

SMART PATIENT BED FOR PRESSURE- INJURY PREVENTION

By

Tyler Marrazzo (tyleram3)

Rayan Soltana (soltana2)

Design Document for ECE 445, Senior Design, Fall 2026

TA: Daegan Fuss (dfuss2)

2 October 2026

Project Team No. 35

Contents

1.	Introduction.....	1
1.1	Problem.....	1
1.2	Solution.....	1
1.3	Visual Aid.....	2
1.4	High-Level Requirements.....	2
2.	Design.....	3
2.1	Physical Design.....	3
2.2	Block Diagram.....	4
2.3	Functional Overview and Block Diagram Requirements.....	5
2.3.1	Sensing Subsystem.....	5
2.3.2	Analog Acquisition Subsystem.....	7
2.3.3	MCU Subsystem.....	11
2.3.4	Alarm Subsystem.....	14
2.3.5	Power Subsystem.....	16
2.4	Tolerance Analysis.....	18
3.	Cost and Schedule.....	21
3.1	Cost Analysis.....	21
3.2	Schedule.....	23
4.	Ethics, Standards, and Safety.....	24
5.	Citations.....	25

1. Introduction

1.1 Problem

Bedridden or otherwise mobility-impaired patients can often remain in the same position for long periods of time, potentially leading to many pressure-related injuries such as ulcers or bedsores. These injuries are concentrated on areas of the body under the most stress when laying down, such as the hips and lower back. As the amount of time the patient is motionless increases, the more the blood flow is restricted and the tissue is damaged. The Agency for Healthcare Research and Quality (AHRQ) reports that more than 2.5 million people in the U.S. develop ulcers from prolonged single-area pressure and identifies frequent repositioning as being among the most critical preventative measures [1].

Preventing these kinds of injuries is not only a matter of public health but also poses to benefit the economics of hospitals with better preventative measures. According to an economic analysis concerned with hospital-acquired pressure injuries (HAPI), the entire United States in 2016 alone was estimated to have spent over \$26 billion in annual healthcare costs treating HAPI's [2], further demonstrating a need for improved preventative practices.

Current preventative measures rely on the discretion of the caregivers in charge of overseeing these patients. Under their assessment, patients are repositioned and assessed on a semi-regular basis. However, following a set repositioning schedule for many patients can be difficult to balance. Additionally, this system does not continuously measure where any pressure is building between assessments to allow for personalized prevention plans.

1.2 Solution

Our solution to this problem is to create a low-cost sensing pad that sits underneath the patient and continuously measures the pressure distribution and positioning. The pad will contain an array of pressure sensors arranged in a grid, focused on the hips/lower back region (where pressure-related injuries are most prominent). Then, the array will feed its readings into a microcontroller to analyze and read out which regions are experiencing prolonged pressure. Not only will this system identify regions of prolonged pressure, but also alert caregivers via Bluetooth to tend to that patient. This provides a significant and novel improvement over the existing preventative practices for pressure-related injuries.

1.3 Visual Aid

A more in-depth description of the system will be expanded in the subsystem overview later in the proposal, but the following visual aid will show roughly how the system will operate.

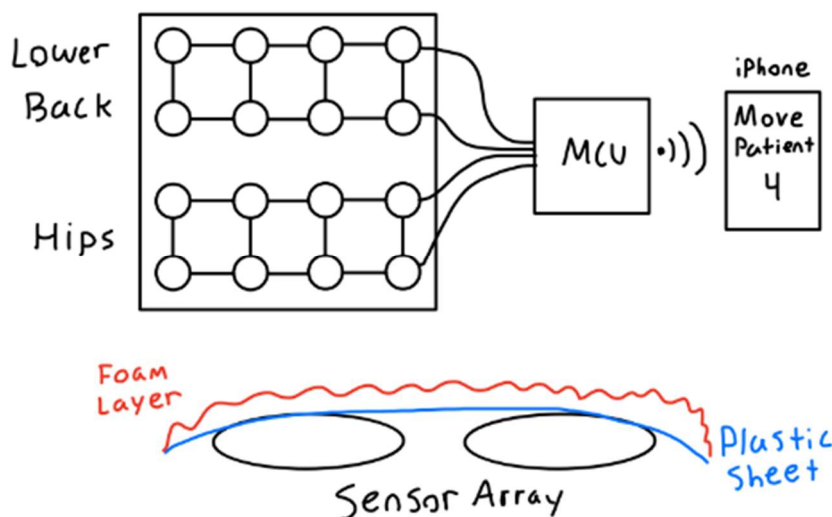


Figure 1: Visual Representation of Solution

At a high level, the readings from the sensing array are sent to the MCU to be interpreted and eventually converted to an alert for the caregiving staff to tend to their patients. As for the physical implementation, we plan to encapsulate the sensor grid in a plastic sheet to ensure the components do not prod the patient. Additionally, a foam layer will be fixed to the top of the sheet where it will contact the patient to ensure comfort for the patient as well as preventing our components from being crushed under their weight. The grid appearance of the sensor array is purely for conceptual understanding, note that the actual sensors will be individually driven by the MCU, with the output being input into the PCB for signal processing via a common path.

1.4 High-Level Requirements

The high-level requirements we will use to prove a sufficient and functioning project are as follows:

1. The pressure-sensing pad contains at least 16 individual sensors capable of providing pressure and spatial information about the patient's pressure distribution.
2. The pressure data collected by the sensing pad is processed and converted to a definitive "needs repositioning of _____ area" or "does not require repositioning" depending on user-defined thresholds for what duration is to be considered as "prolonged" long enough for concern.
3. The feedback generated by the MCU is converted to a Bluetooth signal capable of alerting a nearby (of a caregiver, e.g.) phone to its status within 30 seconds of the established pressure threshold being reached.

2. Design

2.1 Physical Design

Most of the subsystems below exist solely on the PCB, with the sole exception of the sensing subsystem. The sensors we have chosen to use for detecting changes in pressure are the Interlink Electronics FSR 400 force-sensing resistors with a short tail, the exact mechanical dimensions of which can be found below.

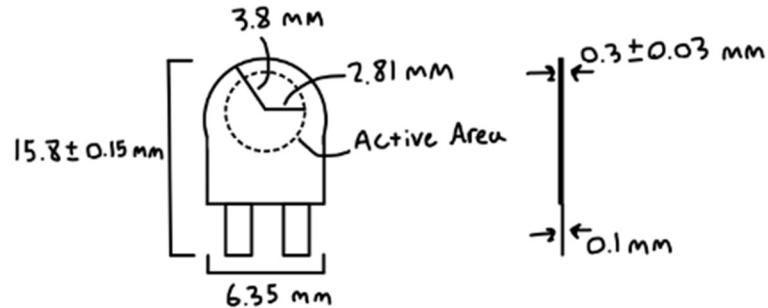


Figure 3: FSR-400 Short Tail Dimensions

For now, we will abstract the exact dimensions of the sensing array, but for now we will analyze the sizing of the overall electronics section and how it will connect with our other layers.

