Sensor-based Hospital Staff Detection and Monitoring System

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I spent four years in the Marines after high school. I then enrolled at Devry to pursue a degree in biomedical engineering technology. I have always been interested in electronics and how they work.

Kulsoom Ahmed
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Abstract

This paper describes the design and implementation of a senior project based on sensor technologies to monitor staff in a hospital environment. In a hospital setting, it can be challenging to monitor how many people, be it visitors or hospital personnel, are in a patient’s room at any given time. This project attempts to solve multiple aspects of potential improvement with regard to hospital room entry, exit, and the subsequent monitoring of occupancy.

There are three main problems that today’s current hospital room access lacks. First are the obvious security concerns that can arise when the hospital staff does not know who is in a patient’s room. Hospitals have strict visiting hours and it is not always possible to know when someone might enter a room out of that time frame. Second, knowing where the closest nurse or doctor is on a floor can often make an enormous difference should an unexpected medical emergency occur. Nurses and doctors are very busy and it is often not immediately known which room they may be in. Finally, room entry in and of itself can be hazardous. If a nurse is carrying heavy equipment into a dark patient room, through a heavy door, it presents a very serious slip and fall incident.

This paper describes the approaches used to solve all of these issues by developing a single point access and monitoring system. Using individually coded RFID tags and motion sensors, the system makes it possible to know not only if someone is in the room, but if that person is a doctor, nurse, visitor, or other hospital staff. Additionally, it allows for hands free access into a room while simultaneously providing a light for safe entry.

The paper covers the details of a system that mounts above the inside and outside of each hospital room. The LED occupancy indicators are located on the outer box, color coded to identify specified roles. A microcontroller was designed that would be able to receive inputs from an RFID module and ping sensors through I2C communications and interpret that data to perform required tasks. Each RFID card is programmed and identifies a specific person – doctor, nurse, visitor, etc. As a person passes through the door, the RFID module recognizes the card, sends the data through the PCB, where it will then activate the corresponding LED, indicating which type of person is now in the room. The ping sensors work in conjunction with the RFID module. As a person is detected by the outer sensor, the software will wait for the inner sensor to be activated, which will send the signal that someone has entered the room. Conversely, if the inner sensor is activated, followed by the outer sensor, the signal is sent that that person has exited the room.

The paper also describes three additional functions that have been incorporated to compliment the main task of monitoring. First, is the ability to automatically lock and unlock, or potentially automatically open and shut the door. When the sensor recognizes that someone is approaching the door, the MCU will send a signal through a low voltage controller which will operate the 120VAC supplied mechanism. This provides hands free access to the room. Next is the system function to activate an internal light for safe, illuminated entry into the room. This is accomplished similarly to the automatic door. The MCU will again be notified of an
approaching person and will send a signal turning on the 120VAC powered light source. Finally is the capability to integrate with the hospital’s CODE BLUE system. When activated by a person inside of the room, the system will process the signal and activate a flashing blue LED on the outer panel, notifying which room the CODE BLUE is taking place. By integrating all of these functions into one device, it is now possible for hospital staff to know, simply by viewing the room’s access panel, who is in that room. It allows for safe, hands-free access. And most importantly it integrates seamlessly with the hospital protocol and allows the hospital staff to function more efficiently with respect to patient monitoring and response. The paper covers the details of the design of hardware and software components of the system.

I. DeVry University’s Senior Project Capstone Course Sequence

DeVry University’s Electronics Engineering Technology program senior project is a four session course sequence in which students synthesize knowledge and skills learned in the previous courses. In the first course (ECET-390 Product Development), students research, plan and develop a project proposal. In the next three courses (ECET-492/493/494), Senior Project Laboratory) students implement the project plan by building and testing a prototype. A typical project involves a solution to a software/hardware based engineering problem. The process of developing and implementing a solution to the problem offers a learning opportunity for students to gain new insights and competencies as a result of “constructivist” and “deep learning” teaching/learning approaches.

