Social Impact

There is a significant market for tracking and data collection of human movement through space. This has many applications outside of an academic environment in spheres such as commercial and residential spaces. By creating a wireless sensor system that monitors foot traffic in an area, it becomes possible to observe how a space is being used. This information can give insight into human movement patterns that can be used to optimize space layouts and building environmental usage. The wireless sensor system developed in this research has been designed to help analyze human activity in spaces.

“We envision a system in the future that allows students to locate a study space at any of the viable locations around the University.”
Abstract
Rice Hall is the School of Engineering and Applied Science’s newest building dedicated to information technology and engineering research. Due to its centralization around technology and collaboration spaces, Rice Hall has quickly become a popular studying and working location for students at the University of Virginia. Many of the collaboration spaces have easily accessible power plugs and monitors to allow students to quickly share their content. This project looks to develop a sensor system for determining occupancy of these study spaces, or “nooks”, and relaying that information to students on a unified platform. Using commercial off-the-shelf technologies, the project aims to create a low-cost fully functional system. These technologies include the Texas Instruments MSP430 microcontroller, ZigBee wireless modules, and Parallax passive infrared sensors. With a custom-designed 3D printed enclosure, each study space will be equipped with a system that counts students who enter and leave the study space. This data will be relayed to a central server where it is stored for user retrieval in a mobile or web application interface. Testing will occur in the Rice Hall study spaces to improve the design. A fully functional system is easily scalable into a university-wide application and can be translated into different disciplines such as retail or environmental research. The system would involve the integration of sensors, such as passive infrared sensors, ZigBee wireless modules, TI MSP430 microcontrollers, a datastore, and user interface to calculate and display data. With such a system combined with a web service through Google App Engine, we created a complete solution that senses people in a space and can be applied to applications like energy usage monitoring.

Introduction
At the University of Virginia’s Information Technology building, Rice Hall, faculty and students have access to state-of-the-art study spaces. Each nook is equipped with dry erase boards and flat screen televisions to encourage group work and collaboration (Figure 1). Students spend time traversing the entire building in the hopes of finding a place to work due to the popularity of the study nooks. Currently, no system exists to detect if these areas are occupied or available. The issue with these types of spaces is their architecture. Each nook is open and does not have a door restricting access to it (Figure 2). Since there is no defined entry or exit point, it is challenging to determine when people are using the area. The issue becomes even harder to resolve when multiple people are in an enclosed area. A system that accurately tracks human activity in an area has to be able to monitor multiple people at a time.

Figure 1. The computer design of the nook is the initial testing site for this project. The sensor system has to be able to detect when the space is occupied even with the absence of a door.

Figure 2. A partial floor plan of Rice Hall with the nook (316 Collab Space).
video cameras or webcams. However, these systems are costly and computationally expensive, and come with a plethora of privacy concerns.

Other occupancy systems, such as those by Dr. Kamin Whitehouse at the University of Virginia, count the number of individuals passing through a doorway using an ultrasonic sensor (Dawson et al., 2012). The ultrasonic sensors add a level of complexity, as the signal processing is more advanced and the sensors are more expensive. While these systems offer interesting ways of detecting presence, Rice Hall provides new and unique opportunities.

Method

Overall architecture

The system design includes two subsystems that share a common server for data storage and retrieval (Figure 3). The in-space sensor package records entries and exits from the study spaces. The microcontroller setup relays that information to a central node which is responsible for correct entry into a database. The database of information acts as the back-end for the second user interface that translates occupancy counts into usable and readable information for students.

Researching other designs

The design process involved the consideration of a wide variety of sensors. Through this process, sensor system designs were evaluated based on cost, reliability, energy usage, intrusiveness, and effectiveness. The results and research show that one sensor technology may not be sufficient for the level of precision needed to reach an effective solution (Jisha, 2010). The team actively researched, tested, and modeled system structures that maximize utility. Based on the various models that have been tested and researched, the team has designed a sensor system layout for one study space that will increase reliability of people detection (Bai, 2008). Further research will provide insight for adding new features, such as people counting and expanding into different study spaces (Hashimoto, 1997). Research shows how to best optimize sensing technologies for tracking presence in any type of area, regardless of the shape or structures inside (Yoshiike, 2007).