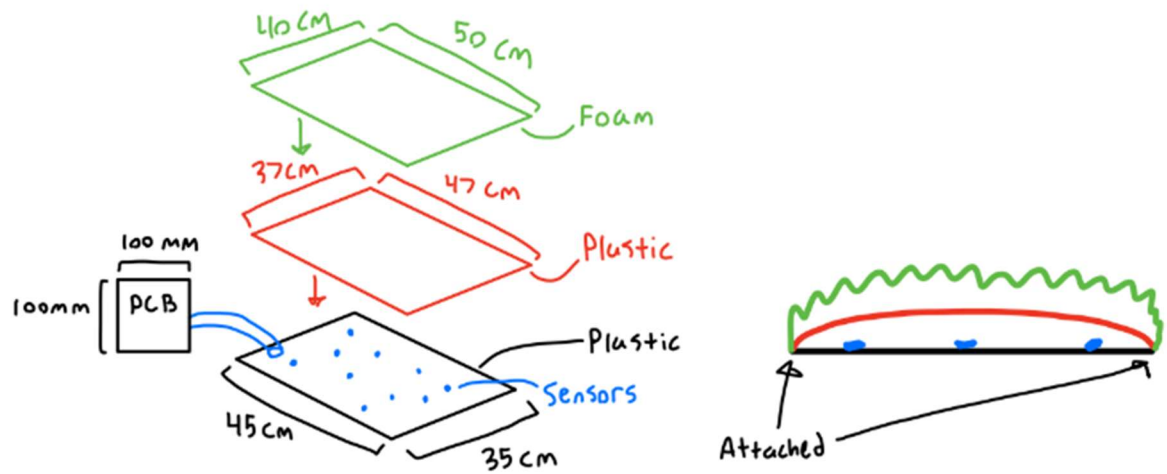


Figure 4: Physical Design Dimensions

The image depicts the sensors as randomly scattered, see section 2.3.1 for the actual orientation of the sensors on the lower plastic sheet. Our design features a hard plastic sheet with sensors stuck onto the top in some pattern using the built-in adhesive. The sensors will be connected directly to the PCB using a conjoined bundle of wires. The exact dimensions of this bundle of wires are unimportant, the only thing to note is that the PCB will not live within the

pad, but rather separately attached. This way, the delicate electronics on the PCB are not in danger during normal use of the sensing pad. The overall size of the entire plastic sheet is 35cm x 45cm, with the exact reasoning for that explained in section 2.3.1. For now, we take that at face value and move on. We plan to cut another plastic sheet but with dimensions 37cm x 47cm, making it slightly larger than bottom sheet. We chose to do this because, as seen in the right-hand-side image, we want to allow for a small gap between the top sheet and the sensors to limit false pressure readings. If the two sheets were the same size, overlapping them would result in near-constant pressure on our sensors and thus jeopardize our readings. Sizing a bit of extra space allows a gap to exist in situations where no pressure is being put under. We also plan to attach these two sheets together at the edges using staples to allow for easy removal during testing and validation phases of the project. The sturdiness of the staples will also be verified and potentially replaced as the project evolves. The reason for this plastic sheet, as discussed previously, is to limit the damage done to the sensors and their corresponding wiring when under pressure, and prevent the user from being jabbed by any electronic components. Lastly, we plan to add an additional layer of foam of dimensions 40cm x 50cm atop the top plastic sheet. We increased the dimensions again to ensure we can staple the border of the foam sheet to the edges without applying any pressure to the sensor array by default. The purpose of this foam sheet is, like with the top plastic sheet, ensure user comfort is not ruined by sitting on top of the sensing pad. With all these additions, the user should have no idea there is a sensing pad underneath them and our pressure readings will remain stable throughout use.

2.2 Block Diagram

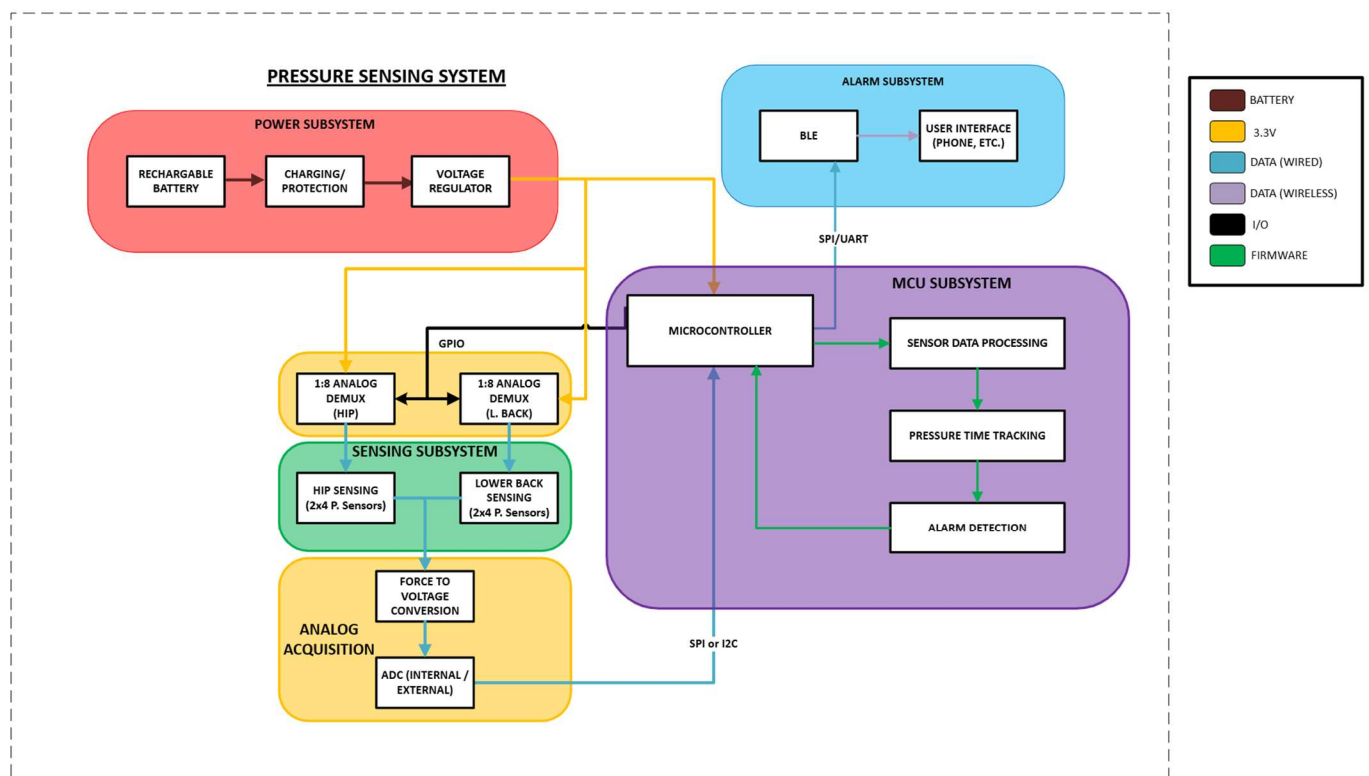


Figure 5: Block Diagram of Solution

2.3 Functional Overview and Block Diagram Requirements

2.3.1 Sensing Subsystem

The sensing subsystem provides the physical interface between the patient and the pressure-monitoring electronics. The sensing pad consists of 16 Interlink Electronics FSR 400 force-sensing resistors divided into two sensing regions containing 8 sensors each. One region is positioned below a patient's lower back and the other positioned below a patient's hips. Each region uses a 2 x 4 physical sensor arrangement. The FSR 400 is a two-terminal piezoresistive sensor whose resistance decreases as more force is applied. The sensor has a nominal 5.08 mm-diameter active sensing area and a specified force-sensitivity range of approximately 0.2–20 N [3], the mechanical interface of the sensing pad will be designed such that the force transmitted to an individual sensor remains within this operating range under expected patient loading.