II. Project Overview and Objective

Hospitals are tending to a lot of patients on daily basis. In case of emergencies and/or daily patient care, urgent assistance may arise that requires quick and organized response from staff. It’s also important to limit access to patients for security reasons and/or safety, that in case of air born or incurable diseases. The hospitals need monitoring systems which can perform to:

a. Improve staff-to-staff or patient-to-staff communication.

b. Provide safer environment without additional resources.

c. Improve critical/emergency rapid response.

d. Provide supporting evidences determining accident cause and analysis.

e. Increase efficiency through better time management.

The objective of the project was to design a system that will perform predetermined tasks according to following requirements:

a. The final product should be neutral in appearance and easy to mount.

b. The product should have an IP65 rating with microbial painted surface to limit potential risk of bacterial growth while being impervious to harsh hospital disinfectants such as alcohol, bleach etc.

c. It should have low power consumption capability while on standby.

d. The dimensions should not exceed the typical door frame.
e. The product should implement a color-coded indicator per the staff’s unique IDs (RFID tag) upon entrance and departure of secured area:

- **Green** identifies RN or Nurses
- **Yellow** identifies PTC or Patient-Care Technician
- **White** identifies Doctor
- **Blue** identifies an Emergency or Code Blue

The staff member will be able to initiate Code Blue at which point the blue LED will blink over the door, indicating the location of the emergency to other hospital staff members. Leaving the room without one’s ID will not turn off the light, indicating to staff member has lost/left the ID while in the room. Figure 1 illustrates a technical overview of the project viz a viz problem statement, systems available in the market, proposed solution and the system description.

The general approach used to develop the prototype is described as follows:

1. First the team researched all hardware components in order to find those that are affordable and meet the system requirements.
2. The next step was to acquire the components and perform component testing.
3. The following step was software acquisition; the environment being used, as well as the compilers, needed were downloaded.
4. Next the pseudo code for the end functionality was written. After this, the code was written to preprogram the automated functions.
5. Finally system was implemented and hardware and software interface was verified, and system was mounted and tested.

### III. Resources

The main hardware devices used are listed below:

- Enclosure (to be mounted above door frame)
- Remote RFID receiver
- Low Voltage Controller (LVC) door opener
- Ping Sensors to sense people approaching
- RF Sensors to turn on:
  - Code Blue
  - Nightlight

Table I lists all the components used and their price breakdown. Hardware design was completed using the following tasks:

1. Research LED driver options (four LED drivers with enable pin)
2. Research LEDs and layout/optics (Blue, Green, Yellow, White, see Figure 5)
3. Analyze and design power management (PSU, step down converters for CC (constant current) & CV (constant voltage) applications.
**Problem:**
Hospitals are tending to a lot of patients on daily basis. In case of emergencies and/or daily patient care, urgent assistance may arise that requires quick and organized response from staff. It’s also important to limit access to patients for security reasons and/or safety, that in case of air born or incurable diseases.

**Already Available:**
1. Clinical-Grade Locating™ – CenTrak delivers certainty-based location data covering entire rooms and hallways, rapid location updates, and extreme battery life. (“Clinical-grade locating solution,” 2014). ¹

**Solution:**
1. Improve staff-to-staff or patient-to-staff communication.
2. Add a benefit of safer environment without additional resources.
3. Improve critical/emergency rapid response.
4. Provide supporting evidences determining accident cause and analysis.
5. Increase efficiency through better time management.

**System:**
1. Microprocessor based central intelligent system.
2. RFID UHF low power ID tags.
3. Dual distance sensors and RFID receivers.
4. Color coded response system with automated door and lights controls.
5. Refer to Figure 3 for the block diagram.

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**Figure 1:** Technical overview of project.
4. Allocate MCU PIC16F1829 pin assignments, and interface I^2C and RFID communications.
5. Design automatic door lock/unlock through low voltage controller with UL508 certifications.
6. Do PCB component research and calculations.
7. Create main PCB schematic and PCB layout.
8. Build and test final hardware design.

