest of the paper is organized as follows. In Section 2, we discuss related works. In Section 3, we first describe the devices that are used in our implementation and then describe our sensing technique. Section 4 details on the detection algorithms for magnetic and ultrasonic sensors. We present our detailed experimental results in Section 5, and finally we conclude in Section 6.

2. RELATED WORKS

In this section we review the existing literature on traffic management systems, and in particular, parking lot applications using wireless sensor networks.

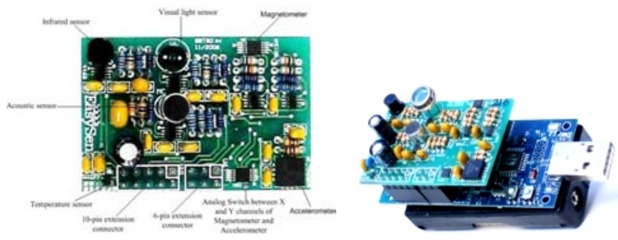
The Parking Space Finder Application that is part of Iris-Net [13] proposed a wide-area sensor network architecture, in which video cameras, microphones, and motion detectors are used to detect occupancy or availability of parking spaces. Using web technologies, users can acquire the processed information that is published on the web and generated by feeding all these sensor-data. However, as mentioned earlier, video cameras generate a large amount of data that incur high energy expenditure and communication bandwidth, both of which are limited in sensor networks.

In [20], an intelligent car parking system using wireless sensor networks is proposed, where each parking space is equipped with one sensor to detect its occupancy. The prototype implementation is based on remote controlled toy cars and uses Crossbow motes [8] that have light, temperature, and acoustic sensors. However, it is not mentioned how to detect a car with those sensors. It is argued that the proposed three layered system architecture will reduce the cost of manpower and minimize human operations, however, as we show in this paper through real world experiments that it is hard to even detect cars with those sensors; especially temperature and acoustic sensors might be useless. Light sensors could work but might malfunction under shadows. Moreover, it is hard to manage a lot of sensor nodes and the overall system could be more expensive.

A traffic surveillance system is described in [7], which uses magnetometers to detect the presence and estimate the speed of vehicles near street intersections and parking lots. Using magnetic signatures the system could also classify and re-identify vehicles. MIT Intelligent Transportation System [15] and Responsive Roadways [14], [18] are also examples of transportation applications using wireless magnetic sensors. However, in all these systems the sensor nodes need to be glued on the pavement or placed just under the road surface where vehicles are to be detected. This is particularly not suitable for parking lots because vehicles could move anywhere inside a parking lot unlike roads, and thus could possibly damage sensors.

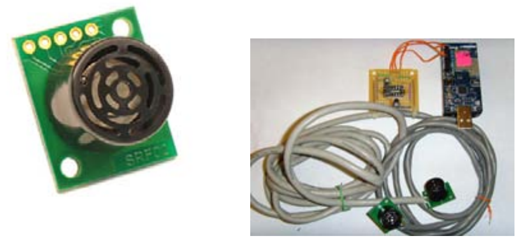
In [5], design and implementation issues for a reliable WSN system using magnetic sensors are presented, which can track available parking spaces in real time and communicate that information to the users. They propose a detection scheme based on magnetometer signature measurements and implement it on Mica2 motes [8]. In [4], and as part of the D-Systems Project [3], an implementation of a car-park management system using a tiered architecture is provided using the DSYS25z [17] magnetic sensor boards developed by Tyndall [22]. It highlights several problems in wireless communications in a parking lot environment and proposes recommendations such as use of dynamic and robust routing, delayed retransmissions, etc., based on experimental results to overcome those problems.

Our work most closely resembles in spirit to the Siemens Sipark PMA [19] solution, in terms of both using ultrasonic sensors to detect vehicles. Sipark PMA is perhaps the most prominent parking guidance system for multi-storied parking lots where ultrasonic sensors are connected using a bus-style network to distribute power and transmit sensing reports. When a car enters a parking lot, the guidance system directs the driver to a free parking space along the shortest possible route. Our work differs from the existing literature and compliments it in the following ways: (1) we propose a reliable vehicle detection algorithm using ultrasonic sensors, (2) we propose to use a combination of ultrasonic and magnetic sensors to increase the accuracy of detection and minimize environmental effects, and show that other forms of sensing such as light, temperature, infrared, and acoustic do not give accurate results, and (3) we conduct real world extensive experiments to demonstrate the efficacy of our approach using these sensors mounted on inexpensive motes running TinyOS 2.x [21].



