TURNING TRACKER FOR PRESSURE ULCERS

By

Bradford J Kearbey
Robert J Paul

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TA: Jose Rodrigo Sanchez Vicarte

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Abstract

Pressure ulcers (bed sores) are a huge problem, predominantly in low-budget medical institutions. One of the main causes is in the inaction of nursing assistants (CNA’s) to flip the patients regularly - every two hours. One of the simple causes of this is bad organization. We have designed a force-sensitive pad in hopes to dilute this problem. A two-hour timer is allocated to each patient which gets reset if a flip is registered. Flipping is measured by changed in stagnations of weight near the waist area. If the nurse forgets to flip the patient, a reminder is sent via a global IP address, and later a local buzzer will sound. There are already existent solutions to this problem (including "self-flippers" and alternating pressure mattresses), but these are primarily more expensive and rare to find. Our product would be used in nursing homes, where budgets are primarily low.
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1. Introduction

1.1 Objective
Pressure ulcers, or bedsores, is a common skin condition affecting millions of bedridden patients in the US [9]. The condition is caused by the compression of blood capillaries supplying the skin, leading to necrosis, or death, of skin cells.

Pressure ulcers are a huge problem for many elderly patients, predominantly in low-budget nursing homes. While there are many factors that go into the accumulation of pressure ulcers, one of the main causes is the inaction of nursing assistants (CNAs) or other medical staff to flip their patients regularly [3][4][5]. Because ulcers can develop within 2-6 hours (depending on the patient) of stagnant positioning, patients are necessarily to be flipped once every two hours (US)[8]. One of the simplest causes of such high levels of bedsores lies within the organization of nursing staff. Our research shows that beyond all other factors, medical staff tend to become overwhelmed with their other duties, and simply forget to flip their patients, or flip their patients far later than necessary [3]. This is the case, however, with the most ethical of medical staff. There have been known cases of staff purposely missing flips [3]- either from laziness or ignorance. In all cases, though, medical staff are trained to react to ‘beeping’ or ‘buzzing’ which we hope to enact as the standard of patient flipping.

The following report makes a step forward in solving the bedsore epidemic - specifically, in lower-budget nursing homes. Our proposed Turning Tracker pad is to be placed underneath respective patient’s waist areas; each pad monitors each patient’s two-hour flip timer. The pad consists of multiple force sensors that keeps track of the patient’s position on the bed. When a significant weight distribution is shifted - i.e. a flip is registered- the Turning Tracker will reset the two-hour timer on that particular pad. When the timer is depleted, a signal is sent to the staff identifying that a patient needs to be flipped. If a flip is not registered after the required 2-hours, a mechanical buzzer on the device will sound. At which point, the patient would call his or her nurse.

1.2 Background
According to the U.S. Department of Health & Human Services [1], pressure ulcers affect 2.5 million a year, costing $9.1-$11.6 billion a year in the U.S. There are more than 60,000 deaths and more than 17,000 lawsuits filed each year directly relating to pressure ulcers.

As of 2017, there are unsurprisingly multiple attempted solutions to this problem.

One solution is the alternating pressure air mattress (APAM). According to a Belgian study by the Department of Public Health at Ghent University, they found that “there was no significant difference in incidence of pressure ulcers (grade 2–4) between the experimental [group using APAM] (15.6%) and control group (15.3%) [group on a visco-elastic foam mattress (Tempur®), flipped every 4 hours].”[2] Because many nursing homes do not carry Tempurpedic mattresses and patients are to be flipped every two hours in the U.S. [3], this study lead us to believe APAMs simply do not solve the problem.
Another solution includes a self-turning bed. According to Christina Paul, an Occupational therapist of five years, self-turning beds are extremely rare to find in most nursing homes [3]. Our research has shown that they are simply too expensive for widespread use in nursing homes.

There is undoubtedly just reason that many nursing homes rely solely on their staff to flip patients. However, while it is the least expensive technique (in the short run), it is also the least reliable. The most steadfast, cheap, and simple solution to the bedsore pandemic is simply reminding the nurses and CNAs to flip their patients. As stated above, medical staff react to ‘beeping’ and ‘buzzing’ on a much bigger scale than a mental note, or schedule.

**1.3 Requirements**
- Assuredly measures if and when a patient has been flipped
- Assertively communicates to medical staff when a patient has not been flipped within 2-hours
- Sufficiently less expensive than other leading solutions
2 Design

Our system requires four different modules to meet all the higher-level requirements that are listed above. This design contains a Power Module, Control Unit, Sensor Module and Communication Module. These modules are shown in Fig. 1. The Power Module is responsible for charging a 2500 mAh battery which powers the rest of the circuit with a regulated 3.3 V. Our force sensitive resistors are the only devices inside of the pad, and they oversee the measuring of weight distribution. The microcontroller uses data from the sensors and the Wi-Fi IC to decide whether a person has been flipped and when to notify a nurse to flip a patient. The Control Unit also warns nurses of low battery and any malfunctions. Finally, the Communication Module will send and receive data to the microcontroller to ensure reliable communication to the nurses regarding the turning of their patients.
2.1 General Design
The sketch depicted in Fig. 2 (not drawn to scale) gives a rough visual of our final product, as seen from the outside. The pad is placed under the waist area of the patient and spans the width of the bed. The side pouch, bearing the PCB and the battery, would hang off the bed as to not obstruct the patient’s comfort with its solid components. For a peek of the internals of the pad, see Fig. 3.