**Table I: Bill of Materials**

<table>
<thead>
<tr>
<th>Components</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID Module - SM130 Mifare (13.56 MHz)</td>
<td>1</td>
<td>$29.95</td>
</tr>
<tr>
<td>RFID Tag - Transparent MIFARE 1K (13.56 MHz) 6 tags</td>
<td>1</td>
<td>$17.70</td>
</tr>
<tr>
<td>RFID Evaluation Shield - 13.56 MHz</td>
<td>1</td>
<td>$19.95</td>
</tr>
<tr>
<td>Main PCB components - total 86 parts</td>
<td>1</td>
<td>$42.26</td>
</tr>
<tr>
<td>PCB board - FR4 1.6mm dual layer</td>
<td>1</td>
<td>$65.00</td>
</tr>
<tr>
<td>LED - 10W Green, Blue, White, Yellow</td>
<td>20</td>
<td>$32.00</td>
</tr>
<tr>
<td>LVC - Low Voltage Controller</td>
<td>23</td>
<td>$22.50</td>
</tr>
<tr>
<td>PSU - Astrodyne 120W IEC60601</td>
<td>35</td>
<td>$34.60</td>
</tr>
<tr>
<td>Fan - Capacitor (Semiconductor SIM Model)</td>
<td>1</td>
<td>$12.00</td>
</tr>
<tr>
<td>Chassis Box - Aluminum 17 x 8 x 3</td>
<td>1</td>
<td>$37.86</td>
</tr>
<tr>
<td>Cover - Aluminum 17 x 8</td>
<td>1</td>
<td>$12.45</td>
</tr>
<tr>
<td>Junction Box Wire Clamp</td>
<td>2</td>
<td>$5.50</td>
</tr>
<tr>
<td>3/4&quot; Hole Saw w/ Pilot Drill</td>
<td>1</td>
<td>$17.00</td>
</tr>
<tr>
<td>Silicon</td>
<td>1</td>
<td>$12.64</td>
</tr>
<tr>
<td>RF Sensor</td>
<td>2</td>
<td>$40.00</td>
</tr>
<tr>
<td>Ping Sensor</td>
<td>2</td>
<td>$60.00</td>
</tr>
<tr>
<td>LED light</td>
<td>1</td>
<td>$10.00</td>
</tr>
<tr>
<td>Arduino</td>
<td>1</td>
<td>$40.00</td>
</tr>
<tr>
<td>Batteries</td>
<td>3</td>
<td>$20.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>99</strong></td>
<td><strong>$531.41</strong></td>
</tr>
</tbody>
</table>
IV. Personnel

Table II lists team members’ assigned tasks. Figure 2 illustrated the planned Gantt chart.

Table II: Members and Assignments

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Assigned Tasks</th>
</tr>
</thead>
</table>
| Kulsoom     | a. Project Management (1\textsuperscript{st} half of project)  
b. Software  
   i. Creating Pseudo code  
   ii. Coding/Pre-programming functions of system. |
| William     | a. Ping Sensor  
   i. Research and testing  
b. RF Sensor  
   i. Research and testing  
c. Nightlight  
   i. Research and testing  
d. Software support for Kulsoom  
   i. On Ping, RF, and Nightlight |
| Ryan        | a. Enclosure acquisition  
b. Bi-weekly reports/presentations (2\textsuperscript{nd} half of project) |
| Chris       | a. RFID Sensors  
   ii. Research and testing  
b. Software support for Kulsoom  
   iii. On RFID sensors |
| Andrew      | a. PCB design and construction  
   iv. Research and testing  
   b. Hardware construction  
   v. Integration of all hardware portions  
   c. Software support for Kulsoom  
   vi. On familiarization with software environment |

V. Technical Details

Figure 3 presents the block diagram of the project. Figure 4 illustrates the logic diagram of the project.
Figure 2: General Planned Gantt Chart

Figure 3: System Block Diagram
Figure 4: Logic Diagram of project functionality

Figure 5: Testing of LED lights
Figure 5 illustrates the testing of LEDs. The next step was to choose MCU that incorporated following features:

1. EEPROM to store the ID numbers
2. Internal oscillator
3. I²C serial communications
4. Free software and compiler support

For this task the team chose Microchip PIC16F1829 which has following features:

1. 32 MHz internal oscillator
2. 256 bytes EEPROM
3. SPI and I²C serial communications
4. Microchip provides free debugging software (MPLAB X)
5. Free compiler XC8

Because of the possibility of all the LEDs being ON at the same time (all colors), creating a lot heat, as seen in Figure 6, the team also implemented a fan control that would switch the fan at predetermined temperature levels. For this task the team employed Microchip TC653 intelligent fan controller. Additional features, than can also be implemented into the design, are the FAN FAILURE FAULT, OVER TEMPERATURE FAULT and FAN SHUTDOWN. The final step was to create a schematic (per the manufacturer’s specifications) and PCB layout (Figure 7).