(a) (b)

Figure 1. (a) SBT80 Sensor Board, (b) SBT80 Sensor Board Mounted on Tmote Sky.



(a) (b)

Figure 2. (a) Devantech SRF02 Ultrasonic Sensor, (b) SRF02 Installed on Tmote Sky.

3. PROPOSED APPROACH

In this section, we first describe the devices that are used for our experiments, and then describe the sensing technique upon which we base our detection algorithms.

3.1. Device Specifications

We use Tmote Sky manufactured by Moteiv [16] (now Sentilla) as the wireless nodes. Tmote Sky's are IEEE WPAN standard 802.15.4 [12] compliant devices that are ideal for mesh networking, featuring a 250 kbps radio, 10 kB RAM, 48 kB flash, and 1 MB storage. One mote is used as the base station and several others are used for measurements. We equip each mote except for the base station with a multi-modality sensor board, SBT80 from EasySen [11] that has six different sensors, e.g., visual light, infrared, temperature, acoustic, magnetometer, and accelerometer, as illustrated in Figure 1(a) and Table 1. Figure 1(b) shows a Tmote Sky mounted with an SBT board.

Table 1. Sensors on SBT80 Board

Sensor Type	Manufacturer, Model
Visual Light	PerkinElmer, VTB9412B
Infrared	Advanced Photonix, Inc., PDB-C139F
Acoustic	Horn, EM6050
Temperature	Maxim Integrated Products, MAX6612MXK
Magnetometer	Honeywell, HMC1052
Accelerometer	Freescale Semiconductor, MMA6260Q

For ultrasonic sensing we use the low cost Devantech SRF02 [9] sensors. These sensors emit ultrasonic waves and perceive the reflected waves from an object to calculate its distance from the object. Thus, they provide much easier detection method than those based on acoustic, magnetic, or visual light which are influenced by environmental factors.

Figure 2(a) shows an SRF02 sensor while Table 2 highlights its properties. Figure 2(b) shows an SRF02 sensor attached to a Tmote Sky.

Table 2. SRF02 Ultrasonic Sensor Properties

Protocol	I2C, Serial
Range	15cm - 6m
Response Time	70ms
Frequency	40kHz
Voltage	5v
Current	4mA

3.2. Sensing Technique

Sensing technique is one of the most important concerns in order to accomplish an accurate and energy-efficient detection scheme. The sensing period should be short enough (e.g., 0.1 second) so as to not miss any moving vehicles; however, too frequent sensing will consume lots of energy. Therefore, there is a trade-off between the accuracy of measurements and energy consumption. It is thus necessary to find an optimal sensing period. We do this by conducting several experiments from analyzing the change in magnetic wave patterns obtained from a passing vehicle. This optimal period is then fed in the main detection algorithm.

4. DETECTION ALGORITHMS

4.1. Modified Min-Max Algorithm For Magnetometers

We use a modified version of the min-max algorithm [10], which is particularly suitable for analyzing the wave-formed raw magnetic and acoustic data. The overall structure of the modified min-max algorithm is illustrated in Figure 3 through six basic steps. In the first step it obtains raw data from magnetometer measurements. Then it calculates

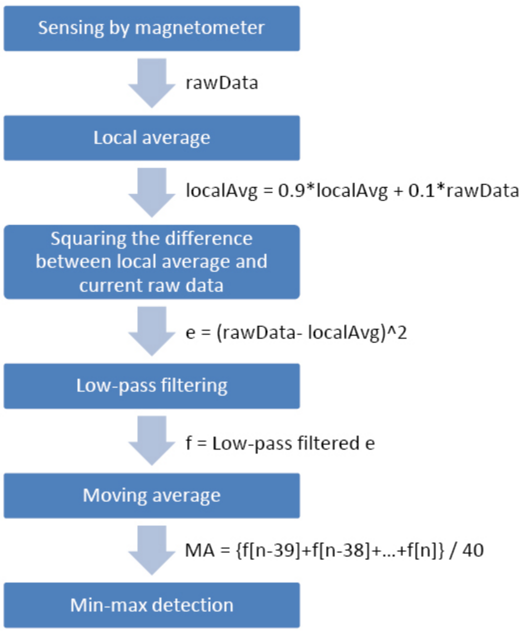


Figure 3. Modified Min-max Detection Algorithm

a local weighted average by weighing the previous average nine times of the new data. This step prevents oscillation of the local average by unwanted impulse data. In the third step, to increase the difference between the signal component and the noise component, a squared difference between the local average and the current raw data is calculated. As we will see shortly, this step makes the signal component more prominent and helps filtering. Step four applies a low-pass filter to reduce noise, which tends to be at a high frequency. Next, we calculate a moving average over forty previous measurements. This choice of forty is made considering the limited memory and energy of Tmotes and the accuracy of detection. In the last step, the moving average is fed in the min-max algorithm to detect the presence of a vehicle.