![Figure 2 Practical Sketch of Final Product](image)

2.2 Sensor Module
Our sensor module, depicted in Fig. 3, will be housed in an 8 X 32” pad made of nylon for its waterproof properties. The pad is designed to sit under the waist of the patient and will send an output voltage to each respective analog input of the microcontroller (see Control Unit) as shifts in weight distribution occur with each individual sensor. We have one row of six sensors, three sensors on one side and three on the other. This is a design choice due to the three main positions for patients: lying mostly on the right side, lying evenly distributed between the two sides, and lying on the left side. The dimensions 8 X 32” are relevant because 8” in the approximate height of the buttocks and 32” is the width of the most thin hospital beds [11], with 2” cut off from each side. We used the force sensitive resistors SEN-09376. These sensors have a large area relative to other sensors on the market, and can handle loads from 100g- 10kg [10].
2.2.1 Sensor Module Calculations

In order to create an appropriate design, the sensors from this circuit were removed and their resistances were recorded as a patient layed in different positions on the pad. These resistance values are shown in Table 1.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Resistance (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laying on back directly on sensor</td>
<td>34</td>
</tr>
<tr>
<td>Laying on back one inch off sensor</td>
<td>150</td>
</tr>
<tr>
<td>Laying on back two inches off sensor</td>
<td>600</td>
</tr>
</tbody>
</table>

In order to appropriately register a flip, an output voltage of 3.3V was needed with a resistance below 40 kΩ, an output voltage of 1.6V with a resistance of 300kΩ, and finally a 0V output with any resistance greater than 600kOhms. This way the microcontroller can see when a patient is at least 1 inch away from a force sensors as well as when the patient is directly on a force sensor. To meet these design specifications, the sensor circuit was changed into a voltage divider circuit which is shown in Fig. 4. A resistor value of 330 kΩ was chosen so the output voltage would be

\[ V_o = V_{ref} \frac{R_0}{R_{FSR} + R_0} = 3.3V \frac{330kΩ}{330kΩ + 150kΩ} = 2.26V \]

(2.1)

which is just above our TOLERANCE (Appendix B) voltage, when the patient was one inch away from the sensor.
2.3 Power Module
The power module is responsible for supplying our system with a constant 3.3 V. To meet the standards and regulations of a nursing home, our design would normally obtain its power from a hospital grade 10’ Nema 5-15 plug. However, our prototype uses a USB power source to supply power to our lithium-ion battery charger. Our complete design will draw around 300 mA which will be broken down when discussing our battery decision.

2.3.1 Lithium-Ion Battery Charger
As mentioned above, our prototype sends power from a USB port to a lithium-ion battery charging. The battery charger chosen is the Micro Lipo LiPoly Charger simply because of its low cost, small size, and because it’s ability to fully charge our battery in

\[
1.25 \times \frac{Ah}{C} = 1.25 \times \frac{2500mAh}{500mA} = 6.25h
\]

(2.2)

where Ah is the battery capacity, C is the charge rate, and the answer is given in hours. This charging time is acceptable because it is shorter than our discharge rate shown in section 2.3.2.

2.3.2 Lithium-Ion Battery
In a nursing home, it is possible that the patients’ beds are moved to other rooms. A battery was used for our device so our system could have isolated power. Also, a lithium-ion battery was chosen so nurses would not have to continually buy new batteries. The Wi-Fi module uses 250 mA, the microcontroller uses 20 mA, the buzzer uses 3.5 mA, the sensors use 1 mA each (6 mA), and the LED uses 15 mA. Our design uses a total power budget of 294.5 A. Using this budget, the appropriate battery capacity is
\[ Ah = h \times A = 8h \times 294.5A = 2356mAh \] (2.3)

2500mAh, where \( h \) is hours, \( A \) is amperes, and the answer is given in total capacity.

2.3.4 Voltage Regulator
The voltage regulator was expected to supply a constant 3.3V to the rest of our system. The voltage regulator takes in 4.2-3.7V from the lithium ion battery. The LM1117 3.3V 800mA voltage regulator chip is used to handle the maximum current from our system. When testing the voltage regulator, it was discovered that our battery did not supply enough voltage for the chosen regulator to maintain a constant voltage. Instead, the voltage outputted from the regulator decreased as the battery voltage decreased.

