DESIGN AND PROTOTYPE OF A WIRELESS TAILGATE DETECTION SYSTEM USING SUN SPOT PLATFORM

Andres Alarcon-Ramirez[1], Madeline Martinez-Pabón[2] and Charles Kim[3]

[1] Department of Electrical Engineering, Howard University, Washington DC
alarconramirezandr@bison.howard.edu
[2] Department of Electrical Engineering, Howard University, Washington DC
martinezpabonmadelin@bison.howard.edu
[3] Department of Electrical Engineering, Howard University, Washington DC
ckim@howard.edu

ABSTRACT

In this paper, we present the design and implementation of a wireless sensor based piggybacking and tailgating detection system to detect unauthorized attempt to gain access to a secured area. A set of Sun SPOT wireless sensor platform is adopted for acceleration sensor, transmitter, and receiver units for the system. A wireless sensor embedded in a security door collects the signal of door movement constantly and transmits the signal wirelessly to another wireless sensor (base unit), which collects the transmitted signals and stores them in the memory of the computer system for analysis. The acceleration signal is analyzed in both time and frequency domain to detect and classify single and tailgate entries. The paper focuses on the description of the wireless sensor network and the sensor-based tailgate detection algorithm.

KEYWORDS

Tailgate, piggybacking, embedded system, wireless sensor network, acceleration sensor.

1. INTRODUCTION

The biggest weakness of automated access control systems is the fact that most systems cannot actually control how many people enter a secured area when an access card is presented or a security code is keyed. Most systems control which card works at which door, but once an employee opens the door, any number of people can follow behind the employee and enter into the building. Similarly, when an employee exits the building, it is very easy for a person to grab the door and enter the building as the employee is leaving. This practice is known as "tailgating" or "piggybacking"[1]. Tailgating can be done overtly, where the intruder makes his presence known to the employee. In many cases, the overt "tailgater" may even call out to the employee to hold the door open for him or her. With so many security breaches reported every day resulting in burglary, attack, and other crimes, a reliable tailgate detection system for doors would become an excellent way to keep places safe.

To overcome the deficiencies of the existing technologies and to provide a simple means of single person and tailgate detection, a wireless tailgate system for a security door is designed and implemented using Sun SPOT wireless network platform. The detection system embedded a SPOT in the door to sense the acceleration motion of the door and to wireless transmit the motion signal to another SPOT as the base station, which in turn is connected to a computer or PC. The

PC analyzes the acceleration signals and indicates and alerts if more than one person enters through the door. The detailed signal analysis and detection algorithm is described.

This paper is organized as follows. In the following section, there is a description of the related work. In Section 3 the Sun SPOT platform and its development system environment are introduced. Section 4 then describes the acceleration sensor embedded in the SPOT. Section 5 details the design and implementation of tailgate detection system using the SPOT platforms. Section 6 covers the developed algorithm of tailgate alert as well as the preliminary test results of the prototype system of tailgate detection. Finally, Section 7 concludes the paper.

2. RELATED WORK

An existing single person detector uses a 3D sensor using MLI (Modulated Light Intensity) technology [2]. MLI technology is based on the optical time of flight principle. A non-scanning light source emits modulated near-infrared light. The phase shift between the light emitted by the source and the light reflected by the persons and objects in the field of view is measured to create a real-time topographic image of the monitored area. By means of time of flight measurement, the overhead-located 3D MLI sensor measures and processes topographic 3D data, in order to detect the number of people in a specific area.

In [3] is reported an arrangement of two synchronized doors known as mantrap. For access to a secure area, a person needs to pass through two doors. Initially, a person enters to a verification area, where the space is arranged to locate only one person, by opening the first door. Once the user is verified, the access to the secure area is authorized and the second door is opened. Additionally, the first door remains locked until the second door is again closed avoiding tailgating.

Another method of single person detector relies on a network of video cameras mounted on the ceiling of the area in front of the access door to the area [4]. Each of the cameras watches over an area of about one square meter and the video signal is fed to a computer that spots when someone is walking up to the door. If it's a single person then he is allowed to authenticate himself at the door and enter as normal but if there is someone else in the area the computer won't let the door open until either the second person has also authenticated or until he walks away.