The sensors are mounted within a 35 cm x 45 cm pad. Within a sensing region each sensor will be placed 9 cm apart. The two sensing regions are separated by 11 cm between the centers of their nearest sensor rows. The uppermost and lowermost sensor rows are positioned 3 cm from the corresponding edges of the pad. Horizontally, the four sensor columns span 27 cm and are centered across the 45 cm pad, placing the outer sensor centers 9 cm from the left and right edges. This arrangement distributes the 16 sensing locations across the lower-back and hip regions while maintaining independent spatial information from each sensing location.

The eight sensors associated with each anatomical region are connected to their corresponding 1:8 analog selection device, allowing the MCU to select one sensing location at a time. The selected FSR is then connected to the Analog Acquisition Subsystem, where its force-dependent resistance is converted into a measurable voltage before ADC conversion. Because only one sensor from each group is selected for measurement at a given time, the system preserves the identity of each sensing location while avoiding the multiple current paths and ghost measurements associated with the previously considered resistive matrix architecture.

The subsystem directly contributes to the system's high-level requirement of obtaining pressure-related and spatial information from at least 16 individual sensing locations. Maintaining independent access to each FSR allows subsequent MCU processing to associate each measurement with a known physical position on the pad and determine whether sustained loading is occurring specifically within the hip or lower-back sensing region.

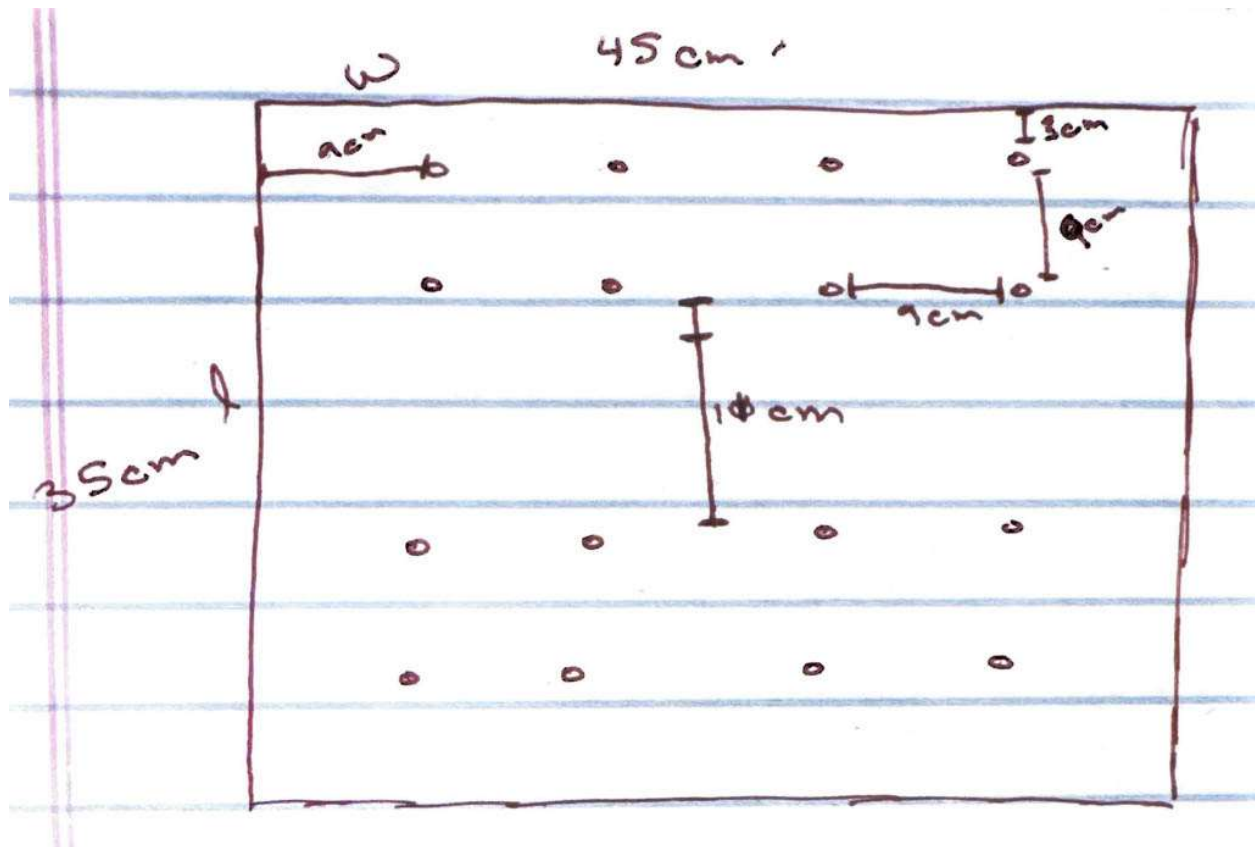


Figure 6: Physical Orientation of Sensors in Pad

Table 1: Sensing Subsystem – Requirements & Verification

Requirements	Verification
The sensing subsystem shall provide 16 independently measurable sensing locations, divided into two groups of eight sensors corresponding to the lower-back and hip regions.	- Connect completed sensing system to Analog Acquisition Subsystem. - Apply a load individually to each of the 16 sensing locations while leaving the other locations unloaded. - Record the measured output associated with all 16 sensor positions - Verify that loading each location produces a detectable charge at its corresponding channel and that all 16 positions can be independently identified. - Record the results in a pass/fail table identifying sensor number, location, and channel.
The centers of adjacent sensors within each 2x4 sensing region shall be	Place the completed pad on a flat, dry surface.

separated by 9.0 ± 0.5 cm, and the nearest rows of the hip and lower-back sensing regions shall be separated by 11.0 ± 0.5 cm center-to-center.	• Using a metric rule or measuring tape, measure the center-to-center spacing between every pair of adjacent sensors within each sensing region. • Measure the center-to-center spacing between the nearest rows of the two regions. • Record all measured distances in a table and verify that they fall within the specified tolerances.
• The sensing subsystem shall produce a monotonically increasing electrical response to increasing applied load over the system's characterized operating range, with no decrease greater than 5% of full-scale output between consecutive increasing load steps.	• Place a sensor on the completed pad assembly. • Apply a sequence of known loads using calibrated weights or a force gauge. • Measure the resulting force-to-voltage output using a DMM at each load. • Repeat for representative sensors from both sensing regions. • Plot output voltage versus applied load and verify that the response satisfies the stated monotonicity requirement.