2.3.5 Comparator
The TLC339 Quad Voltage Comparator was used to notify the microcontroller when the battery was low on charge. Fig. 5 shows the low battery circuit which consists of the comparator as well as the voltage regulator. Resistors are used so when the battery voltage is less than 4V, the positive input voltage will be greater than the regulated voltage, which will make the comparator output a high voltage. Equation 2.4 shows how the values for the two resistors were determined.

\[ V_o = V_{\text{bat}} \frac{R_0}{R_1 + R_0} = 4V \frac{50k\Omega}{50k\Omega + 10k\Omega} = 3.33V \] (2.4)

\( V_{\text{bat}} \) is the battery voltage and \( V_o \) is the positive input voltage to the comparator.
2.4 Control Unit
The Control Unit, consisting of the very essential microcontroller, will garner information from the six sensors of the Sensor Module and decide whether a patient has been flipped. The Control Unit also oversees the patient’s two-hour timer. In both the cases of a flip and an expired timer, a packet is sent (TX Pin - UART) to the Communication Module describing the state of the pad. This packet will, in turn, be deciphered and displayed in plain English to the medical professional (refer to section 2.5). On top of this, the Control Unit manages the local buzzer given certain circumstances. Those being, low battery, expired timer, or malfunction of the sensors. The Control Unit is powered by the Power Module. For a list of constant values used in this section, see Appendix B.

2.4.1 Buzzer
The buzzer being used in this design, sprouting of BUZZER_PIN, is the Adafruit LLC 1739. The buzzer is necessary to alert the patient and/or medical professional when something amiss has occurred relating to the patients’ inevitable safety concerns. The buzzer will sound in such situations including and limited to:

- A sensor has malfunctioned. This is registered by a maximum reading of 3.3V from any sensor for 1 minute, meaning that a sensor has shorted (buzz is a one second pulse every second at 3000Hz)
- A patient has not been flipped for two hours ± five minutes (buzz is a 200 millisecond pulse every eight seconds at 4000Hz)
- The battery is low. The microcontroller would be alerted of such an instance by the comparator of the Power Module, by a HIGH voltage value being sent to LOW_POWER_PIN (buzz is a 100 millisecond pulse every 10 seconds at 5000Hz)

See Appendix A for a detailed list of buzzer requirements and verifications

2.4.2 Microcontroller
The microcontroller used in our design is the AVR ATmega328. While the code for the microcontroller is quite cumbersome, a comprehensive flowchart is seen in Fig. 6
The microcontroller first waits for a patient apply force (lay) on the pad. The state then begins the two-hour timer. The machine then starts by taking in sensor readings from the Sensor Module every READ_INTERVAL milliseconds. It then smooths these readings in order deter a flip from being registered by basic patient movement (shaking, slight repositioning). Every CHECK_FLIP_INTERVAL milliseconds, the microcontroller checks a flip. It does this by confirming that both a weight shift has taken place (to protect against the corner case of an external weight on the pad) and at least one sensor reading has shifted by TOLERANCE Volts. High reliability was found with the above flip detection.

If a flip is registered, a FLIPPED signal is sent to the Communication Module via the TX pin. If the Communication Module is not connected to the internet however (AWK signal from the RX pin is not changed to 1 by the Communication Module), a microcontroller continually sends the current packet until an AWK of 1 is read.

Every CHECK_NEEDS_FLIP_INTERVAL, a check is made to see if the timer has expired. If the timer is between one-hour and forty-five minutes and two-hours, a friendly NEEDS_FLIP signal is sent to the Communication Module for display to the global IP-Address. However, if more than two-hours has elapsed without registering a flip, the buzzer sounds, alerting the patient of the mishap.

The machine restarts when the patient gets off the pad, ensuring no false NEEDS_FLIP signals would be sent.

### 2.5 Communication Module

The Communication Module is an essential medium between the state of the microcontroller and the general vigilance of the medical staff. This module consists of the internal Wi-Fi IC and a Display Application.
The Display Application is used for both communication to and from the Wi-Fi IC via the user; it is used by the user to connect the Wi-Fi IC to the local Wi-Fi network and it is used to visually show the data sent to Wi-Fi from the Wi-Fi IC.

The Wi-Fi IC receives packet data based on the state of the patient. As of now, the packet is two bits: [AWK, FLIP_TYPE]. Described in Section 2.4, the AWK signal is changed to 1 and sent back to the control unit only in the case that the user has connected the pad to the local Wi-Fi network (see 2.5.1). FLIP_TYPE is 0 if a patient is flipped and 1 if a patient needs to be flipped. As to be described in Section 5.4, in the future, the packet will be modified to include the room number of the patient and the pad’s unique ID.