In the same way, a video camera is used in [5] as a security system to recognize tailgating by comparing and analyzing behaviors against rules which has been defined beforehand in video stream. Finding an event deemed to be a potential rule violation; it alerts personnel on a customized basis.

T-DAR is another system which uses three-dimensional optical imaging to detect piggybacking and tailgating attempts [6]. T-DAR systems can be adapted for two types of applications: secure doorways and high-security mantraps. The primary difference between the two systems is that the door system alerts security to tailgating and piggybacking incidents and sounds a local alarm, but has no capability to stop the violator, while the mantrap system effectively prevents tailgating and piggybacking by allowing only one person to pass through a vestibule at a time.

In [7] is presented a security system on access-controlled doors named Door Detective to prevent the open door from tailgaters and other unauthorized entries. The Door Detective is constituted by an infrared beam array crossing the doorway together with microprocessor-based intelligence to ensure only one person passes through a door. A similar work constituted by an optical security system, which uses unique algorithms and infrared sensor beams to detect tailgating, is presented in [8]. Upon alarm, Door Detective can lock nearby entrance control doors or trigger cameras while informing local and remote security personnel.

The work made by Jae Hoon Lee uses multiple of laser range finder. This technology measures the range distance from sensor to target object [9]. The method has many merits in data manipulation, robustness, and resolution in distance information. Also, it uses Multi-target tracking technology with Kalman filter to track human objects in motion and count their number in the region of interest. Motion model and geometric feature of human is also considered for detecting the walking humans. Unfortunately, the price of this system is very high, its installation is very complex, and architectural modification is often required for different installations. In all, the existing technologies are expensive and complex; therefore, an economical and simple detection system is needed in replacement of the existing technologies.

3. SUN SPOT – WIRELESS SENSOR PLATFORM

A SPOT (Sun Small Programmable Object Technology) is a wireless sensor network mote developed by Sun Microsystems. The device is built upon the IEEE 802.15.4 standard. Unlike other mote systems, the SPOT is built on the Squawk Java Virtual Machine [10]. A SPOT is about the size of a 3x5 card with a 32-bit ARM9 CPU, 1 MB RAM and 8 MB of flash memory, a 2.4 GHz radio and a USB interface. Our project also made used of a Java ME VM and the NetBeans 7.0 Integrated Development Environment.

The hardware platform of SPOT includes a range of built-in sensors as well as the ability to easily interface to external devices. There are two different kinds of SPOTs: Free-range SPOT and base station SPOT. The anatomy of a free-range SPOT consists of a battery, a processor board, a sensor board and a sunroof as shown in Figure 1. The sensor board has three difference kind of sensor to measure acceleration, temperature and light intensity. Our single person detector used only the acceleration sensor [11].

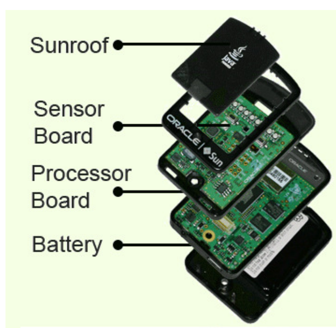

Figure 1. SPOT Anatomy

The base station SPOT does not have the sensor board and its purpose is to allow applications running on the host to interact with applications running on targets. The Host can be any of the supported platforms (e.g. Windows PC, Mac). The Host application is a J2SE program [12], and the target application is a Squawk Java program. Host applications have access to libraries with a subset of the API of the libraries used by SPOT applications. This means that a host application can, for example, communicate with a SPOT via a base station using code identical that which you would use to communicate between two SPOTs. Note that the host application does not run on the base station; it sends commands to the base station over a USB connection.

The base station may run in either dedicated or shared mode. In dedicated mode, it runs within the same Java VM as the host application and can only be used by that application. In this mode, the host's address is that of the base station. In shared mode, two Java virtual machines are launched on the host computer: one manages the base station and another runs the host application. In this mode, the host application has its own system-generated address, distinct from that of the base station. Communication from host application to the target is therefore over two radio hops, in contrast to one hop in the dedicated case. The main advantage of shared mode is that more than one host application can use the same base station simultaneously. Shared mode also allows multiple host processes to communicate with each other using the radio communication stack, which makes it possible to simulate the communication behavior of a group of SPOTs using host applications.