2.3.2 Analog Acquisition Subsystem

The Analog Acquisition Subsystem is responsible for selecting individual pressure sensors, converting the force-dependent resistance of each FSR 400 into a measurable analog voltage, and converting this voltage into digital data for processing by the MCU Subsystem. The subsystem consists of two 1:8 analog multiplexers, a force-to-voltage conversion circuit, and an analog-to-digital converter (ADC). The two multiplexers independently interface with the eight FSRs located in the hip sensing region and the eight FSRs located in the lower-back sensing region. This subsystem allows all 16 sensors to be measured while requiring significantly fewer MCU connections than individually connecting each sensor to a dedicated acquisition circuit.

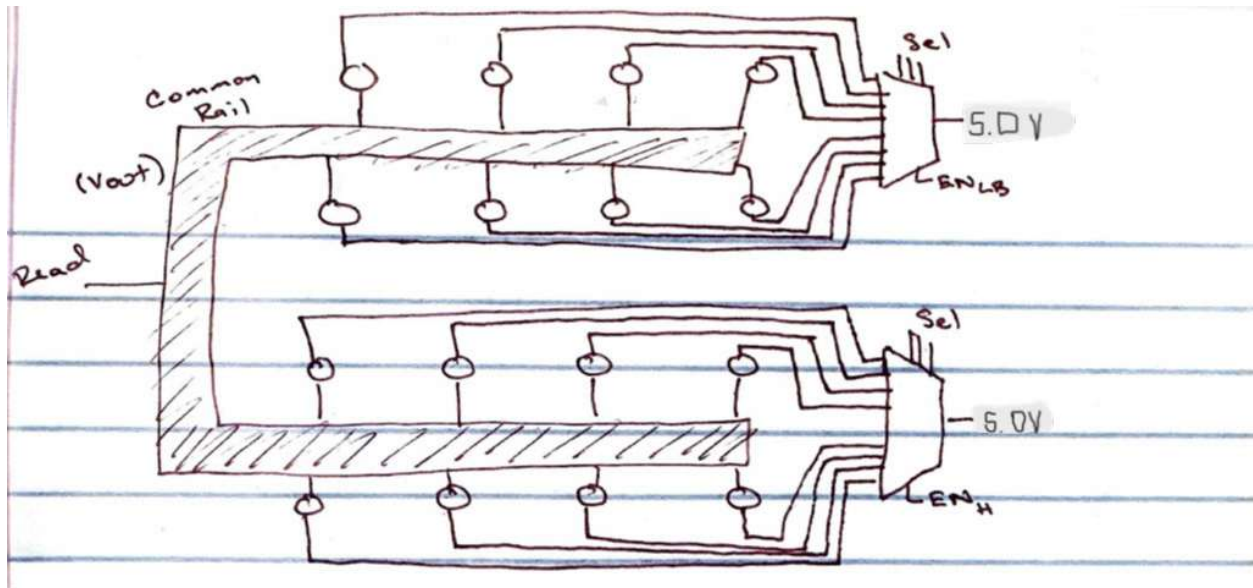


Figure 7: Circuit Schematic for DEMUXs and Sensing Subsystem

The FSR 400 behaves as a variable resistance whose resistance decreases with increasing applied force. Since an ADC measures voltage rather than resistance directly, the selected FSR is connected to a force-to-voltage conversion circuit. The FSR is excited using the system's 5.0 V supply, and a measurement resistance of $R_M = 10\text{k}\Omega$ is used to establish the relationship between FSR resistance and output voltage.

The $10\text{k}\Omega$ measurement resistance was selected based on the force-versus-output-voltage characterization provided in the FSR 400 datasheet. With a 5 V excitation, larger measurement resistances such as $47\text{k}\Omega$ and $100\text{k}\Omega$ cause the output to approach the 5 V supply at relatively small applied forces. In comparison, $R_M = 10\text{k}\Omega$ provides a wider usable voltage range as force increases. From the manufacturer's characteristic curve, the $10\text{k}\Omega$ configuration produces approximately 1.7 V at 100 g of applied load, 2.9 V at 500 g, and 3.4 V at 1000 g. These values are approximate and will be experimentally characterized for the completed sensing assembly because individual FSR response and the mechanical interface can affect the relationship between applied force and output voltage.

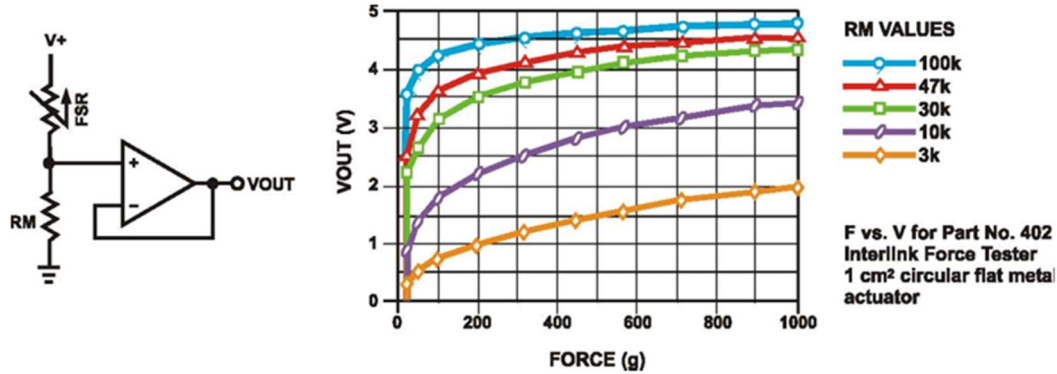


Figure 8: Force to Voltage Conversion Circuitry with Different Rm Values [3]

The output of the force-to-voltage conversion circuit must be converted into a digital value before it can be processed by the MCU Subsystem. An analog-to-digital converter (ADC) will therefore sample V_OUT from the force-to-voltage conversion circuit and provide a corresponding digital representation to the microcontroller. The required ADC resolution will be determined experimentally after characterizing the FSR 400 sensors and force-to-voltage conversion circuit under representative loading conditions. This characterization will determine the magnitude of voltage differences that must be distinguished between relevant pressure levels.

The initial implementation will evaluate the MCU's internal ADC, provided that its input voltage range and resolution are sufficient for the measured V_OUT range and required pressure sensitivity. If the internal ADC cannot reliably distinguish the required changes in sensor output, an external ADC with greater resolution and/or a more appropriate input range will be incorporated. If an external ADC is required, digital communication with the MCU will be implemented using an appropriate serial interface such as SPI or I²C. Regardless of the final ADC implementation, its input range must accommodate the output of the force-to-voltage conversion stage without exceeding the ADC's maximum allowable input voltage.