TI MSP430 microcontroller

The main component of this system is the microcontroller responsible for data collection and communication. The TI MSP430 microcontroller was chosen as the most viable option to use in this low power solution (Figure 4). Another consideration for using the MSP430 is that the current developer board is sold for less than $5 direct from the manufacturer. This low-cost product is a suitable development option because it requires minimal configuration to use. Part of the research done for this project has been to analyze how this microcontroller is used in other sensor systems and how to best optimize its functionality for both communication and sensor data collection. The processor has many input/output ports and a powerful clock system that allows for multiple digital peripherals and communication simultaneously.

ZigBee wireless protocol

It was crucial that the human tracking application developed for this research be wireless in order to increase its convenience and marketability. To allow for the most modular approach, the team decided to use a wireless RF specification to send information from the study space to a central hub where the information could be collected. Through the research, it was determined that the ZigBee wireless protocol is an affordable option that offers rapid interfacing to the microcontroller, low power consumption, and a “self-organizing” system (Song, 2008; Zhang, 2007). This technology is built on mesh networking, a protocol that requires
low hardware overhead and fast, efficient communication. In this project, the pre-packaged XBee module was chosen to implement the ZigBee protocol, which allows for simple configuration and maintenance for wireless communication. The module natively supports the serial protocol (UART) that is output from the TI MSP430 to make the software interface easy to use on the server end. After testing, it was determined that the range in Rice Hall for the XBee modules is about 45-50 feet which includes the in-building interference. Currently, more powerful modules are being investigated that could allow an in-building range close to 100 feet. This could increase ZigBee’s effectiveness for this project and help minimize the amount of equipment needed to encompass an entire building.

**PIR Sensor**

This project’s current approach for detecting people in the nooks is to use a linked system of three passive infrared (PIR) sensors. We selected the Parallax PIR Sensor for motion detection and people counting, as it is the current industry standard (Figure 5). The simplicity of infrared allows us to detect humans in the study space, as the change in temperature will trigger the sensor and report the high voltage to the microprocessor. The Parallax product is digital, thus the guesswork of analog voltage thresholds for high and low states from the IR sensor are bypassed and the detection algorithm on the processor is streamlined. The current configuration has two PIR sensors in conjunction to count people and a third PIR sensor to verify the people in the occupied space. The two PIR sensors are adjacent to each other and are blinded on the sides so that each one can only detect a narrow beam in front of them. Each time a person enters or exits a nook, the beams will be broken sequentially and based off which beam is broken first, it can be determined if an individual walked in or out. The third PIR sensor is kept in the space to detect human motion at all times. This last sensor is crucial in detecting idle time in study spaces. With this counting beam and spatial beam, we can achieve a more accurate reading of the space and deliver better results.

**Algorithm**

To tie the hardware to actual functions, the microcontroller needs to be programmed to accept data from the sensors and relay that information to the server. The MSP430 is programmed in the C language which is used widely in embedded systems applications and low level operating systems. The program in C needs to be simple so that the microprocessor is programmed once and can be deployed into the nook without further configuration.

To have accurate information about the occupancy count inside of study space, a simple algorithm was designed to detect direction. Two sensors are motion triggered and the program records their relative timings. If the sensor closest to the exit is triggered first, it is clear that the individual was entering. The microcontroller will send a message to the central hub indicating the direction of movement, and the server stores the net in and out movements to have an accurate count of occupants at any given time (Figure 6). The datastore, controlled by Google App Engine, is a running log of the daily activity that can be used for data analysis.