Two of the platforms used in our design and prototype are the SPOT Manager tool and NetBeans 7.0 Integrated Development Environment. The SPOT Manager comes with two important tools for managing the software on the SPOTs: SPOT Manager and Solarium [13]. Each Sun SPOT is listed by its IEEE network number. The solarium tap also is an important application because it makes easier to manage SPOTs and the application software of those SPOTs. Solarium includes an emulator that can be used to run applications on a virtual SPOT. Figure 2 shows two SPOTs being simulated by the Solarium application.

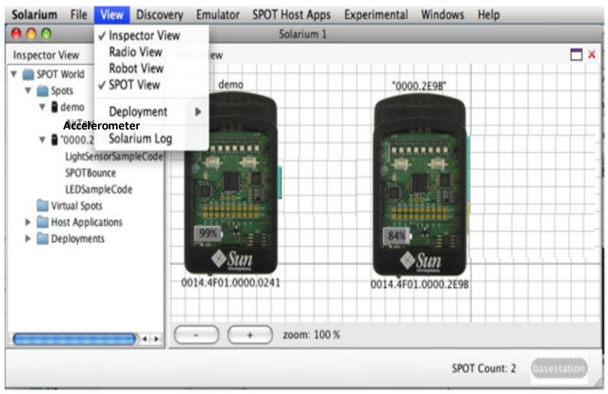

Figure 2. Solarium Application

The other platform used in the prototype of the tailgating detection system to facilitate the interaction of the accelerometer program written in Java and the SPOTs is NetBeans. The NetBeans platform is a reusable framework for simplifying the development of Java Swing desktop applications. It was used to compile, deploy and run the accelerometer program. The steps that were followed when using NetBeans to run the accelerometer program are as follow. First, the program has to be opened and set as main project. Second, it has to be cleaned and built. After these two steps, the output panel shows the output from the compile operation. This text ends with "BUILD SUCCESSFUL" and the time it took to build the object code as shown in Figure 3.

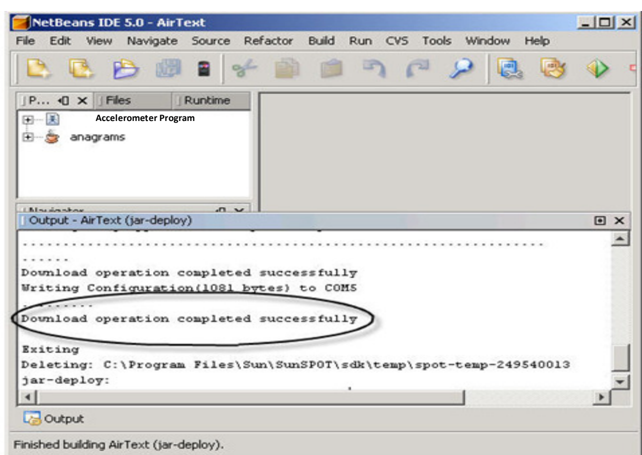

Figure 3. NetBeans Window showing that the operation was successful

4. SPOT ACCELEROMETER SENSOR SYSTEM

4.1 General Architecture of SPOT-based System

The free range SPOT is an embedded computer that has an accelerometer sensor incorporated to measure the orientation and motion in all three dimensions. The accelerometer wireless sensor system inside a free-range SPOT that is used for our design of the tailgate detection system monitors and measures the acceleration, and it constitutes a complete system with a base station, and a PC as illustrated in Fig. 4. The accelerometer sensor runs a program using Java that measures the acceleration motion of the door. The program was made using the 1.6.0_20 version of Java and was run in a Sony PC.

Figure 4. Elements of the accelerometer sensor network

Once the accelerometer sensor of a free-range SPOT embedded in the door has captured the acceleration data, this information is sent via wireless to the base station which is connected through a USB cable to the PC. The base station connects by 802.15.4 radio to the free-range SPOT. This free-range SPOT starts transmitting data to the base-station once the acceleration program is deployed and run on it.

The PC contains all programs that the SPOTs need to run the acceleration program, including the SPOT Manager [14] and NetBeans [15]. Additionally, the PC runs a program that analyzes the acceleration data. This program is created in MatLab and is able to make a file with the acceleration data, so this information can be analyzed for algorithm development for real-time tailgate detection system. Figure 5 shows the acceleration data vs. time after two abrupt changes in the door's acceleration.