Table 2: Analog Acquisition Subsystem – Requirements & Verification

Requirements	Verification
The Analog Acquisition Subsystem shall independently select each of the 16 sensing locations with 100% correct channel selection over 10 consecutive complete scans (160 total selections).	- Connect the completed sensing and acquisition circuitry and power it normally. - Apply a known load to one FSR while leaving the remaining sensors unloaded. - Command the MCU to sequentially select all 16 sensor locations. - Record which channel produces the loaded-sensor response. - Repeat for every FSR and repeat the

	- complete scan 10 times - Record commanded sensor, detected sensor, and pass/fail in a table
Over the defined normal operating force range of the sensing subsystem, the force-to-voltage circuit shall produce an output that increases monotonically with increasing applied force and remains within the allowable input-voltage range of the selected ADC for 100% of tested loads.	- Connect a DMM or oscilloscope to V_OUT. - Apply a series of known increasing forces using calibrated weights or a force gauge, covering the defined operating range. - Record applied force and V_OUT at each test point. - Repeat the test for representative FSRs from both sensing regions. - Plot V_OUT versus applied force. Verify that V_OUT does not decrease between successive increasing-force test points and that no measured voltage exceeds the ADC input range.
The selected ADC shall have a voltage resolution of no greater than one-half of the minimum experimentally measured voltage difference $\Delta V_{\min}$ that the system must distinguish between relevant loading conditions: $\Delta V_{\text{ADC}} \leq \Delta V_{\min}/2$	- Using the force-characterization measurements from above, determine the minimum voltage difference $\Delta V_{\min}$ that must be distinguishable by the system. - Determine the ADC resolution from $\Delta V_{\text{ADC}} = V_{\text{REF}}/(2^N)$. - Using a bench power supply or function generator, apply two known ADC input voltages separated by $\Delta V_{\min}$. - Acquire at least 100 samples at each voltage. - Verify that the resulting ADC readings distinguish the two input levels and that $\Delta V_{\text{ADC}} \leq \Delta V_{\min}/2$. - Record the applied voltages and ADC readings in a table.
The Analog Acquisition Subsystem shall acquire and deliver one valid digital measurement for all 16 sensing locations during each complete sensor scan, with 0 missing measurements over 100 consecutive scans.	- Operating the complete acquisition system under normal power conditions. - Configure the MCU to perform 100 consecutive scans of all 16 sensors. - Log the sensor address and returned ADC value for every measurement. - Verify that every scan contains exactly 16 valid measurements corresponding to the 16 sensing locations.

2.3.3 MCU Subsystem

The MCU subsystem serves as the primary processing and control unit of the pressure-sensing system. The microcontroller will operate using 3.3 V logic and will control sensor selection through GPIO signals while receiving digitized measurements from the Analog Acquisition Subsystem. The 16 pressure sensors are divided between the hip and lower-back sensing regions, with each group of eight sensors connected to a 1:8 analog multiplexer. The MCU will control the select inputs of these multiplexers to sequentially select individual sensing locations for measurement. The selected sensor's force-dependent resistance is converted into an analog voltage by the Analog Acquisition Subsystem and subsequently digitized by either the MCU's internal ADC or an external ADC, depending on the resolution and input-range requirements determined during system characterization. By associating each acquired measurement with the corresponding multiplexer address, the MCU can identify both the magnitude and physical location of the detected load.

For each of the 16 pressure-sensing locations, the MCU will continuously compare new measurements with previous measurements to identify meaningful changes in applied pressure. A short history of sensor measurements may be maintained and filtered to reduce the effect of noise and brief pressure fluctuations; the required sampling rate, number of stored samples, and filtering method will be determined through characterization of the completed sensing and analog acquisition subsystems. Once sustained loading above the defined threshold is detected at a sensing location, the MCU will independently track the duration of that condition and determine the corresponding alert state, such as normal, reposition soon, or reposition immediately. Each sensing location will maintain its own pressure state and duration information so that sustained loading can be associated with a specific location within the hip or lower-back sensing regions.

Pressure analysis, duration tracking, and alarm-state determination will be performed locally by the MCU rather than by the external user interface. Therefore, alarm determination does not depend on maintaining a continuous Bluetooth connection. The Bluetooth subsystem is responsible only for transmitting the pressure status, affected sensing region or location, and corresponding alarm state generated by the MCU to the user interface. This architecture allows the pressure-monitoring and alarm-detection algorithms to continue operating if the wireless connection is temporarily interrupted.