### 2.5.1 Display Application

The Display Application is broadly-termed because anyone with the IP-Address specified by the Wi-Fi IC can view the state of the patient. In other words, any device with an internet browser installed can act as the Display Application.

To set up the device for proper functioning, the user must specify to the device the SSID and password of their local network so the pad can speak to everyone under that Wi-Fi network. When the user first starts up the pad, they can see their Turning Tracker appear as a local network. When the user connects to the pad, they can go to 192.16.4.1 (standard with the ESP8266) where they will be greeted with a small form to input the SSID and password they would like to use, seen in Fig. 7. If the connection times out, they are directed to a page to try again. Otherwise, they are given the IP address that can be used by all under the Wi-Fi network to view the state of their patient. As to be described in Section 5.4, in the future, it would be beneficial to enhance the encryption of the patient’s information along with an enhancing GUI to view multiple patients at once (rather than just one).
After the Wi-Fi IC is properly connected to the local network, the pad switches from AP mode to STA mode. This means that it uses the network specified rather than behaving as its own network. At this point, the state of the patient can be properly viewed, as seen in Fig. 8.
2.5.2 Wi-Fi IC

The Wi-Fi IC is the physical device that communicates back-and-forth with the communication module. The hardware used is the ESP8266 due to its reliability and range [14]. It harbors all the code of the Display Application, including the code while acting as an STA and an AP. A comprehensive flow chart of the harbored code is seen in Fig. 9.

![Flow Chart of Wi-Fi IC Code](image)

Figure 9 Flow Chart of Wi-Fi IC Code

Described in Section 2.5.1, the Wi-Fi IC starts its machine as an Access Point (AP). If an error occurs setting up to Wi-Fi, the user is given another chance to input the credentials. Upon proper credentials, the Wi-Fi IC switches to Station (STA) mode, where it remains until reset. The machine then continually checks for incoming packets from the microcontroller. As described in Section 2.4.2, if the Wi-Fi IC is in AP mode at the time of an incoming packet, the machine simply sends the packet back, leaving the AWK bit unscathed. However, if a packet is received in STA mode, the packet is unwrapped. If the packet describes a flip, the word “FLIPPED” is shown in the Display Application (seen in Fig. 8). Else, “PATIENT NEEDS FLIPPING” is displayed. In both cases, the AWK bit is changed to 1 and sent back to the microcontroller. The machine then waits for the next packet.
3. Design Verification
A more detailed list of our requirements and verifications can be found in Appendix A.

3.1 Sensor Module
The force sensitive resistors stayed in place after we performed five consecutive flips. Also, the output voltage from the sensors were from 3.09V-3.25V when a patient was directly on a sensor. Lastly, the output voltages from the sensors met our requirement of being 1.25V ± 0.25V when a patient was 1.5 inches away from a sensor.

3.2 Power Module

3.2.1 Lithium-Ion Battery Charger
Our battery was charged at a rate of 0.5C and went from no charge to a full charge in under eight hours.

3.2.2 Lithium-Ion Battery
The lithium-ion battery provided 3.3V for eight hours in our system. However, the system could not fully operate with voltages below 4.0V, so the actual operating time for our design was much less than expected.

3.2.3 Voltage Regulator
The voltage regulator that was used was not able to maintain an output voltage of 3.3V with an input voltage varying 4.2V-3.7V. Instead, the regulator was only able to output a consistent 3.3V when the input voltage was above 4.0V.

3.2.4 LED
By using a current limiting resistor, the LED only drew 10mA of current which was considerably less than the power budget specified in our requirements.

3.3 Control Unit

3.3.1 Buzzer
Our buzzer successfully met the requirement of sounding when a patient has not been flipped for 1 minute 30 seconds ± 10 seconds (changed from 2 hours for demo purposes). The buzzer failed to sound when there was a low battery. This is because the low battery circuit expected a consistent 3.3V being outputted from the voltage regulator at all times. Since the voltage regulator failed, this requirement for the buzzer failed as well. Finally, the buzzer failed to sound if there was a malfunction to any sensor. To fix this problem, we would need to adjust the resistors used with the force sensitive resistors so that the output voltage when a patient is directly on a sensor is less than 3.3V. This way if we saw a 3.3V output, it would be known there is a short in the circuit.
3.3.2 Microcontroller
The microcontroller successfully made all requirements. It did an excellent job at registering appropriate flips and did an even better job not registering false-positive flips. In other words, when the test subject would shake or perform regular laying motion, a flip would not be registered. On top of this, when an external force was added (simulating a loved one lying beside on the bed), a flip also was not registered. The microcontroller’s clock, being very important to bookkeeping the patient’s timers, was only one minute, two seconds off from two hours.

3.4 Communication Module

3.4.1 Display Application
The user display passed all tests, but would experience glitches under IllinoisNet Wi-Fi. For instance, timeouts would often occur when attempting to connect the device to Wi-Fi. And in other instances, the IP address given would be unusable. No such behavior occurred under hotpot networks. Other than this, the proper state of the microcontroller was appropriately displayed.