The min-max detection algorithm has a state machine which has five states, $state(x) = \{flat, flat\_count\_up, flat\_count\_down, hill\_count\_up, hill\_count\_down\}$. The input to the state machine is the sign of the current slope and defined as:

$$u[n] = \begin{cases} sign(f[n] - f[n-1]), \text{ if } |f[n] - f[n-1]| > \\ \qquad\qquad MIN\_DELTA\_U \\ 0, \text{ otherwise} \end{cases} \tag{1}$$

where MIN_DELTA_U is a predefined positive constant, 2000. A counter, *stateCounter* is associated with each state, which resets when the machine jumps to a new state, and counts up when the state loops back to itself. There are also two variables, $localMin[n]$ and $localMax[n]$, to keep track of the local minimums and maximums, defined by Equations (2) and (3). Finally, the machine decides that a vehicle has passed if it jumps from state $hill\_count\_down$ to $flat$ and the difference between the local maximum and minimum is greater than a certain threshold T, determined empirically as 70000.

$$localMin[n] = \begin{cases} \min\{f[n] - localMin[n-1]\}, \\ \qquad \text{if } x \in \{flat, flat\_count\_down\} \\ f[n], \text{ if } x \in \{hill\_count\_down\} \text{ and} \\ \qquad localMax[n] - localMin[n] > T \\ unchanged, \text{ otherwise} \end{cases} \tag{2}$$

$$localMax[n] = \begin{cases} \max\{f[n] - localMax[n-1]\}, \\ \qquad \text{if } x \in \{hill\_count\_up\} \\ unchanged, \text{ otherwise} \end{cases} \tag{3}$$

4.2. Ultrasonic Sensor Detection Algorithm

The detection algorithm for ultrasonic sensors is relatively simple and based on distance measurements from the object to the sensors. A flowchart of the algorithm is shown in Figure 4. If the distance is smaller than a certain $DISTANCE\_THRESHOLD$, a counter is started, and incremented until the distance returns to the normal value, at which point there is no object anymore. If the value of the counter is more than a certain $DURATION\_THRESHOLD$ then a vehicle is detected. A moving person is easily distinguished from a moving vehicle because a person's passing duration is much smaller than that of a vehicle. The experimental results presented later demonstrate this fact. The values of the $DISTANCE\_THRESHOLD$ and $DURATION\_THRESHOLD$ depend on the placement of the sensors in the parking lot and are empirically determined to be 140 and 5, respectively, for our experiments.

5. EXPERIMENTAL RESULTS

5.1. Sensing Experiments

The success of an intelligent parking application in accurate and reliable detection of vehicles is crucially dependent on the types and locations of the sensors. To determine the best sensing method for our vehicle counting experiment, we first conduct several measurements using all the six sensors of the SBT80 multi-modality sensor board, the SRF02 ultrasonic sensor, and visual light with laser pointer. We conducted these experiments in a multi-storied parking structure inside our university campus (see Figure 5(a)). Figure 5(b) shows the placement of a mote mounted with a SBT80

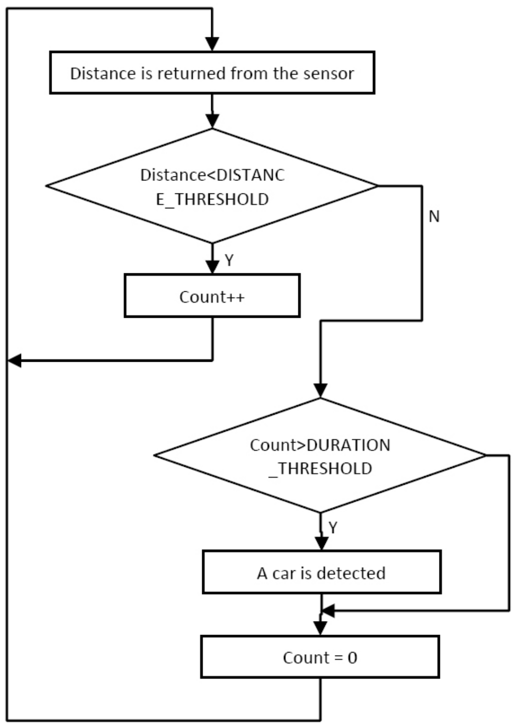


Figure 4. Ultrasonic Sensor Detection Algorithm

(a)