Figure 6: Thermal Pictures of LED lights
The RFID module system was easily programmed through an Arduino Uno to get the RFID system up and running. The module would read the serial number of a scanned card and then output the data to a location specified in the programming of the module. The cost of the module was low in comparison to the customer reviews and overall satisfaction and performance.

The system was user friendly to program since it was easily setup through an Arduino Uno and is adaptable through many different boards that are similar to Arduino. The RFID tags and reader operate in the 13.56 MHz frequency spectrum. The tags are passive tags, this means that they do not require a power source and activate when a signal from the reader is sent to the ID.
The ping sensor\(^6\) was easily programmed through an Arduino Mega\(^7\). The ping sensor would react to the proximity of an object and display the distance of object was to the sensor. The sensor was easy to program because of the test code being available in the Arduino code editor. The pins on the ping sensor consist of one 5V input and ground output with a single pin for input and output of a signal. It had a narrow acceptance angle and the range was useful from one inch to ten feet. The return pulse range was from 115 us to 18.5 ms. Its operating frequency is 40 kHz. Figure 8 illustrates the ping sensor.

![Ping Sensor](image)

Figure 8: Ping Sensor

As the team began acquiring the hardware for the system, the team needed to figure out how best to mount and enclose primary hardware into a single unit. The goal was to minimize a bulky appearance in order to produce a professional, hospital grade device. To select the size of the enclosure, the team gathered the hardware and arranged it in a manner that the team thought might work best. For the main enclosure the team settled on a 17” x 8” x 3” box. The material selected was aluminum. Plastic was also seriously considered because the reduced cost and ease of modifications. However, aluminum provided a lightweight, durable option that also provided important heat dissipation qualities. With each LED being capable of putting out 100W, the team needed a way to handle their heat output as well as that of other components. The aluminum acts as a cooling medium as it quickly radiates the generated heat instead of keeping it in a centralized location.
VI. Testing Methods

The test method involved building and testing each component first and then integrating them into their own subsystems and finally testing the overall system. The testing encompassed the following:

1) Hardware test plan

- Test the following subsystems:
  - PSU → DC/DC CC LED driver → LED module
  - RFID tag antenna → RFID receiver module
  - Operation of the LVC board
  - Operation of the Nurse Call and Emergency call transmitter → receiver
  - Remote terminal I/O indicators
  - Distance sensor hardware

2) Software test plan

- Program and test MCU to:
  - receive and check the RFID tags #'s
  - receive data from ping sensors
  - output data to external hardware
  - store and retrieve data from EEPROM
- Test MCU as single integrated controller by combining all software subsystems into single program

3) Full system integration:

- Integrate all hardware components into single system
- Test and adjust software/hardware system
- Make necessary adjustments in software and hardware to meet objectives

VII. Synthesis of Learning

The system was successfully designed, implemented and tested. The XET program provided a solid educational experience that allowed the development of the Sensor-based Hospital Staff Detection and Monitoring System. Each course in the sequence has proven useful in the development process of the project. Since the team consisted of Electrical Engineering Technology (EET), Computer Engineering Technology (CET) and Biomedical Engineering Technology students, the team members had the opportunity to learn outside of their field. The project also enabled the team to incorporate concepts learned in the introductory classes of electronics and programming. The project also helped the group to develop higher levels of knowledge by learning totally new items that were not covered during the course work.
Conclusion

This paper described the design and implementation of a senior project based on sensor technologies for monitoring staff in a hospital environment. In a hospital setting, it can be challenging to monitor how many people, be it visitors or hospital personnel, are in a patient’s room at any given time. The paper also described the approaches used to solve all of these issues by developing a single point access and monitoring system. Using individually coded RFID tags and motion sensors, the system makes it possible to know not only if someone is in the room, but if that person is a doctor, nurse, visitor, or other hospital staff. Additionally, it allows for hands free access into a room while simultaneously providing a light for safe entry.

References


