# Patient Motion Detection Report

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# 1. Introduction

1.1 Motivation

Patients who are cognitively impaired or have just had a surgical operation are at a unique risk for one of the most common hospital injuries: falls. Each year, approximately 700,000 to 1,000,000 people in the United States fall in the hospital, with a significant portion inducing injuries. One out of every five falls causes a serious injury such as broken bones or a head injury. In addition, the direct medical costs for fall injuries comes to around $31 billion annually, with hospital costs accounting for two-thirds of that total[1].

A typical case scenario is an elderly patient with a cognitive impairment who is told to notify the nurse if they require anything. The patient understands these instructions at the moment but forgets them soon after. After 15 minutes, the bed alarm is activated and the nurse enters the room to find the patient has fallen on the floor next to their bed. The patient had wanted to use the restroom and did not remember to call for assistance. During these past two semesters, I have been working with West Penn Hospital to develop a technical solution to the widespread problem of patient falls in their rehabilitation unit.

1.2 Status Quo

To combat this prevalent issue, hospitals generally utilize physiologic changes, environmental changes, and staff education. We are focusing on environmental changes, of which there are two types: alarms and restraints.

There are currently two main types of alarms: pressure-based and motion-based. Pressure-based sensors either detect when a patient shifts position on a bed or completely gets off a bed. Motion-based sensors detect motion when a patient exits a bed. Most of these sensors give off an audible alarm, and nurses will arrive in a patient's room after hearing this alarm.

In West Penn hospital specifically, the alarms are mainly used on two objects, the bed and the wheelchair of a patient. The nurses do not have a central alert or paging system, so the alarms are all standalone and use a loud noise to call the nurses. The "call nurse" button activates a light near the door of a patient for a nurse to see.

There are varying bed alarms, depending on the age of the bed and if the bed was donated by another hospital. Most beds only sound an alarm when the weight of a person is completely off a bed. There are some beds that have better sensors for shifting weight, such as when a person starts to sit up. The nurses can activate and deactivate this alarm. There are also some alarms with voice recordings of the doctor or patient's family reminding them to not leave the bed.

For the wheelchair, there is a weight-based sensor that beeps when a patient leaves the wheelchair. There is also a clip-on alarm that is clipped onto the patient's clothing activates when the patient moves too far and the clip becomes detached. The clip-on alarm is imperfect because of its higher false alarm rate and because the patient can disable it easily.

There are also some restraints that deter a patient from exiting the wheelchair and bed. There is a Velcro seatbelt for the wheelchair that can remind a patient to not get up without assistance. Similarly, the beds sometimes have a small Velcro restraint as well with a similar function.

1.3 Benefits

At West Penn hospital, I am working with the nursing staff and administration to develop a method for prevent patient falls. We are mainly focused on the rehabilitation unit, as post-op patients have a high likelihood of falling and inducing additional injuries. As these patients are not receptive to standard fall prevention measures, I began developing an alert system for detecting patient movement out of bed, a possible precursor for falling. This system's objective is to notify nurses of this movement as soon as possible so that they can deter patients from continuing to exit the bed. By using an improved system that incorporates better sensors and better communication among nurses, the most direct benefit is faster nurse response time. This indirectly would prevent patient falls as nurses would arrive at the scene before the patient has moved off or stepped out from their bed.

https://www.cdc.gov/homeandrecreationalsafety/fallsadultfalls.html

## 2. Methodology

Through communication with the nurses and staff at West Penn hospital, I was able to understand the setting that my product would be located in and the functions it would need to demonstrate. In-person visits have been the most helpful, though we have also communicated through email and Skype successfully.

### 2.1 Environmental Constrains

**Types of Patients**
The patients we are assisting are in the Rehabilitation Unit of West Penn Hospital. They are almost all classified as high risk for falls. Most of the patients in this unit are post-op and have undergone surgeries for cardiac, brain, or trauma injuries. Due to the nature of these procedures, the patients' length of stay is may range from a couple of days to a few weeks. Some patients need special assistance and devices, such as IV tubes, urinary catheters, and more.