![Figure 5. The Parallax PIR sensor.](image)

![Figure 6: The flowchart explains how the algorithm running on the microcontroller works. The system determines if a person enters or exits the study space based on which PIR is triggered first.](image)

**Modeling**

In order to maintain a small physical footprint in the study space and minimize construction costs, a custom enclosure was designed for the detection system using Autodesk Inventor. Custom designing in 3D allowed us flexibilities which traditional manufacturing models did not (Senese, 2012). Instead of shopping around to find an enclosure that fits the hardware, the team was able to create their own enclosure design that would minimize the space occupied while providing maximum protection. Using U.Va.’s Rapid Prototyping Lab, the team was able to print out multiple enclosure designs and test for functionality. Through this process, the
initial design was streamlined to create an inconspicuous and efficient enclosure to hold the sensor system (Figure 8). Not were we able to complete a design review prior to incurring any construction costs, but we were able to make significant design modifications instantly. One modification involved joining the squares that contained the sensors to provide more space. The second change modified the thickness on the back of the enclosure’s sliding case so the enclosure could support the entire weight of the embedded system. On the first prototype design there were problems with structural integrity as the thickness of 0.1” was an issue on the joints on the model (Figure 7). Once the design was finalized, the only cost associated with manufacturing was the material itself, regardless of the number of units printed - which allows for quick scaling.

The enclosure was constructed with ABS plastic, a lightweight yet durable type of plastic which allows for it to be mounted in the nook (Figure 9, Figure 10).

User interface

With a sensor network in place, the information will be presented to users in the form of a simple and clear web and mobile interface. Once the data from each nook is stored in the “cloud” using via Google App Engine, the project website pulls nook information from the server and displays it to the user.

Future Work

Future work entails solving a difficulty with tracking simultaneous entry of people, creating a mobile application, and designing a customized circuit board to further minimize the design. Currently, when two or more people enter the space at the same time, the PIR sensors cannot detect the quick movement due to the nature of the rise and fall of the voltage in the PIR sensing circuit. We are currently exploring if different hardware could solve this difficulty or if the system’s third sensor may correct the simultaneous entry altogether. A mobile application would increase the project’s reach, allow the project to expand to other areas, and make the system even more accessible to students. The team is also working on finalizing a design for a custom printed circuit board (commonly referred to as a PCB), using the computer aided circuit design software, Ultiboard, by National Instruments. Creating a custom circuit board will reduce most of the components to a single board, thus significantly reducing our footprint. On this board will be the ZigBee wireless module and the MSP430 microprocessor with their respective decoupling capacitors, status-indicator light-emitting-diodes, and a voltage regulator.

There is value in knowing the amount of people that occupy a space in new applications like smart building energy management systems. Buildings can be made more efficient by optimizing system usage for areas based on their occupation density. Rice Hall currently has a “living lab” to monitor
building usage and our data could tie in directly to the building's systems in the future. The data collected from this research could be shared with university administrators which would allow them to make better informed decisions about building usage in the future.

Conclusion

The original motivation behind this project was to supply students of The University of Virginia with an easy way to find available study spaces within one of the most popular studying spots for engineering students. Upon completion, this project can be easily modified to function in a variety of studying environments, or “learning commons,” around the University (Britto, 2011). We envision a system in the future that allows students to locate a study space at any of the viable locations around the university. Our data shows that a counting system cannot be the only solution to detecting presence in a space; the system will need to be augmented with more sensors that will allow for more accurate detection.

Though on the surface our research will culminate in a tangible application, there are deeper themes and fields that could possibly utilize our work and the data that it provides. At its core, the system tracks the movement of people in and out of a certain space. The data that is collected will provide insight into the behavioral patterns of students in these environments. Researchers across fields could be very interested in these patterns and their implications, especially with the rapid growth of public study spaces in educational institutions (Bennett, 2009; Donkai, 2011). Rice Hall was built as a “living laboratory” that collects large amounts of environmental data regarding the efficiency of the building. The team’s research and application can provide very interesting correlations between the movement of people and how it impacts the efficiencies, temperatures, and usage patterns within the building. The system promises great benefit in the University community, and it offers great promise to expand research in many other fields of interest.

Acknowledgements

We would like to thank Dr. Archie Holmes for being our faculty advisor and mentoring us throughout this project. In addition, we would like to thank the Electrical and Computer Engineering Department at the University of Virginia for their assistance with this project.

Works cited