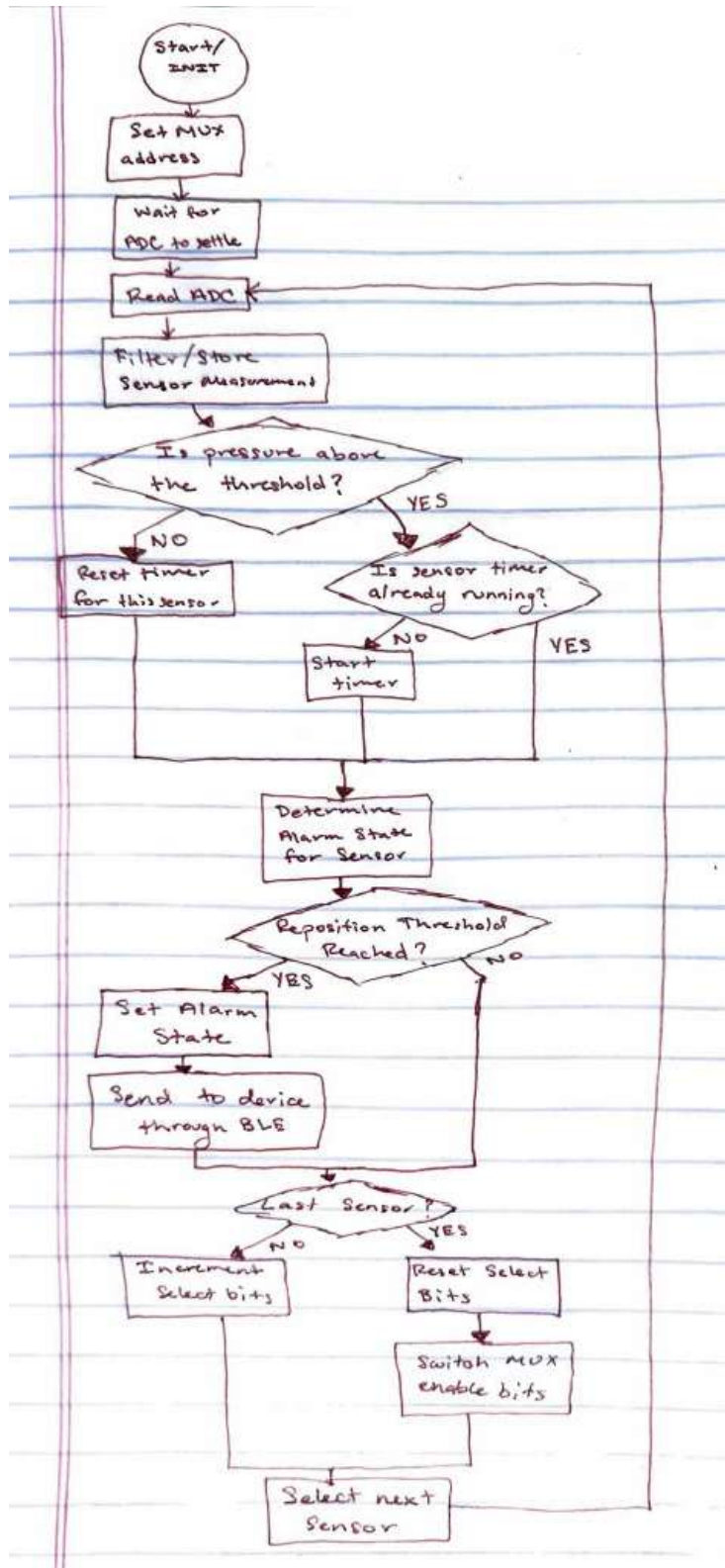


Figure 9: Flowchart for MCU Logic

Table 3: MCU Subsystem – Requirements & Verification

Requirements	Verification
The MCU shall command and acquire a measurement from all 16 sensing locations at least once every 1.0 second, and shall associate each acquired measurement with the correct sensor location with 100% accuracy over 100 consecutive complete scans.	- Connect the completed MCU and Analog Acquisition Subsystems. - Instrument the MUX select GPIO lines and ADC acquisition signal using an oscilloscope or logic analyzer. - Run the normal sensor-scanning firmware for 100 complete scans. - Log the sensor address, corresponding physical sensor number, and acquisition timestamp for every reading. - Verify that every group of 16 measurements is completed within 1.0 s and that all 1600 measurements are associated with the correct sensor location. - Present the results as a table showing scan duration, sensor address, and pass/fail.
The MCU shall independently maintain the pressure state and elapsed pressure duration for all 16 sensing locations. For any sensor continuously above the configured pressure threshold, the recorded duration shall remain within ± 1.0 s of the actual elapsed time over a test interval of at least 5 minutes. Pressure applied to one sensor shall not alter the timer associated with any other sensor.	- Configure a known pressure threshold in firmware. - Apply a constant load above that threshold to one FSR while leaving the remaining sensors below threshold. - Use a calibrated stopwatch or computer timestamp as the reference time. - Maintain the load for at least 5 minutes while recording the MCU's timer value once every minute. - Repeat with multiple sensing locations, including sensors in both the hip and lower-back regions. - Verify that timer error remains within ± 1.0 s and that timers for unloaded sensors remain at zero. - Present measured versus reference time in a table.
For each sensing location, the MCU shall assign the correct alarm state based on the configured pressure and time thresholds with 100% correct classification over at least 30 test cases. The state shall transition from Normal $\rightarrow$ Reposition Soon $\rightarrow$ Reposition Immediately when the corresponding	- Configure known test values for the pressure threshold, T_s, and T_i. - Provide simulated ADC values or controlled sensor inputs above and below the pressure threshold. - Generate at least 30 combinations covering: below-pressure threshold, above-pressure threshold but below

programmed thresholds are reached, with the transition occurring within ± 1.0 s of the configured time threshold.	T_s, between T_s and T_i, and beyond T_i. - Record the MCU-generated alarm state and transition time for every test case. - Compare the results with the expected states calculated beforehand. The requirement passes if all 30 classifications are correct and all timed transitions occur within ± 1.0 s. Present results in a test-case table.
Loss of the Bluetooth connection shall cause 0 missed sensor scans and 0 incorrect alarm-state transitions during a continuous 10-minute Bluetooth-disconnection test. Pressure acquisition, duration tracking, and alarm determination shall continue locally while BLE is unavailable.	- Operate the complete system normally with an established BLE connection. - Apply a known load above threshold to at least one sensing location. - Disconnect or disable the BLE receiving device for 10 minutes. - During the disconnection, log sensor measurements, timers, and alarm states through a wired serial/debug interface. - Introduce conditions during the test that cross both the Reposition Soon and Reposition Immediately time thresholds. - Verify that scanning and alarm logic continue correctly despite BLE loss. Report number of completed scans, missed scans, expected alarm transitions, and observed alarm transitions.

2.3.4 Alarm Subsystem

The alarm subsystem provides wireless communication between the pressure-monitoring system and an external user device. The system will use an ESP32 microcontroller with integrated Bluetooth Low Energy (BLE) capability, eliminating the need for a separate Bluetooth communication module. After the MCU processes the pressure measurements and determines the current alarm state, this information will be transmitted using the ESP32's internal BLE functionality. The subsystem will transmit the current system status, including whether the patient is in a normal, reposition soon, or reposition immediately state, to a BLE-capable external device such as a smartphone, tablet, or computer.

The purpose of the external device is to allow a caregiver or user to remotely monitor the status of the sensing pad without requiring a physical connection to the system. Development of a dedicated graphical mobile application is not required for the operation of this subsystem; the primary requirement is that alarm information can be successfully transmitted and accessed by a compatible external device. Because pressure analysis, timing, and alarm-state determination occur locally within the ESP32, loss of the

Bluetooth connection will not interrupt pressure monitoring, pressure-duration tracking, or alarm-state determination. Once the BLE connection is restored, the ESP32 can resume transmitting the current system status to the external device.

Table 4: Alarm Subsystem – Requirements & Verification

Requirements	Verification
The Alarm Subsystem shall transmit the current alarm state (Normal, Reposition Soon, or Reposition Immediately) and corresponding sensing location to a connected BLE-capable external device with 100% correct transmission over at least 30 commanded alarm-state changes.	- Connect a BLE-capable smartphone, tablet, or computer to the ESP32. - Use test firmware or controlled sensor inputs to command at least 30 known combinations of alarm state and sensor location. - Record the expected state/location from the MCU through a serial/debug terminal and independently record the BLE-received state/location on the external device. - Compare the two records. The test passes if all 30/30 BLE messages contain the correct alarm state and location. - Present results in a table containing expected state, transmitted state, expected location, received location, and pass/fail.
While a BLE connection is active, a change in alarm state generated by the MCU shall be received by the external device within 2.0 s of the MCU generating the new state for at least 95% of 30 consecutive alarm transitions, with no transition taking longer than 3.0 s.	- Maintain an active BLE connection between the ESP32 and an external device. - Generate 30 controlled alarm-state changes. - Record the MCU transition timestamp using the ESP32 serial/debug output and the BLE reception timestamp using BLE logging software or the receiving computer/device. - Calculate the latency for each transition. - Verify that at least 29 of 30 transitions are received within 2.0 s and that none exceed 3.0 s. - Present the 30 measured latency values and calculated success percentage in the final report.
The Alarm Subsystem shall maintain a	Place the ESP32-based system and

BLE connection and successfully transmit alarm information at a separation of at least 5 m line-of-sight between the pressure-monitoring system and external device, with at least 95% successful reception over 100 transmitted status messages.	BLE receiving device 5.0 ± 0.1 m apart, measured using a tape measure. • Establish a BLE connection. • Transmit 100 numbered status messages at regular intervals. • Record the number of messages successfully received by the external device. • Verify that at least 95 of 100 messages are received correctly without loss of connection. • Record distance, transmitted-message count, received-message count, and reception percentage.
• Following an intentional loss of BLE communication, the Alarm Subsystem shall re-establish communication and transmit the current alarm state within 10 s after the external device again becomes available, for 10 out of 10 reconnection trials.	• Establish a normal BLE connection. • Disconnect or disable Bluetooth on the receiving device. • Change the system alarm state while BLE is disconnected. • Re-enable Bluetooth and make the receiving device available for connection. • Measure the time from BLE availability to receipt of the current alarm state using a stopwatch, software timestamps, or serial/BLE logs. • Repeat for 10 trials. The test passes if the correct current state is received within 10 s in all 10/10 trials. • Present reconnection times and received states in a table.