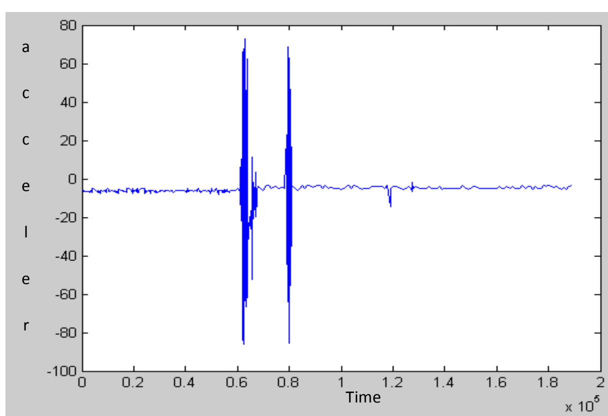

Figure 5. Acceleration vs. Time

Here, we discuss in detail the Free-range SPOT, base station SPOT, and the SPOT host software architectures, as well s the characteristics of accelerometer sensor.

4.2 Free-range Sun SPOT Software Architecture

The free-range SPOT is not provided of any operating system; therefore, the Squawk JVM runs on the bare hardware and provides low-level operating system support, as well as application isolation. The various SPOT libraries allow access to the SPOT device and basic I/O. This includes access to the low-level MAC radio protocol [16]. The Sun SPOT application, which extends the Java ME MIDlet class, runs on top of a number of libraries which constitute the free-range SPOT architecture. They provide an environment where a user-written SPOT application can access to a variety of sensors and communication components with which the free-range SPOT is provided.

4.3 Sun SPOT Host Software Architecture

The SPOT host software stack is comprised several elements. At the bottom of the stack is located the host operating system, that is, Linux, Windows, Mac OS X or Solaris. Just above the OS is a Java SE JVM along with all the regular Java class libraries. In the middle of the stack are the various SPOT libraries that provide access to the SPOT device, basic I/O, and the low-level MAC radio protocol such as USB connection to PC or socket connections to other host applications. One SPOT library provides higher-level radio protocols, such as radiogram and radio stream, and also takes care of routing of packets. Another gives access to a number of over-the-air commands that can be sent to a free-range SPOT. This includes the command used to discover SPOTs within radio range. Finally, at the top is the user-written host SPOT application, which is just a regular Java SE program. It can do everything a regular Java application can do: file I/O, display Swing GUI's, etc.

4.4 Base-Station SPOT Software Architecture

The base station SPOT software stack is constituted by two components, namely, squawk Java ME JVM, and the SPOTlib library. The host applications communicate with free-range SPOTs by using the base station's radio. Additionally, no user code runs on the base station; therefore, the host application runs solely on the host computer. On the other hand, the host computer sends packets to the base station via USB, which then sends them out over its radio. Similarly when the base station receives a radio packet it forwards it to the host application. The base station can also run on share-mode, where more than one host application uses the base station to broadcast packets, and where a socket connection is established as a medium through which packets received from other host applications are relayed to free-range SPOTs.

4.5 Accelerometer Sensor Architecture

Each of the free-range SUN SPOTs is constituted by a low-power, three-axis linear accelerometer sensor. The SPOT uses MMA7455L accelerometer that can be set to measure accelerations over a scale of ±2, ±4g or ± 8g. An accelerometer sensor can be visualized as a very small mass suspended in the center of the device by tiny springs. When acceleration is applied to the device, the mass deflects along one or more axes inside the device. Built-in circuitry constantly measures the amount of deflection along each axis and translates it into voltage data. Then the data becomes available to be read by an analog-to-digital converter, which receives as input a raw voltage and generates a digital signal [17].

The MMA7455L accelerometer is a low power, micro-machined a Micro-Electro-Mechanical System (MEMS) sensor capable of measuring acceleration along its X, Y, and Z axes [18]. The sampling rate of the accelerometer is either 125 or 250 Hz. The output signal from the accelerometer is read by the ARM9 processor and then converted to g-force units. The SPOT library includes the IAccelerometer3D interface that defines the basic methods to read any three axis acceleration in the free-range SUN SPOT. The MMA7455L accelerometer classes implement the IAccelerometer3D interface along with methods specific to the sensor.