(b)

Figure 5. Test Bed: (a) Parking Structure Inside USC Campus. (b) A Tmote Mounted With SBT80 Placed Near the Entrance.

sensor board near the entrance. The ultrasonic sensors are attached to the ceiling.

Figure 6 and 7 presents the results of one sample run of our experiment with an optimal sensing period set to 70 ms. The x-axis in all the graphs represent packet numbers and y-axis represents the measured value by each sensor in appropriate units depending on the sensing modality. A car enters the parking lot during the experiment corresponding to the packets from 100 to 130. Clearly, visual light and infrared sensors are not applicable in this case because their values do not change at all. Temperature sensor, acoustic sensor, and the x-axis of the magnetometer also could not catch a car. The best sensors that detect the car are the y-axis of the magnetometer, the ultrasonic sensor, and visual light with laser pointers. In Table 3 we present the summary of these sensor characteristics. We also tested for hardware variations of the same sensing modality. In particular, five magnetometers are tested in the same environment and the variance between four of them is found to be very large. In addition, one of them shows very little change in the magnetic field when a car passes.

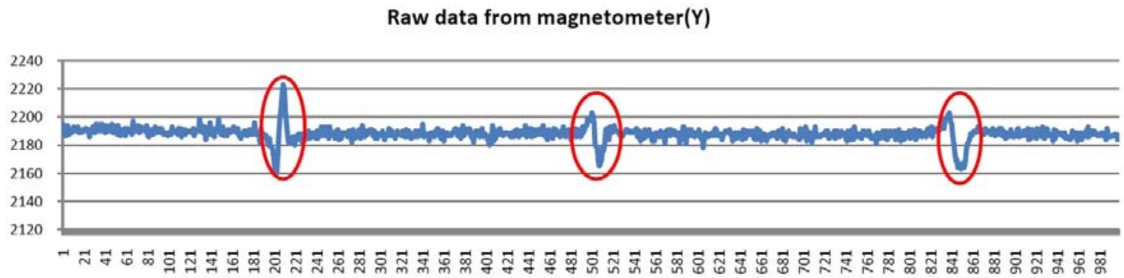
5.2. Detection Experiments

5.2.1. Magnetometer

Based on the y-axis measurements of the magnetometer, the modified min-max algorithm is implemented to detect passing cars. We use Java to test it on the laptop and port the code to TinyOS programming language NesC. Figure 8 shows the graphs for each step of algorithm as described in Section 4.1. Clearly, even the raw data from magnetometer y-axis show three fluctuating places, indicating three cars have passed consecutively. In the next step, squaring of difference between the local average and the raw data makes the car-passing points more prominent than non-passing points. The low-pass filter eliminates the noise in the wave forms, and the moving average reduces the fluctuating characteristics, which might result in miss-detection. In the final step, the min-max detection algorithm results in a value 1 for a passing car and 0 for no cars, thus detecting all the cars successfully.

5.2.2. Ultrasonic Sensor

Two ultrasonic sensors, SRF02, are mounted on Tmotes and attached to the ceiling on the fourth floor of the parking lot to detect cars going up and down, as shown in Figure 9. Sensor 1 detects cars going up and sensor 2 detects cars going down. Because an ultrasonic sensor returns the distance of a sensed object from itself, the returned distance is shorter when a car passes. It is even possible to distinguish vehicles from persons. Sensing with same frequency (70 ms sensing period), a person is detected for much shorter duration that a car, although a car is faster than a person. Figure 10 presents the results of our experiment. Note that