Patient behavior is also an important factor. Some patients fall intentionally for different reasons. Because alarms are loud and can be irritating, sometimes patients or their visitors will deactivate the bed or chair alarm. This can lead to an issue, or if they forget to turn the alarm back on, that is also a hazard.

There are not specific demographics that trend more towards falling. Many of the patients in the ward are older (50+ years), though falls do not follow a general trend based on age, race, or gender.

**Communication**
The nurses vary in numbers during the shifts based on the number of patients. There is normally at least one nurse on each side of the wing. Nurses bring the mobile computer device around with them during their rounds. They help the patients with medication and getting ready for their day.

There is no central nurse or pager system. This means that all alarms need to be loud enough to draw the attention of the nurses. When a nurse makes their rounds, they bring with them a mobile computer, a "Computer on Wheels." The nurses almost always have this device with them, and it contains a computer and also drawers for patient medication. The computer can connect to the internet and access some patient records.

The hospital has both a private secure and public guest Wi-Fi system. Starting in the spring of next year, the nurses will receive mobile phones to improve their communication system. The public guest Wi-Fi is noticeably slower than the private Wi-Fi, and the guest Wi-Fi also requires registering with the system with every connection. Thus, the system should eventually be connected to the private secure Wi-Fi of the hospital.

**Room Layout**
For the current rooms, there are normally two patients living there and thus two beds. The rooms have sinks and a private bathroom. The floor is hardwood. Inside the room, there are normally also the wheelchairs for the patients. In addition, there are TV's with audio near the beds. Guests may visit the rooms and walk around during certain hours.

The beds can be pushed up against the wall, but not all are arranged in that manner. For stroke patients, one side of the bed will definitely be pushed against the wall. The beds normally have one rail down and three rails up. However, the rails are not very good at preventing patients from exiting the bed because the rails come up very low. Sometimes, the bed is lowered to minimize the height of potential falls. The lowest setting a bed can have is 1.5 feet above the ground to the top of the mattress.

However, the beds have varying properties since they are sourced from different wings and different hospitals. Due to this, West Penn's beds may have built-in pressure alarms, different height limitations, and different side railings. For the alarms, smaller patients may not activate the bed alarm due to their light weight. In the beds, patients may shift around a lot and set off an alarm. Some of the patients may also have additional equipment and utilize urinary catheters, IV's, or other tubing or wiring.

Last winter, the rehabilitation unit was split into the old space and a new space. In this new space, the rooms are private and many hold only a single patient. The beds are also in the middle of the room and not up against a wall. This entails that patients without any railing restraints may exit their bed from either side.

**Hospital Layout**

The wing of the rehabilitation unit consists of two long hallways. The nurse's central station is in the middle of these two long hallways. The alarms in the room are audio-based, and there are visual alerts above the doors of the patients. These light alerts are hard to see because of the shape of the ceiling.

Last winter, the rehabilitation unit was split among the old location and a new location. The new location has more accessible rooms for the nurses because the hallways are not as long and the nurse's station is more centrally located among all the rooms.

## 2.2 Functional Requirements

Given the logistics of the situation, there is a set of criteria that the system should fulfill.

Timing – The system should be quick in detecting motion, as earlier detection will lead to a faster response rate from the nurses who can aid the patient.

Accuracy – Having a low false positive rate is desirable so nurses spend less time following up on every alarm call if the the alarm is unreliable.

Usability – Powering the device on and off should be simple for nurses to do once nurses are in the room. The sensor's position should be easily adjustable to conform to a variety of patient needs and habits.

Integration – The system's alarm functionality should not overshadow those of the current alarms. In addition, if the nurses' alarm system transitions into more digital alarms (i.e. not audio-based), the system should also be able to transition to that state.