5. Design and Algorithm for SPOT-based Tailgate Detection System

The sensor-based tailgate detection system is formed by a door-embedded SPOT with internal acceleration sensor and wireless transmitter unit, a receiver formed by a base-station SPOT, a PC, and an alarm indicator such as speaker or LEDs (light emitting diodes). The accelerometer MMA7455L [5] accelerometer used in the SPOT is set to measure accelerations over a scale of ± 2g. The free-range SPOT collects the signal of door movement continuously and transmits the signal wirelessly to the base-station SPOT, which at the same time uses a serial port to transmit via USB the data to a PC, where a program running constantly storages and analyses them.

In practical installation, the free-range SPOT can be placed inside or outside the door near the door handle or any place of the door without compromising the dimensions or functional features of the space, while the receiver or base station (another SPOT), the PC, and the alarm can be remotely located in a security room or any place to monitor the door access. The alarm is connected to the PC to generate an alarm when there are two or more unauthorized people trying to access through the door. The diagram of the sensor-based tailgate detection system is shown in Figure 6.

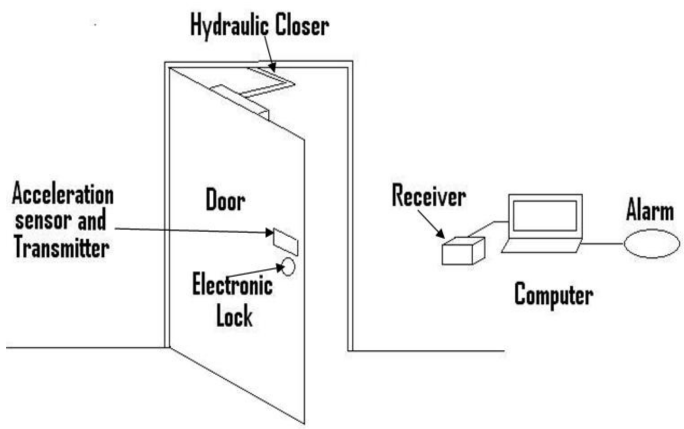

Figure 6. Diagram of the single person and tailgate detection system for doors.

The analysis of the characteristics of the acceleration signal will determine if a tailgate condition is occurring. Figure 7 shows a single cycle of acceleration sensor signal for door opening/closing followed by a much faster multi-cycle noise for the door contact moment with the door frame when a person opens the door and enters an area.

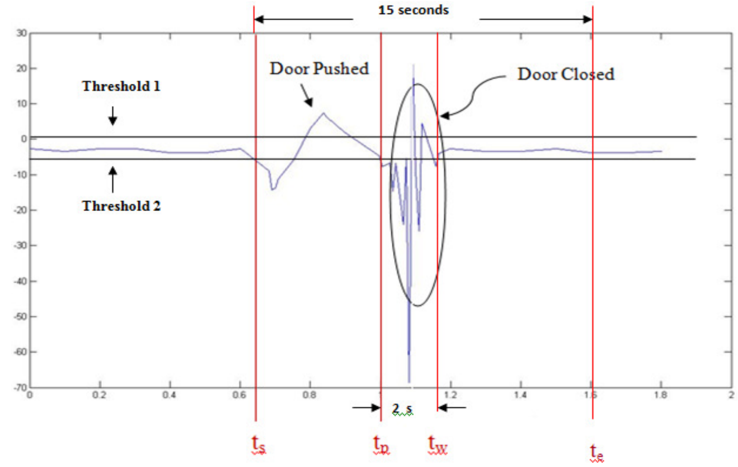

Figure 7. Acceleration signal of a single person entry condition.

When the door contact noise is ignored, the door movement signal for a door with a hydraulic closer under single entry is characterized by a low frequency full cycle as an indication of door opening and closing without any interruption in the signal pattern. However, as illustrated in Figure 8, when other person(s) tailgate a person, then the usual door movement signal is added with another cycle of similar door open/close signal followed by the same door contact-generated faster multi-cycle noise.