2.3.5 Power Subsystem

The power subsystem provides the electrical energy required to operate the sensing, analog acquisition, MCU, and BLE subsystems while allowing the pressure-sensing pad to operate without a continuous wired connection. The system will use an off-the-shelf rechargeable battery solution with the LTC1730 IC to aid in the charging of the battery safely. The battery will be rechargeable through an external low-voltage power source, such as a USB wall adapter, allowing the device to be recharged without removing the battery. Voltage-regulation circuitry will convert the battery output to a regulated 5.0 V rail used to power the system electronics and provide the required 5.0 V excitation for the FSR sensing circuitry. The ESP32 and any other components requiring lower operating voltages will use appropriate onboard or additional voltage regulation as necessary. The power subsystem contributes to the

overall design by allowing continuous operation of the sensing, processing, analog acquisition, and wireless communication functions while maintaining the portability of the pressure-sensing pad.

Table 5: Power Subsystem – Requirements & Verification

Requirements	Verification
The Power Subsystem shall provide a regulated output of $5.0\text{ V} \pm 5\%$ (4.75–5.25 V) under all normal system operating conditions.	- Connect the completed power subsystem to the full system or an equivalent electronic load. - Measure the 5 V rail using a calibrated DMM at idle load and at the maximum expected operating load. - Repeat measurements while BLE is actively transmitting and while the analog acquisition circuitry is scanning sensors. - Verify that the rail remains between 4.75 V and 5.25 V for all conditions. Record load condition, current, and measured voltage in a table.
The Power Subsystem shall continuously supply at least 1.25 times the measured maximum steady-state current consumption of the integrated system while maintaining the 5 V rail within the 4.75–5.25 V range.	- Measure maximum steady-state current draw of the fully integrated system using a bench power supply with current readback or a DMM in series. - Calculate $I_{\text{req}} = 1.25 I_{\text{max}}$ - Connect an electronic load to the 5 V output and increase current to I_{req}. - Monitor output voltage for at least 10 minutes. - Verify that voltage remains within 4.75–5.25 V and that no thermal shutdown or protection event occurs. Record current and voltage versus time.
The rechargeable battery subsystem shall power the complete device for at least 8 hours of continuous normal operation from a fully charged battery before the system can no longer maintain its required operating voltage.	- Fully charge the battery using the normal charging circuit. - Disconnect external charging power. - Operate the complete system continuously with normal sensor scanning and periodic BLE transmissions. - Measure battery voltage and 5 V rail voltage once every 30 minutes using a DMM or data logger. - Record total operating time until the 5

	V rail falls outside specification or the system shuts down. • The requirement passes if operation lasts at least 8 hours. Present voltage-versus-time data and total runtime.
• The charging subsystem shall recharge the battery from its discharged operating state without exceeding the battery manufacturer's specified maximum charging voltage or current, and shall terminate or reduce charging appropriately when the battery reaches full charge.	• Discharge the battery to the system's normal low-battery cutoff condition. • Connect the specified USB wall adapter. • Use a DMM or oscilloscope/current probe to monitor battery voltage and charging current throughout the charge cycle. • Compare measured values against the selected battery manufacturer's allowable charging voltage/current specifications. • Verify that neither maximum limit is exceeded and that charging current decreases or terminates when full charge is reached. • Record battery voltage and current versus time.
• A short circuit applied to the regulated 5 V output shall not cause permanent damage to the battery, charging circuitry, or voltage-regulation circuitry, and normal operation shall resume after the fault is removed.	• Fully power the subsystem under normal conditions. • Using a current-limited test fixture or electronic load, apply a controlled short-circuit condition to the 5 V output for a predetermined duration, such as 5 s. • Monitor output current and battery voltage using a DMM or oscilloscope. • Remove the fault and verify that the regulated 5 V output returns to 4.75–5.25 V and the system resumes normal operation. • Record peak fault current, voltage during fault, and post-fault output voltage.

2.4 Tolerance Analysis

A critical aspect of the pressure-monitoring system is the ability of the Analog Acquisition Subsystem to distinguish between different levels of applied force despite variations in the sensor and supporting circuitry. If the measured output voltage changes significantly due

to component tolerances rather than an actual change in applied force, the MCU could incorrectly classify the loading condition of a sensing location. Therefore, the tolerance analysis focuses on the FSR 400 force-to-voltage conversion circuit.

The FSR 400 is used in a voltage-divider configuration with a 5 V excitation voltage and a measurement resistor of 10 k Ω . According to the manufacturer, the output voltage is described by:

$$V_{out} = V_{+} \times R_M / (R_M + R_{FSR})$$

where V_{+} is the excitation voltage, R_M is the measurement resistor, and R_{FSR} is the force-dependent resistance of the FSR. The FSR resistance decreases as applied force increases, causing V_{out} to increase. Interlink Electronics specifies a nominal force-sensitivity range of approximately 0.2 N to 20 N, a single-part repeatability of $\pm 2\%$, a part-to-part repeatability of $\pm 6\%$, and an average hysteresis of approximately 10%. The manufacturer also notes that the actual response depends on the mechanical interface and measurement electronics.

The nominal force-to-voltage values are taken from the manufacturer-provided FSR 400 graph for a 5 V supply and $R_M = 10 \text{ k}\Omega$. Approximate nominal values are:

$$100 \text{ g applied load} \rightarrow V_{out} \approx 1.7 \text{ V}$$

$$500 \text{ g applied load} \rightarrow V_{out} \approx 2.9 \text{ V}$$

$$1000 \text{ g applied load} \rightarrow V_{out} \approx 3.4 \text{ V}$$

These values are used only as representative operating points because the manufacturer states that the graph is intended for reference and may vary between sensors and mechanical implementations.[3]

The corresponding nominal FSR resistance can be estimated by rearranging the voltage-divider equation:

$$R_{FSR} = R_M \times (V_{+} / V_{out} - 1)$$

For an applied load of approximately 100 g:

$$R_{FSR,100} = 10 \text{ k}\Omega \times (5 / 1.7 - 1)$$

$$R_{FSR,100} \approx 19.4 \text{ k}\Omega$$

For an applied load of approximately 500 g:

$$R_{FSR,500} = 10 \text{ k}\Omega \times (5 / 2.9 - 1)$$

$$R_{FSR,500} \approx 7.24 \text{ k}\Omega$$

For an applied load of approximately 1000 g:

$$R_{FSR,1000} = 10 \text{ k}\Omega \times (5 / 3.4 - 1)$$

$$R_{FSR,1000} \approx 4.71 \text{ k}\Omega$$

To evaluate worst-case output variation, three primary tolerances are considered. The regulated 5 V rail is assumed to remain within the power-subsystem requirement of $5.0 \text{ V} \pm 5\%$, giving:

$$V_{+,min} = 4.75 \text{ V}$$

$$V_{+,max} = 5.25 \text{ V}$$

A 1% tolerance resistor is assumed for $R_M = 10 \text{ k}\Omega$, giving:

$$R_{M,min} = 9.9 \text{ k}\Omega$$

$$R_{M,max} = 10.1 \text{ k}\Omega$$

The FSR datasheet specifies approximately $\pm 6\%$ part-to-part repeatability for devices from a single batch. For this preliminary analysis, this $\pm 6\%$ value is conservatively modeled as variation in the effective FSR resistance at a given applied force. Interlink Electronics