2.3 Product Feature Matrix

| | Pressure Sensor | String Alarm |
|---|---|---|
| Description | Detects pressure/ absence of pressure | Box with string and clip |
| Usage | On bed, chair, floor, under/ above mattress | Clip attached to patient's clothes, pulls magnet off to trigger |
| Timing | Late because weight needs to be completely off | Pretty good because can vary distance |
| Accuracy | Pretty accurate at its goal | Accurate once patient moves certain distance |
| Challenges | Not comfortable and small weights do not trigger the alarm | Easy for patient to remove themselves. If on back, is uncomfortable |
| Cost | $60-100 | $30 |

| | Smart Pressure Sensor | GPS Geo Fence | Passive Infrared Sensor | Bed Rails/Lowering | RFID | Assistive Bench |
|---|---|---|---|---|---|---|
| Description | Detects change in pressure | Uses GPS to track | Unit on head and foot board of bed | Beds come with rails and can be lowered | Radio frequency identification tracks tags attached to objects | Bench with touch sensor on the handlebar |
| Usage | On bed, chair | Detects wandering movement | Alarm sounds when plane along bed is broken | Raise rails and lower bed so patient cannot exit | Passive tag on patient's wrist, reader in close proximity | Patient uses bench to get out of bed. Touch sensor on bench sounds alarm. |
| Timing | Less late because it detects sitting up | Need to move large distance away from bed | Catches leg swinging over, fairly fast | Deterrence, no alarm | Fairly fast if wrist to certain place farther away from bed | Fairly fast, hands touch bench then rest of body gets up out of bed. |
| Accuracy | Varies depending on weight of patient | Have to be far from bed | Pretty accurate | Deterrence because patients cannot climb over or are not strong enough to stand from floor | Very limited range for passive readers | Accurate (touched/not touched) |
| Challenges | Small weights and false positives. Also | Short battery life. Patient needs to | Patient wiring or tubing can interfere with beam. | Patient may climb over rails and fall. Does not alert nurses if exiting | More for tracking presence, not specific motions. Normally used to track objects | Additional object on floor is tripping hazard. Patient may not use bench to |

| | | | | | | |
|---|---|---|---|---|---|---|
| | difference between sitting up and exiting bed | move far from bed to detect | False alarms from certain movements | | present in rooms. Wrist too specific, range not large enough. | help them get out of bed. |
| Cost | Not found | $100 | $30 | Cost of bed that has rails and can be lowered | $50 | |

2.4 Product Iterations

The product has undergone several iterations for testing to develop into the current final design. The first put-together product featured a raspberry pi, the sensor, and a breadboard for visual testing. There were LED's for visualizing when the sensor activated. I connected to the Raspberry Pi by SSH'ing over my cell phone's data network.

Another iteration included a switch to power the Raspberry Pi on and off. The Raspberry Pi functions better with this button since it prevents an unexpected shutdown happening when the device is reading or writing memory. In general, shutting off the power is okay when the green LED that indicates read/writes is off. However, this button is preferred. As my switch button was attached to the breadboard, this was not included in the next iteration.

The next iteration removed the breadboard from the system, drastically cutting down the size of the product. I used print statements to display when the signal activated. The wiring had to be reworked for compactability and functionality.

In order to incorporate notifications, I changed the software to send push notifications. Initially I thought of writing my own application for the device but realized that using a 3rd-party application would be much simpler. I got the Twitter API to work with the device. When the sensor activated, it would send a tweet containing the time the sensor triggered along with what room the sensor was in.

Realizing that the Twitter API would require the Raspberry Pi and nurses to have their own hospital Twitter accounts, I decided to look for another external notification service. I found Pushbullet, which is exclusively for sending push notifications, and their process was more streamlined than Twitter's.