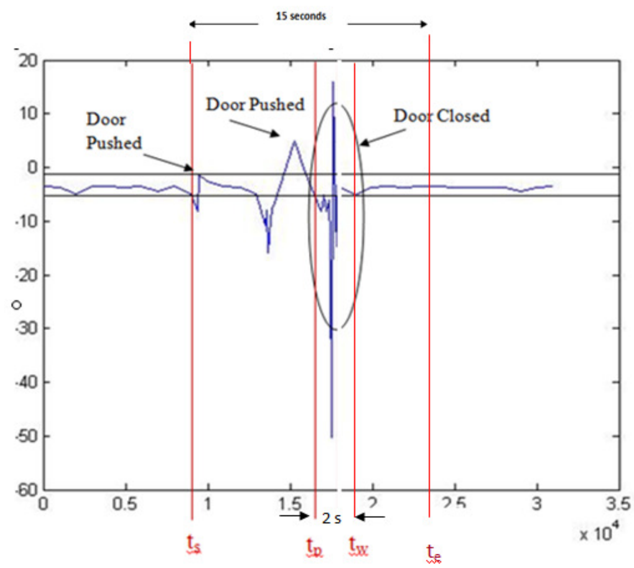

Figure 8. Acceleration signal of a tailgate condition.

The two cycles of the signal, unequal magnitudes and unequal frequencies, result from the first door opening and closing movement and, even before the movement is not completed, immediately following next door opening and closing made by the second person. When the door contact noise is ignored as above, the door movement signal for a door with a hydraulic closer under tailgate entry is characterized by two or more concatenated cycles of different low frequency signals.

6. TAILGATE DETECTION PROTOTYPE AND INITIAL TESTS

The wireless sensor based tailgate detection algorithm is executed on a PC which receives data from a base station SPOT. The algorithm developed for the prototype is summarized in a flowchart of Figure 9 and each step of the algorithm is explained here.

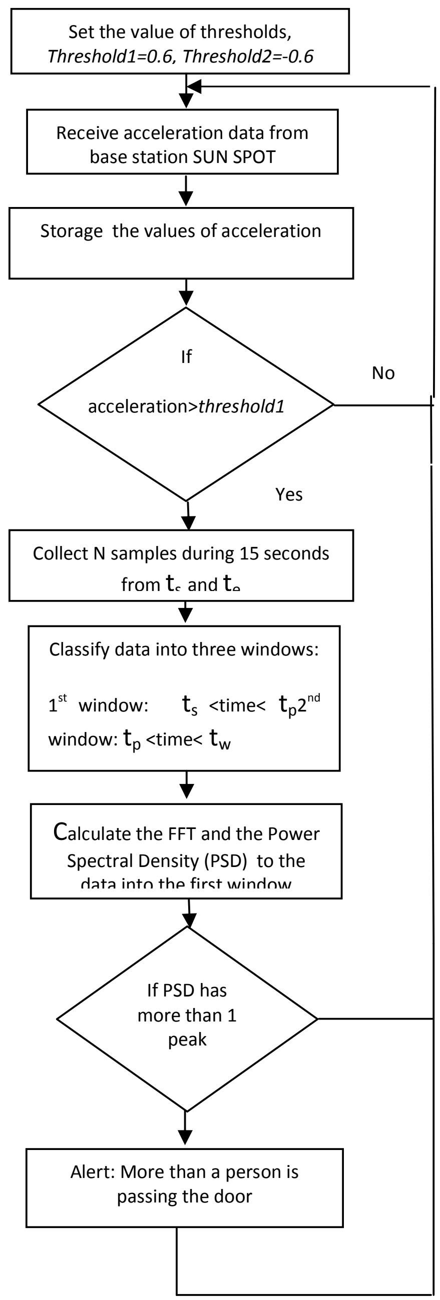

Figure 9. Flow chart of sensor-based tailgate detection algorithm.