3.4.2 Wi-Fi IC
Because the Wi-Fi IC was off-the-shelf, our requirements were limited. We simply checked if the range was appropriate, and that the device was accessible under AP mode and STA mode with a plethora of display devices, which is was.
4. Costs

4.1 Parts
To develop the Turning Tracker, the parts in Table 2 were used. We found that our total cost of parts was $100.72.

<table>
<thead>
<tr>
<th>Part</th>
<th>Manufacturer</th>
<th>Retail Cost ($)</th>
<th>Bulk Purchase Cost ($)</th>
<th>Actual Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Module</td>
<td>Adafruit</td>
<td>$9.95</td>
<td>$9.95</td>
<td>$9.95</td>
</tr>
<tr>
<td>ATMega328</td>
<td>Sparkfun</td>
<td>$5.50</td>
<td>$5.50</td>
<td>$5.50</td>
</tr>
<tr>
<td>Force Sensitive Resistor (6)</td>
<td>Sparkfun</td>
<td>$9.95</td>
<td>$9.95</td>
<td>$9.95</td>
</tr>
<tr>
<td>Lithium-Ion Polymer Battery</td>
<td>Adafruit</td>
<td>$14.95</td>
<td>$14.95</td>
<td>$14.95</td>
</tr>
<tr>
<td>Micro Lip USB Li-Ion</td>
<td>Adafruit</td>
<td>$5.95</td>
<td>$5.95</td>
<td>$5.95</td>
</tr>
<tr>
<td>JST Male Connector</td>
<td>Sparkfun</td>
<td>$0.95</td>
<td>$0.86</td>
<td>$0.95</td>
</tr>
<tr>
<td>Quad Comparator</td>
<td>TI</td>
<td>$1.57</td>
<td>$1.09</td>
<td>$1.57</td>
</tr>
<tr>
<td>Voltage Regulator</td>
<td>TI</td>
<td>$1.04</td>
<td>$0.72</td>
<td>$1.04</td>
</tr>
<tr>
<td>Surface Mount Switch</td>
<td>Sparkfun</td>
<td>$0.95</td>
<td>$0.86</td>
<td>$0.95</td>
</tr>
<tr>
<td>Buzzer</td>
<td>Adafruit</td>
<td>$5.95</td>
<td>$5.95</td>
<td>$5.95</td>
</tr>
<tr>
<td>Anti-static Foam Sheet</td>
<td>Foam Factory</td>
<td>$18.98</td>
<td>$18.98</td>
<td>$18.98</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td><strong>$100.72</strong></td>
<td><strong>$99.74</strong></td>
<td><strong>$100.72</strong></td>
</tr>
</tbody>
</table>

4.2 Labor
The total labor cost was determined by the number of hours spent by each student multiplied by our hourly rate, and finally multiplied by a cost factor of 2.5. The total labor cost is shown in Table 3.

<table>
<thead>
<tr>
<th>Name</th>
<th>Hours Invested</th>
<th>Hourly Rate</th>
<th>Cost Factor</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brad Kearbey</td>
<td>240</td>
<td>$40.00</td>
<td>2.5</td>
<td>$24,000.00</td>
</tr>
<tr>
<td>Robert Paul</td>
<td>240</td>
<td>$40.00</td>
<td>2.5</td>
<td>$24,000.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>480</td>
<td>$40.00</td>
<td>2.5</td>
<td>$48,000.00</td>
</tr>
</tbody>
</table>

The cost of the entire project including both parts and labor is $48,000.00 + $100.72 = $48,100.72.
5. Conclusion

5.1 Accomplishments
We understood from the start of the project that the sensor module and control unit would be the most difficult parts of the design. The challenges we faced with the sensor module came from having only six analog inputs to our microcontroller. This meant that we were only able to use six force sensitive resistors and had to figure out the ideal placement for each of them. By conducting research on how patients were flipped, we discovered that the patient does not move much vertically during a flip, but they do move a lot horizontally. This is why we decided the ideal placement is six sensors equidistant in a horizontal line along the width of the bed.

Another challenge that we are proud to say we accomplished was figuring out how to not register a flip if a nurse puts weight onto the pad without flipping the patient, or a family member was to sit or lay in bed with the patient. This was accomplished by treating each sensor as a zone, and a flip would only register if weight was found on a new sensor while at the same time weight was taken off a previous sensor.

5.2 Uncertainties
There are a couple aspects of the design that may have negative results if left untested in the practical sense. For one, the pad is somewhat thick in nature and is designed to rest below patients’ waist areas. We are unsure if such a design could lead to significant health problems after prolonged use. This can include back problems, friction sores, or other spontaneous problems. Again, such problems would stay unknown unless real tests are done on real patients.