## 3. "Final" Design

3.1 Description

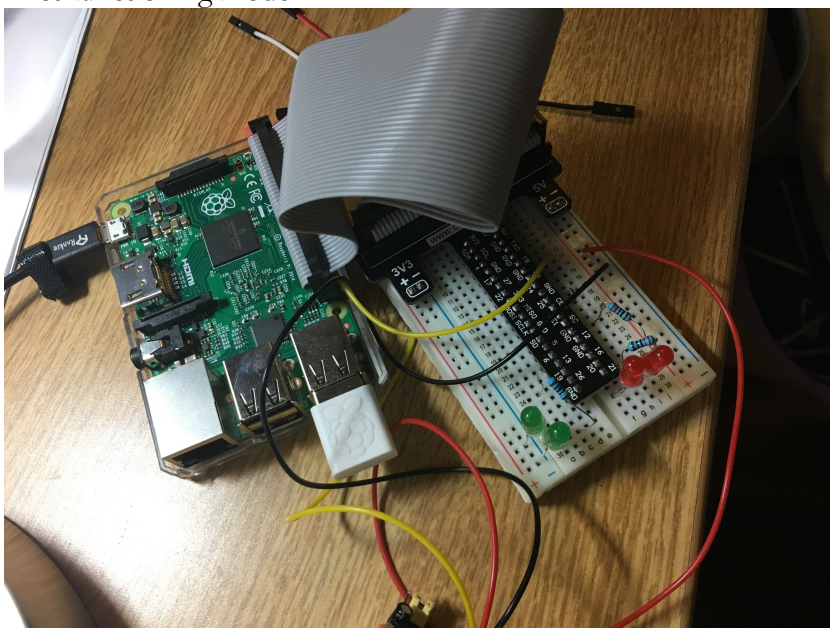
Although the design is deemed "final," it is only final in the sense that it is where the product currently stands. This design meets the functional specifications listed by the nurses, but there is room for improvement in many aspects.

The final specification physically uses a Raspberry Pi, a passive infrared sensor, and cardboard housing. The passive infrared sensor detects motion by measuring infrared light radiating from objects in its field of view. The raspberry pi processes the message from the sensor, and if an object is detected, sends a push notification to an external application Pushbullet. Devices that download this application will receive notifications from a shared channel that an alarm has been sounded. The cardboard housing provides spaces for external ports to connect, including a port for charging the Raspberry Pi via USB.

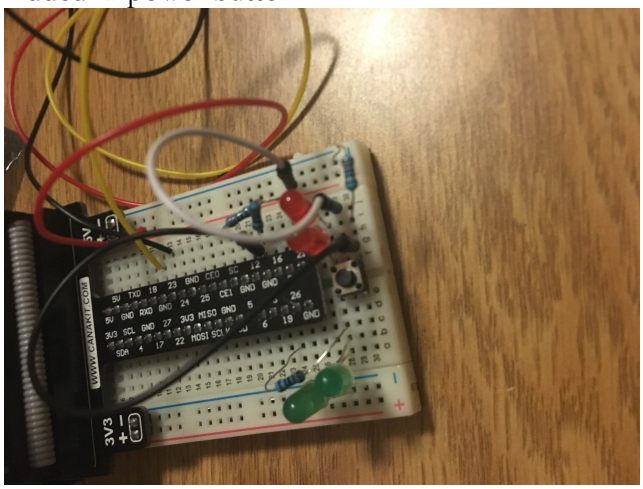
There are Velcro strips on the side of the device for attachment to the bedside surface. The sensor has a wide angle of 120 degrees and thus needs to be angled inwards in order for the sensor to not detect too much external movement. The Raspberry Pi is normally positioned at the foot of the bed looking towards the head of the bed. As both sides of the bed are generally open and do not have restraints, two products would be needed in order to fully cover any potential movement off the bed. However, there is normally one side of the bed that is closer to the restroom, and that side therefore would have a higher priority.