The algorithm analyzes constantly acceleration data following a set of stages to detect and alarm piggybacking. The algorithm seeks to detect the first time where the acceleration is above or below a range defined by a set of thresholds (positive and negative as horizontally lined in figure 7 and 8), and whose levels can be acquired from experience or heuristics. This point is called ts, and is set to detect the door opening/closing signal. Then, a number of N samples are collected for the next 15 seconds until a time te. The sampling rate used in the PC needs explanation since the rate is much different, slower, from that of the accelerometer of the free-range SPOT. Even though the sample rate from the MMA7455L accelerometer is of 8ms or 4ms, delays due to storage, and transmission in the free range Sun SPOT, which are higher than 8ms, reduce considerably the minimum rate at which the acceleration have to be read without loss of information. That is, the transmission rate of the free range Sun SPOT is 250kbps, which means a 128-byte packet would take 4.096ms to be transmitted. However, there is an overhead of sending the MAC and LowPan packet header information, which can be over one fourth of the packet of 128 bytes, so that reduces the payload data rate to 187.5kps.

Additionally, a time of 1.2ms is added for the SPOT to stuff the data in the packet before it can hand it off to the radio code, bringing the payload data rate down to 145kbps. The SPOT radio stack deliberately introduces a 15 msec delay after sending a packet so that one SPOT does not use all of the radio bandwidth. This delay increases (by 5-15msec) for packets sent over multiple hops so that the next packet sent does not collide with the retransmission of the previous packet. Adding in the delay and the payload data rate is now down to about 38kbps. Another few milliseconds for other overhead such as checking the route to the destination, waiting for the ACK packet, flow control for a RadioStream, becomes data rate about 30kbps; namely, a 128-byte packet would take about 42.6ms to be transmitted. For our application, one sample every 80 ms, which is higher than 42.4 ms, experimentally guarantees that the sensor data has enough time to be arrived at the PC for real-time analysis for the algorithm execution for our tailgate detection system.

By the much reduced rate of one sample every 80 ms in the PC and signal analysis, the number of samples collected during 15 seconds is approximately N≈187. Additionally, the last pulse point above or below the thresholds within 15 seconds is called tw., this point is used as reference to select a range of data which begins at tw and ends in a point called tp.

Then, the acceleration data is selected from ts (first time the acceleration is above or under the range defined by threshold 1 and threshold 2) to tp. This is a critical range that will define when one or more people access the door. Figure 10(a) and 10(b) show the two situations that have to be analyzed. Figure 10(a) represent the acceleration behavior when one person access the secured area, while, figure 16(b) shows the acceleration between ts and tp when more than one person has had access to this area.

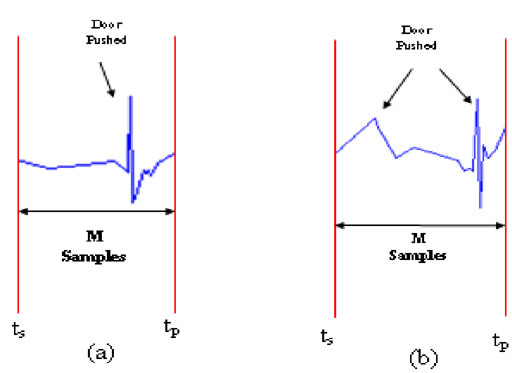

Figure 10. (a) Acceleration between points – t_s and t_p- when one person accesses the door. (b) Acceleration between points - t_s and t_p- when two people access the door.

The next step of the single person and tailgate detection/discrimination is to do frequency analysis for the event signal segment between ts and tp. A simple signal analysis method is the Discrete Fourier Transformation (DFT) but other method such as Wavelet analysis can also be applied to find the frequency component of the event signal segment. For this work it is used the Discrete Fourier Transformation to analyze the acceleration signal that is previously sent by the acceleration sensor to the PC.

Figure 11 shows the DFT result of the event signal of Figure 10(a) for the case of a single person gaining access to the secured area. It shows only one peak detected above a certain threshold, 0.03 for example. This threshold can be adjusted and the system is able to continue working properly. In the case of single person entry the tailgate detector does not trigger the alarm. It can be appreciated that the DFT results are very accurate establishing when one person is having access through the secured door.

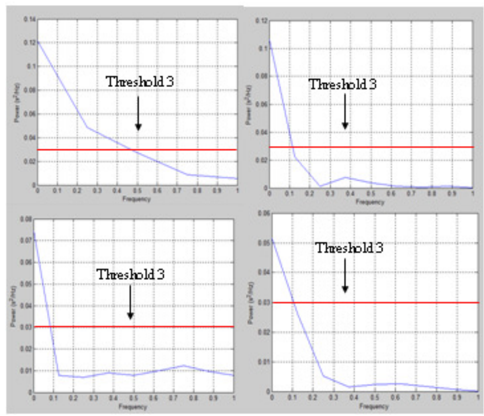

Figure 11. Power spectral density for single person entry.