We are also unsure that the pad will stay in place. If the pad slides to the under-back area (which is likely due to its Nylon shell), there is a chance that a flip will not be registered. This could likely be fixed with a Velcro strap to the side railings of the bed, but we don’t know for sure.

It is also important to note that not every bed is the same. The pad may be too big for some or too small for others. Will we have to produce different pads for different types of beds? How long should the power chord be? All these uncertainties need to be tested in real-world settings.

We originally planned to test the waterproof capabilities of our pad, but were too afraid to do so. We will eventually need to check this feature because after all, accidents happen.

5.3 Ethical considerations

5.3.1 Developmental Concerns
As stated in Section 1.3, two of our three main requirements call for our product to be reliable. If our product does not work, injury will follow. As Section 1.2 describes, more than 17,000 lawsuits are filed each year due to bedsores. This shows the strong ethical risk involved with the build of the device. Before putting our device on the shelf, rigorous testing needs to be enacted to prepare for the inevitable audits to follow. The confidence of registering flips needs to be at its highest peak. To not have such confidence would be in violation of IEEE 1st and 9th codes of ethics [6]. The prior obligates decisions to
be made in the best health and safety of the public. The latter obligates an avoidance of the injuring of others. We will strive to make the most reliable, well-made device possible, and will be honest with those in the case of failure.

5.3.2 Operational Concerns
Continuing with IEEE 1st code of ethics [6], we would have to accurately and promptly inform the public of the reliability of our product, and the risk involved in using it. We would let them use honest data (conforming to the 3rd code of ethics [6]) in their decision to adapt the device.

Because the pad is designed to work at the use of professionals, we would want to make sure all staff that use this product are certified to flip patients correctly. If not, there is a chance that a flip could be misregistered, leading to a fault in a flip cycle. This conforms with the 6th code of IEEE code of ethics [6]; we would have to issue a “disclosure of pertinent limitations” to make sure those who use the device are certified healthcare providers.

We would never want to see our device as a way for medical staff to cheat their way out of work by false-triggering a flip. To deter this action, we designed the device to not register a flip unless a weight shift is registered (see Section 2.4.2). In other words, it is close to impossible to register a flip without lifting the patient from their previous state.

5.3.3 Healthcare Standards and Federal Regulation
Besides sensing and communicating, power is also a concern. We have designed our pad to never die without warning via the low battery buzzer, which is a must with any medical device with a battery. However, we need to choose an improved battery and add the ability to plug into the wall. Both will increase the devices on-time, which will most likely be 12 hours a day. As of now there is no electrical risk of the patient due to the anti-static foam and Nylon casing (conforming with the 9th code of ethics [6]).

5.4 Future work
As described in Section 5.3, our product is not ready for the shelves, especially in the medical industry. There are certain steps we must take to have our device at a point of mass production and at a point of rigorous testing.

5.4.1 General Expansion
To make our pad sufficiently less expensive in the sense of mass production, we need to severely change the physical design. In the most practical sense, a flex PCB would be used instead as the body of the pad. The flex PCB would essentially act as a large force resistor, also holding all electrical components. This way, we would need not the expensive FSRs and the side pouch would likely not be needed, improving the design and driving down costs.
5.4.2 Versatility
If multiple pads are to be produced, the code also needs to be changed. The packet used will have to include the room number and unique ID of the pad. On top of this, the user GUI would need to be improved so they can set up and manage all their pads in an aesthetically appealing manner.

5.4.3 Encryption
In the healthcare industry, there is much speculation on the safety of patients’ information (HIPAA). As of now, anyone with the IP address (on the same Wi-Fi network) specified by the Wi-Fi IC can access the state of the patient. An encryption standard would likely need to be added to keep safe the states of the given medical institution’s patients.

5.4.4 Power
As discussed in the design verifications, (section 3) the only modules that failed was from the voltage regulator not maintaining 3.3V. This mistake caused the low battery circuit, as well as the malfunction buzzer to not operate properly. We can easily fix this issue by using a 6V battery instead of a 3.7V battery. This way the voltage going into the voltage regulator is always greater than 4V allowing the regulator to operate as expected with a consistent 3.3V output.
References


## Appendix A  Requirement and Verification Table

### Table 4 Sensor Module Requirements and Verifications

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
<th>Requirement Status (Y or N)</th>
</tr>
</thead>
</table>
| Pad remains in-order upon 5 flips                                         | A. Lay the pad on a hard surface  
B. Open the Velcro, and note the positioning of each plate.  
C. Perform 5 flips. (Refer to microcontroller requirements for proper instructions.)  
D. Open back up the Velcro and make sure no plates have flipped.  
E. If the sensors move in a way that would lead to a disconnect mark FAIL  
F. Else PASS                                                              | Y                           |
| Voltage reading from sensors are 3.0V ± 0.2V when directly laying on a sensor | A. Place the pad on a hard surface  
B. For each sensor (0-5), lay directly on the sensor  
C. Ensure that each sensor reading is 3.0V ± 0.2V. If so, PASS, else FAIL | Y                           |
| Voltage reading from sensors are 1.25V ± 0.25V when you are laying 1.5 inches away. | A. Place the pad on a hard surface  
B. For each sensor (0-5), lay 1.5 inches away from that sensor.  
C. Ensure that each sensor reading is 1.25V ± 0.25V. If so, PASS, else FAIL | Y                           |
Table 5 Power Module Requirements and Verifications