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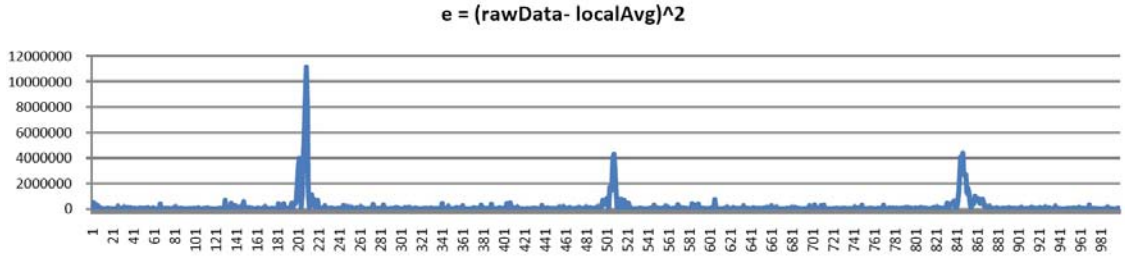

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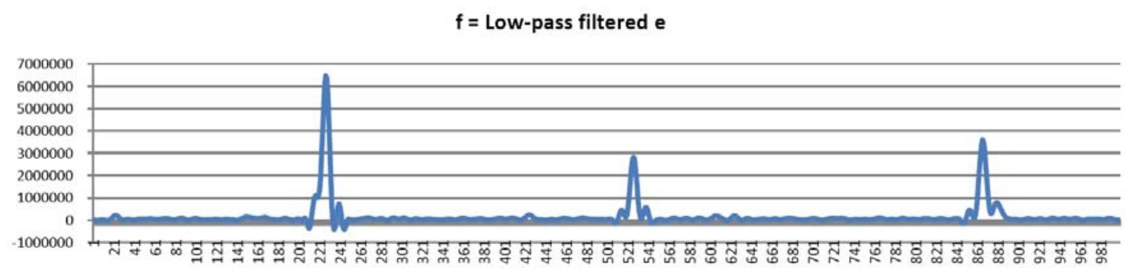

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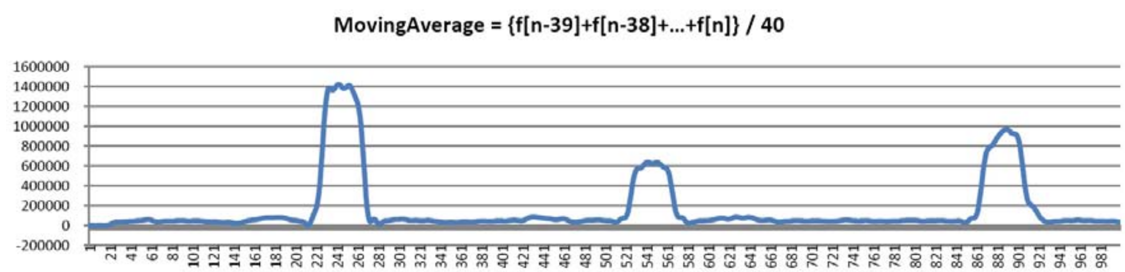

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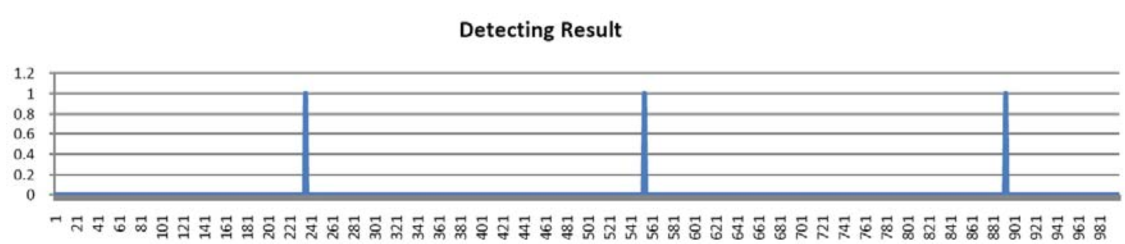


(e)

Figure 8. Results at Each Step of the Modified Min-max Algorithm

Table 3. Summary of Sensor Characteristics

Sensor Type	Characteristics
Acoustic	- seriously influenced by environmental noise - detection algorithm is difficult
Visual Light	- too sensitive, always maximum at day time - cannot be used at night because of ceiling lights
Infrared	- too sensitive, always maximum at day time
Temperature	- no change in measurements, hard to detect vehicles
Magnetometer	- reacts to only certain objects (cars, not humans) - location dependent, raw data differs quite a lot based on locations - relatively difficult detection algorithm
Ultrasonic	- detection is easy and reliable
Visual light with infrared	- detection is easy - difficult to distinguish cars and humans - could be used as secondary sensors - laser is always turned on, thus consuming lot of energy

the graph even shows the shape of the car.