On the other hand, as illustrated in Figure 12, the DFT result of the event signal of Figure 10(b) (multiple person entry case) which shows 2 peaks above the threshold. In this case, the algorithm alerts of multi-person or tailgate entry. These four graphs show clearly that the calculation of the DFT when two or more people are having access through the secured area is very accurate because we get always the same pattern (two or more peaks above the threshold). It can be possible to get more than two peaks above the threshold when more than two people are tailgating a person. In the last case also an alert is triggered. Therefore, the number of peaks is the determinant factor that detect if the door was correctly opened or not.

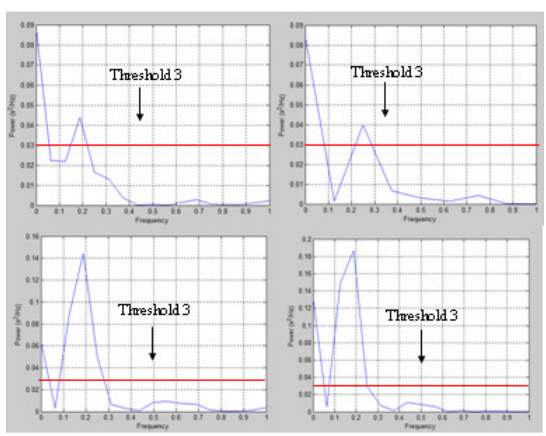

Figure 12. Power spectral density for tailgate entry.

As a preliminary test of the algorithm and the entire detection system, a number of 200 tests using the designed platform were carried out in which 100 tests corresponded to single entries, and the reminder, tailgates. As summarized in Table I, the result showed that 93% of the data was classified successfully as tailgate and a similar success rate for single entry classification, which demonstrates a potential of the detection system in robust detection of tailgate entries.

Table 1. Preliminary Test Result of the Detection System.

Predicted				
		Single Entry	Tailgate	Total
Test Cases	Single Entry	94	6	100
	Tailgate	8	92	100
Success Rate		92.16%	93.88%	

7. Conclusions

The paper described a design and prototype of an economical tailgate detection system implemented using the SPOT wireless platform. The detection system tracks the acceleration of the door constantly through a built-in accelerometer sensor of a free-range SPOT that is installed inside the door to detect and alarm any unauthorized access. These acceleration signals are transmitted to a base station SPOT which in turn send them via USB to a PC, and in the PC they are analyzed in both time and frequency domain. The detection algorithm developed determines if one or more people are attempting to get access to the secured area. When the system detects that more than one person has gained access to the secured area, it provides an output by triggering an alarm, thereby adding a security layer to the existing access control system, unnoticed to the person.

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AUTHORS

Andres Alarcon-Ramirez is a PhD student in Electrical and Computer Engineering at Howard University. He received his M.S. in Computer Engineering from University of Puerto Rico (2009), where he was a research assistant for The Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems. He also received a M.S. in Electrical Engineering (2006), and his BS in Electrical Engineering (2003) from Universidad del Valle (Cali-Colombia). Currently, he is working as research assistant at the Electrical Department at Howard University.

Madeline Martinez received her BS in Electronic Engineering (2007) from Industrial University of Santander (Bucaramanga, Colombia). Currently, she is an M.S student in Electrical Engineering at Howard University and has worked on several areas such as Telecommunications and Power Systems. Madeline's research interest includes safety analysis of Telecommunication Networks and sustainable energy systems.

Charles Kim (M'90, SM'06) received a Ph.D. degree in electrical engineering from Texas A&M University (College Station, TX) in 1989. Since, 1999, he has been with the Department of Electrical and Computer Engineering at Howard University. Previously, Dr. Kim held teaching and research positions at Texas A&M University and the University of Suwon. Dr. Kim's research interests include failure detection, anticipation, and prevention in safety critical electrical/electronic systems in power, aerospace, and nuclear industries.