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
<th>Requirement Status (Y or N)</th>
</tr>
</thead>
</table>
| Be able to fully charge a 2500mAh battery within 8 hours. (length of battery life) | A. Fully drain the battery  
B. Test that the battery is outputting 2.75V with a multimeter.  
C. Plug battery into charger and use a stopwatch to measure the time it take for the battery to reach 4.2 volts (fully charged voltage). | Y |
| Lithium-Ion battery stores 2.35-2.5 Ah of charge | A. Connect a fully charged battery to a constant current test circuit.  
B. Discharge the battery at 300 mA for 8 hours.  
C. Use a multimeter to make sure the battery voltage is above 3.3 V | Y |
| Voltage regulator must maintain an output voltage of 3.3V +/- 1% from a input voltage varying from 4.2-3.7 V. | A. Construct a constant current circuit using the voltage regulating chip and draw 300 mA of current.  
B. Use an oscilloscope to verify that the output voltage maintains a 3.3V +/- 1% range | N |
<p>| Must not draw more than 20mA of current. | A. Use a multimeter to test the current running through the LED. | Y |</p>
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
<th>Requirement Status (Y or N)</th>
</tr>
</thead>
</table>
| The buzzer sounds when a patient is stagnant for 1 minute 30 seconds ± 10 seconds | A. Lay on the pad, making no major movements  
B. Immediately start a stopwatch  
C. Ensure the NEEDS_FLIP buzzer-pulse sounds (200ms chirp every 8 seconds) when the stopwatch reaches 1 minute 30 seconds ± 6 seconds. If so, PASS, else FAIL | Y                         |
| The LOW_BATT buzzer-pulse sounds when the battery voltage reaches 3.3V ± 0.15V | A. Let device run in the ON position for 8 hours or until the LOW_BATT buzzer-pulse sounds (100ms pulse every 10 seconds)  
B. Immediately measure the voltage of the battery and ensure the reading is 3.3V – 3.0V. If so, PASS, else FAIL | N                         |
| The MALFUNCTION buzzer-pulse sounds when there exists a malfunction of any individual sensor | A. Short the two leads to each buzzer separately.  
B. Ensure the MALFUNCTION buzzer-pulse sounds (1s pulse every second) | N                         |
| The microcontroller registers when a patient's weight distribution is shifted to/from any zone by 50% | A. Set up pad to Wi-Fi as to graphically show the state of the microcontroller  
B. Lay on the pad in a stagnant matter facing up until the display reads “PATIENT OK”  
C. Have a friend flip you on your left side in a professional manner (right arm on chest, right leg over left, flip to the left)  
D. Ensure the display reads “FLIPPED” followed by “PATIENT OK”  
E. Now have a friend flip you to your right side in a professional manner (flip upright, left arm on chest, left leg over right, flip to the right)  
F. Ensure the display reads “FLIPPED” followed by “PATIENT OK”  
G. Now have a friend flip you to your original position in a professional manner (flip upright, arms to the side)  
H. Ensure the display reads “FLIPPED” followed by “PATIENT OK”  
I. PASS if all read 3 “FLIPPED” signals else FAIL | Y                         |
| The microcontroller does not send FLIPPED signal when foreign weight is added to the pad | A. Stagnantly lay upright on the pad for approximately 1 minutes 30 seconds or until the NEEDS_FLIP buzzer starts to sound  
B. Have a friend apply force in every possible combination in the areas surrounding the stagnant patient (to the left, to the right, both on the left and the right).  
C. PASS if the buzzer continues to sound else FAIL | Y |
| The microcontroller does not send FLIPPED signal when foreign upon natural patient movement (on the extreme case of flutter kicks for 10 seconds) | A. Stagnantly lay upright on the pad for approximately 1 minutes 30 seconds or until the NEEDS_FLIP buzzer starts to sound  
B. Perform flutter kicks for 10 seconds  
C. PASS if the buzzer continues to sound else FAIL | Y |
| The microcontroller sends packet data every 10 seconds ± 1 second to the Com Module upon NEEDS_FLIP if no AWK is received | A. Restart the Wi-Fi IC and/or the whole system to ensure the device is not connected to the internet  
B. Stagnantly lay upright on the pad until the NEEDS_FLIP buzzer starts to sound.  
C. Connect the device to Wi-Fi by inputting the SSID and password appropriately  