5.3. Transmission Experiments

We conducted several experiments inside the parking lot to get estimates about the link qualities between the sensors on different floors. A good link quality is essential for the sensors to efficiently collaborate their individual measurements and send the consolidated results to a base station. In particular, we measured the packet reception rates (PRR) and the received signal strength (RSSI) between two nodes transmitting at maximum power, as shown in Table 4. Our results, presented in Figure 11 show that the nodes cannot communicate with each other unless they are on the same or adjacent floors. Transmission is seriously hindered by obstacles, such as parked cars and walls, thus, causing routing problems. To overcome this, additional motes, possibly without sensors that could act as intermediate forwarders, are needed.

Table 4. PRR and RSSI Measurement Results

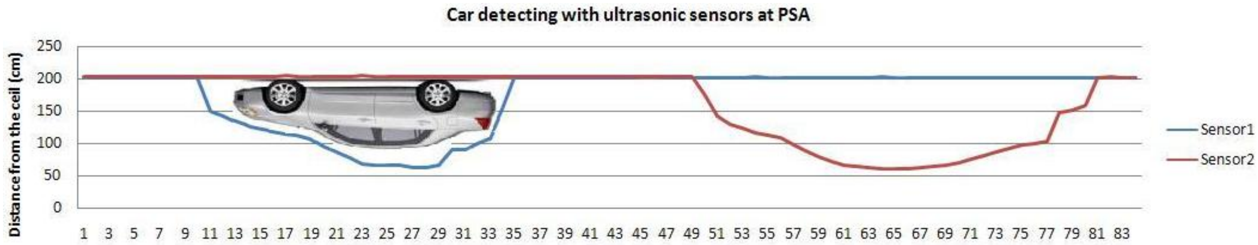
Link	PRR	RSSI
A - D (along the roadway)	0.67	-88.35
A - B	0.72	-85.64
D - E	0.54	-85.01
A - C	0	none
D - F	0	none
B - E	0	none
C - F	0	none

5.4. Car Counting Experiments

Finally, we conducted experiments to count the number of cars moving in and out at the one of the two entrances of the university parking lot over a day. Ultrasonic sensors are installed on the ceiling of the entrance. When a passing car is detected, the motes connected with sensors record the time and passing direction into its flash memory. The results during one day of the experiment are shown in Figure 12. As evident, the number of cars increases from morning 8am until 2pm, and then decreases until 11pm. There are rarely moving cars during the night time from 11pm to 6am except for periodic patrol cars.

6. CONCLUSIONS

In this paper, we have argued the use of both ultrasonic and magnetic sensors in accurate and reliable detection of vehicles in parking lots. We have also proposed detection algorithms for both these sensing modalities. Our extensive experimental results show that the most effective of the sensors are the magnetometers in the SBT80 sensor board, and the ultrasonic sensor, SRF02. In addition, acoustic sensors could be used as secondary sensors to provide specific characteristics of the vehicle and help a primary sensing method. Each kind of vehicle has its own characteristics, such as body shape, magnetic wave pattern, engine sound pattern, etc. One could create a database of these characteristics for each vehicle and make the detection algorithm match their patterns, thus, being able to detect and identify specific types of vehicles. It is also possible to implement more energy efficient sensing techniques by changing the sensing period dynamically. For instance, in the normal mode an ultrasonic sensor could have a relatively long sensing pe-



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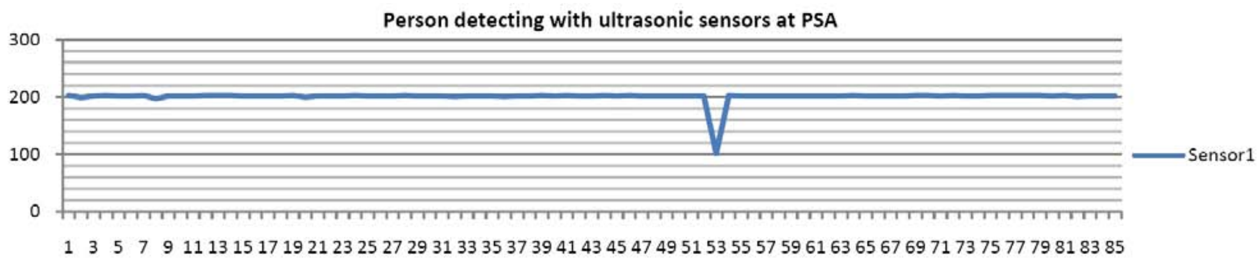