3.2 Images

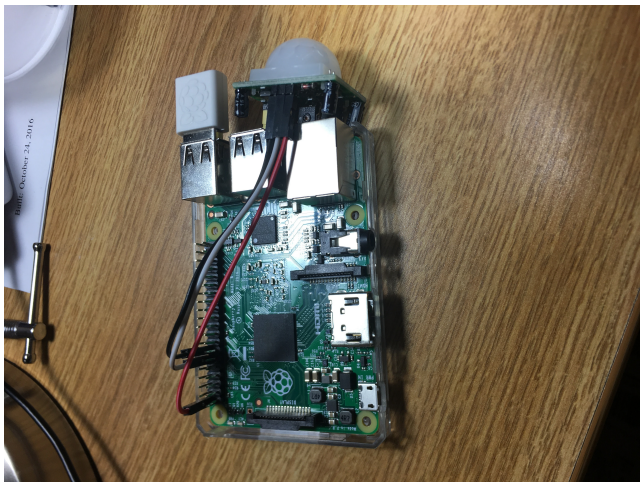
First functioning model



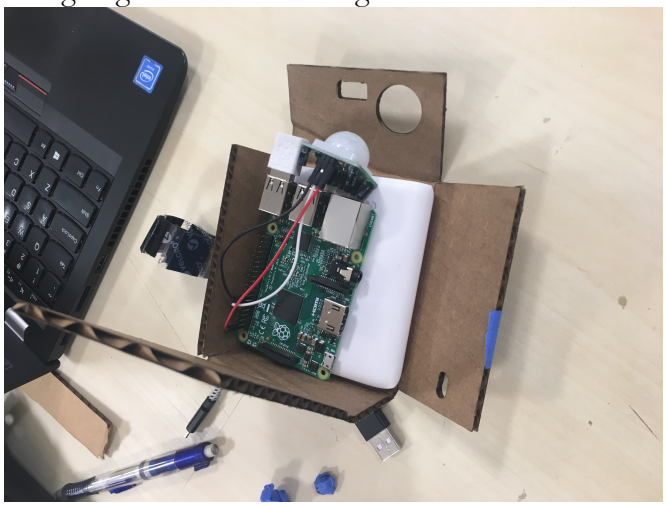
Added in power button



Removed breadboard



Designing cardboard housing



Final design

3.3 Evaluation

The sensor has a range of 120 degrees and around 7 meters. The first detection takes less than a second, and then it takes one to two seconds for a push notification to be sent to a device with the Pushbullet application installed. This first detection is very fast, though subsequent detections have a delay.

The sensor takes around 8 seconds to perform another read of the room and be ready to detect further motion. This delay is not considered too detrimental by the nursing staff if the first detection is accurate. The delay took around 11 seconds under a different passive infrared sensor brand, and the current sensor I use takes 8 seconds. This lengthy delay is still not optimal though and is something should be explored further. Since the first detection after the needed delay is almost instantaneous, it is possibly more important for the first detection to be very accurate so nurses know to come when the first notification is sent.

Due to this delay, it makes a two-stage detection system harder to implement due to a slow speed. The nurses note that they would prefer more false alarms and start walking towards patients rather than a detection system that may miss patient movement. Thus, the system would mostly just include the motion detection as the sole stage needed.

Further testing is required to determine the accuracy of the product. Come fall semester, I will work with the hospital staff to procure a testing environment so we can gauge the number of false positives, true positives, false negatives, and false negatives of the product.

## 4. Future Work

In my last hospital visit, we identified areas of improvement for the system and how best to start incorporating the product into the West Penn hospital setting.

Setting up the data network using an alternative cell phone did not run smoothly. We initially planned on leaving the device there for testing, but currently, setting up the Raspberry Pi with a tester's cellular device is too complicated for the staff or IT to do themselves.

Due to the complications with setup and also finding and utilizing devices with data plans for testing, we decided that we would instead start looking at utilizing the hospital's internal secure Wi-Fi. This Wi-Fi is eventually the network that we would want the Raspberry Pi to connect to since it has fast internet speeds and has extensive reach throughout the hospital. As there are a number of policy regulations to go through, Wendy Cutright will work on getting the appropriate permissions for the product to use the hospital's secure Wi-Fi.

In the meantime, I want to make the system more robust and have less variability for turning on and functioning properly. This will require analyzing more carefully what happens on Pi startup and what leads the program to run and not run. Part of this is hardware problems and part of this is software, so I want to fix what I can on the product side and elaborate on the troubleshooting guide for unmatched wires, what the LED status lights mean, etc.

A different, larger battery will be required if the system is to stay on for 24 hours. Measuring watt usage, we found that the Pi consumes approximately one ampere per hour, thus requiring a fairly large external battery. Including a larger battery will require a different housing design, and I will consider splitting the battery part and sensor part of the product so that the product focused on detecting motion is not too heavy for the side-rail of the bed.

In all, I think there has been good progress made on the project and the hospital nursing staff is interested and enthusiastic to move forward with future testing and incorporation. The nurse manager thought the project was promising and could be helpful in preventing patient falls. As such, I am still interested and invested in continuing this project with West Penn hospital come fall semester.