D. PASS if the display reads “PATIENT NEEDS FLIPPING” else FAIL | Y |
| The microcontroller clock is uninterrupted and accurate to two hours ± 3 minutes | A. Stagnantly lay on the pad until the NEEDS_FLIP buzzer begins to sound.  
B. Wait 10 chirps and begin a stopwatch at any given chirp  
C. Stop the stopwatch at the next consecutive chirp  
D. PASS if the stopwatch reads 8 seconds +/- 20 milliseconds else FAIL | Y |
| The microcontroller does not send a NEEDS_FLIP signal when no weight is administered on the pad | A. Let pad sit for 2 minutes 10 seconds  
B. PASS if the NEEDS_FLIP buzzer does not sound in the interval else FAIL | Y |
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
<th>Requirement Status (Y or N)</th>
</tr>
</thead>
</table>
| Wi-Fi IC both sends and receives signal at distance of at least 300 meters from the device and within same Wi-Fi network | A. Open the pad’s Display Application and link the Wi-Fi network with the pad  
B. Separate your Display Device from the pad by approximately 300 meters within the same Wi-Fi network.  
C. Simulate a flip and ensure “FLIPPED” is displayed on the device | Y                           |
| Wi-Fi IC accessible via Android, iPhone, and Computer when the IC is in Access Point (AP) mode upon at least 10 seconds after resetting Wi-Fi | A. Reset the device and start a timer  
B. Search for available networks on iPhone, Android, Mac, and PC  
C. PASS if “Turning Tracker 1D749” displays on all platforms before the timer reaches 10 seconds, else FAIL | Y                           |
| Wi-Fi IC accessible via Android, iPhone, and Computer when the IC is in Station (STA) mode, given appropriate Wi-Fi credentials | A. Restart the Wi-Fi IC and/or PCB  
B. Connect to “Turning Tracker 1D749” and go to “192.168.4.1”.  
C. Input appropriate Wi-Fi credentials and wait for the success page to show  
D. Copy the IP address shown on the success page.  
F. Ensure the page “PATIENT STATUS” shows on Safari (iPhone and Mac), Chrome (All devices), Internet Explorer (PC), and Firefox (All devices)  
G. PASS if so, else FAIL | Y                           |
| Display Device shows “FLIPPED” within 10 seconds ± 2 seconds appropriate flip | A. Link your Display Device with pad  
B. Lay on the pad and simulate a FLIPPED signal by having a friend flip you to your right side in a professional manner (flip upright, left arm on chest, left leg over right, flip to the right)  
C. PASS if after 10 seconds ± 2 seconds the Display Device reads “FLIPPED”, else FAIL | Y                           |
| Display Device shows “PATIENT NEEDS FLIPPING” upon 1 minute ± 12 seconds of inaction on pad | A. Link your Display Device with pad  
B. Simulate a NEEDS_FLIP by stagnantly laying on the pad  
C. If after 1 minute ± 12 seconds the Display Device reads “NEEDS_FLIP” pass, else FAIL | Y                           |
| The Display Application displays an error message, and allows the user to retry inputting Wi-Fi credentials upon a 8 seconds ± 3 seconds connection timeout | A. Reset Wi-Fi Module, connect to “Turning Tracker 1D749” and go to “192.168.4.1”  
B. Input “abcd” as SSID and “efghi” as PASSWORD | Y                           |
C. Ensure that after 8 seconds ± 3 seconds an error page is shown directing the user back to the Wi-Fi credential page

A. Reset Wi-Fi Module, connect to “Turning Tracker 1D749” and go to “192.168.4.1”
B. Input a valid SSID and PASSWORD to the application (If under IllinoisNet, simply input “IllinoisNet_Guest” with no password)
C. PASS if after 10 seconds, a success page appears with a usable IP address, else FAIL
D. Note that while using the battery, during startup, the Wi-Fi module will sometimes either timeout, or (under IllinoisNet), sometimes the device will show a trash IP address. In such a case, reset the Wi-Fi module and restart the process.

### Appendix B  Constants

#### Table 8 Constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUZZER_PIN</td>
<td>3</td>
</tr>
<tr>
<td>LOW_POWER_PIN</td>
<td>8</td>
</tr>
<tr>
<td>READ_INTERVAL</td>
<td>100 (milliseconds)</td>
</tr>
<tr>
<td>CHECK_FLIP_INTERVAL</td>
<td>2000 (milliseconds)</td>
</tr>
<tr>
<td>TOLERANCE</td>
<td>2.0 (Volts)</td>
</tr>
<tr>
<td>CHECK_NEEDS_FLIP_INTERVAL</td>
<td>120000 (milliseconds)</td>
</tr>
</tbody>
</table>