(b)

Figure 10. Results of Ultrasonic Sensor Experiments

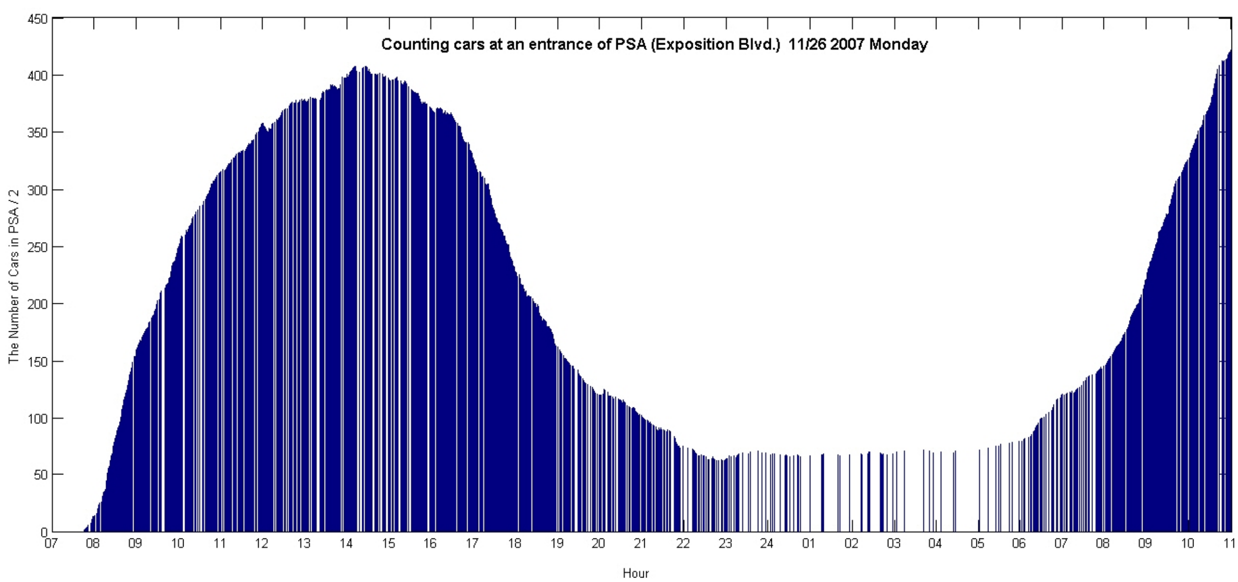

Figure 12. Results of Car Counting Experiments

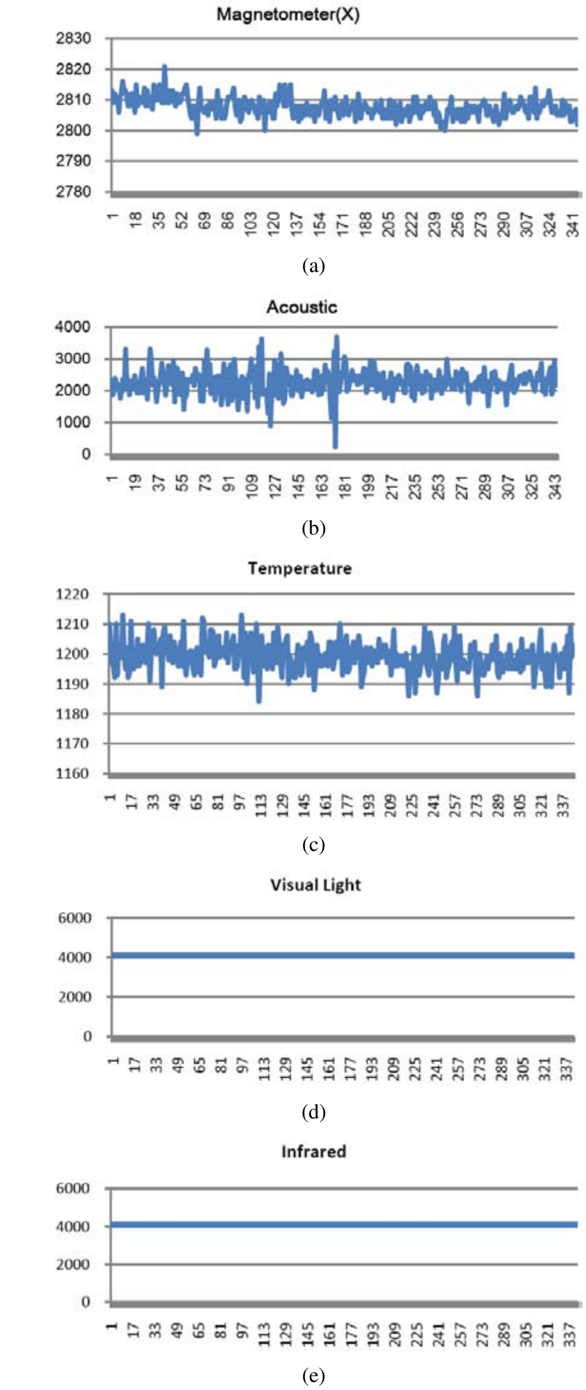

Figure 6. Raw Experimental Data from Magnetic(x), Acoustic, Temperature, Light, and Infrared Sensors

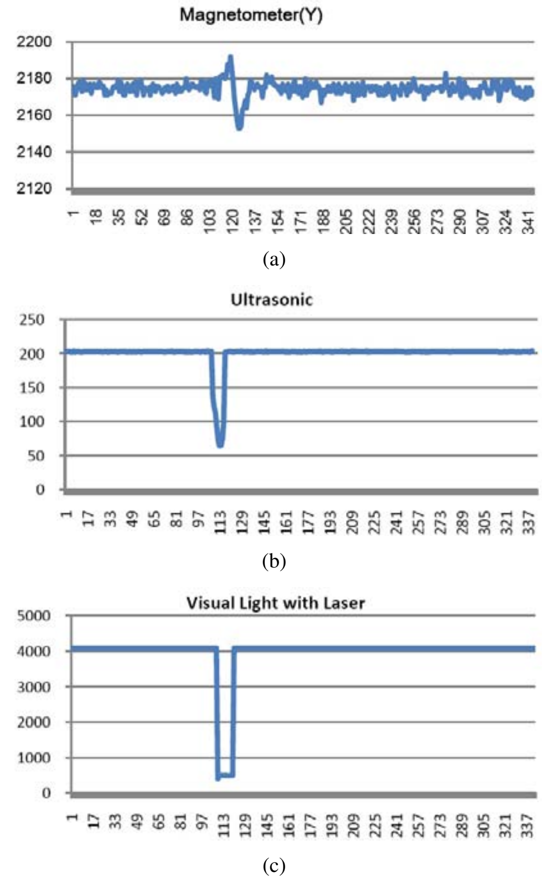

Figure 7. Raw Experimental Data from Magnetic(y), Ultrasonic, and Visual Light with Laser

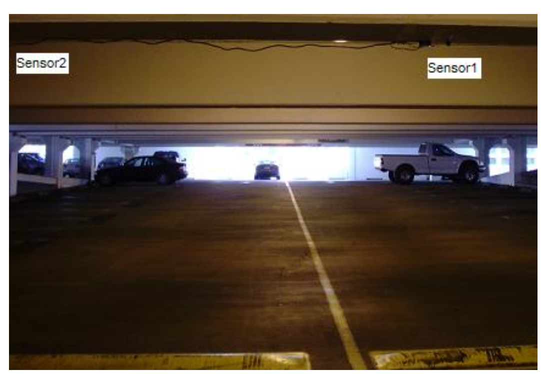

Figure 9. Ultrasonic Sensors Deployed on Ceilings

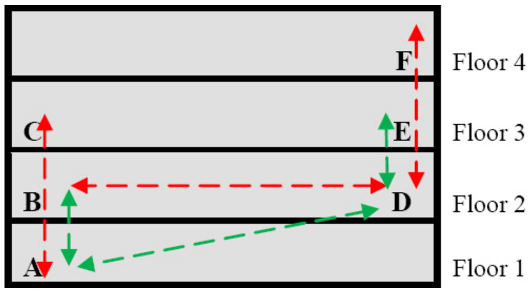

Figure 11. Transmission Experiments

riod; however, once it detects that the returned distance is smaller than a pre-specified threshold, it reduces its sensing period. After the object passes and the returned distance becomes more than a threshold the sensor recovers its normal sensing period.

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