The minimum output voltage occurs when the supply voltage and measurement resistance are at their minimum value while the FSR resistance is at its maximum value:

$$V_{out,min} = V_{+,min} \times R_{M,min} / (R_{M,min} + 1.06 \times R_{FSR,nom})$$

The maximum output voltage occurs when the supply voltage and measurement resistance are at their maximum value while the FSR resistance is at its minimum value:

$$V_{out,max} = V_{+,max} \times R_{M,max} / (R_{M,max} + 0.94 \times R_{FSR,nom})$$

Using these equations, the approximate worst-case voltage ranges are:

Applied Load	Nominal Vout	Minimum Vout	Maximum Vout
100 g	1.70 V	1.54 V	1.87 V
500 g	2.90 V	2.68 V	3.14 V
1000 g	3.40 V	3.16 V	3.65 V

The 100 g and 500 g voltage ranges remain clearly separated even after including supply-voltage, resistor, and sensor variation. Therefore, the analog acquisition circuit should be able to distinguish relatively large changes in applied load with substantial margin.

However, the calculated 500 g and 1000 g tolerance bands are much closer together. The worst-case upper voltage at 500 g is approximately 3.14 V, while the worst-case lower voltage at 1000 g is approximately 3.16 V, leaving only approximately:

$$3.16 \text{ V} - 3.14 \text{ V} = 0.02 \text{ V}$$

of separation.

This indicates that component and sensor variations become increasingly significant at higher force levels, where the voltage-divider response begins to compress toward the 5 V supply. The FSR datasheet also specifies approximately 10% average hysteresis, which could further reduce the effective separation between nearby loading conditions. Interlink Electronics

Therefore, the system should not rely on a single theoretically calculated voltage threshold to determine precise force values. Instead, the final design will experimentally characterize the completed FSR and pad assembly and establish pressure-state thresholds with sufficient voltage margin between operating regions. If characterization shows that adjacent relevant loading conditions produce overlapping output-voltage ranges, the system can compensate through calibration, adjustment of RM, filtering, or by selecting an ADC and decision thresholds appropriate for the measured response.

This analysis shows that the selected $R_M = 10 \text{ k}\Omega$ configuration provides useful voltage separation over a significant portion of the expected operating range, but sensor variation and hysteresis are likely to be the dominant limitations on measurement precision. Once the physical sensors are obtained, the tolerance analysis will be refined using measured force-versus-voltage data from the actual pad assembly.

3. Cost and Schedule

3.1 Cost Analysis

The members of our group price the value of our labor at \$35/hour, which working 2.5 hours per day for 9 weeks (45 workdays) places our total cost of labor at (2 partners) * (\$35/hour) * (2.5hours/day) * (45 day/semester) = \$7,875. The total cost for parts in Figure 10 comes out to \$182.97 with 8% shipping totaling \$197.61, making the total cost for the entire project \$8,072.61. We don't use the machine shop so we do not need to price their services.

Description	Manufacturer	Quantity	Price	Link
CAP CER 0.1UF 50V X7R 0603	KEMET	8	\$0.77	Link
CAP CER 10PF 200V C0G/NPO 1206	YAGEO	2	\$0.58	Link
LED RED CLEAR 0805 SMD	Visual Communications Company - VCC	5	\$2.00	Link

FERRITE BEAD 30 OHM 0805 1LN	Bourns Inc.	1	\$0.12	Link
RES SMD 330 OHM 0.5% 1/8W 0805	YAGEO	4	\$0.51	Link
RES SMD 1K OHM 0.1% 1/5W 0805	Vishay Dale Thin Film	1	\$1.15	Link
RES SMD 5.11K OHM 1% 1/8W 0805	YAGEO	2	\$0.21	Link
RES 33K OHM 1% 1/8W 0805	YAGEO	1	\$0.10	Link
RES SMD 500 OHM 0.05% 1/4W 0805	Vishay Dale Thin Film	1	\$3.42	Link
RES SMD 1.5K OHM 0.5% 1/8W 0805	YAGEO	1	\$0.10	Link
RES SMD 82K OHM 1% 1/8W 0805	YAGEO	1	\$0.10	Link
IC REG LINEAR 3.3V 300MA SOT23-5	Texas Instruments	1	\$0.17	Link
RF TXRX MOD BT WIFI TH SMD (ESP32 IC)	Espressif Systems	1	\$4.99	Link
USB 3.2 GEN 2 TYPE C REC, 3" GOL	GCT	1	\$1.36	Link
BATT LITH-ION 3.7V 500MAH 702528	US Electronics Inc.	1	\$5.49	Link
IC BATT CHG LI-ION 1CELL 8SOIC	Texas Instruments	1	\$4.70	Link
CONN HEADER VERT 2POS 2.54MM	Amphenol ICC (FCI)	20	\$3.80	Link
SWITCH TACTILE SPST-NO 0.05A 12V	E-Switch	1	\$0.32	Link
CRYSTAL, 5.0X3.2MM, +/- 30PPM, -4	Vishay Dale	1	\$0.72	Link
IC MUX 8:1 195OHM 16TSSOP	Texas Instruments	2	\$1.16	Link
RES 10K OHM 1% 1/8W 0805	YAGEO	1	\$0.10	Link
IC OP AMP 1CH 8-PDIP	Texas Instruments	1	\$1.22	Link
JUMPER KIT PREFORM 3.93" 28AWG	BusBoard Prototype Systems	1	\$13.00	Link
THIN FILM PRESSURE SENSOR, 30G-10KG FORCE SENSING RESISTOR, 2PCS	Interlink Electronics, Inc.	8	\$98.32	Link
OFFICE STAPLER WITH 1000 STAPLES	Amazon	1	\$9.59	Link
PLEXIGLASS SHEETS, 5 PACK OF 8 X 10 INCH	Art3d	1	\$4.99	Link
FOAM PADDING 4PCS 16 X 12 X 0.5 INCH	FENYUAN	1	\$14.99	Link
PILLOWCASES QUEEN PACK	Bedsure&Bedshe	1	\$8.99	Link

OF 2, 20 X 30 INCH				
--------------------	--	--	--	--

Figure 10 – List of Components, Cost, and Links to Datasheets

3.2 Schedule

Week	Task	People
October 5th – 11th	• Design Review with TAs • Finish PCB design • Complete PCB audit • Submit PCB design for 2nd Round • Test FSR behavior using Arduino prototype • Finalize bill of materials using prototype measurements	• Both • Both • Both • Tyler • Tyler • Rayan
October 12th – 18th	• Order ESP32 for testing and integration • Order components from bill of materials • Breadboard Demo with TAs using Arduino • Teamwork Evaluation	• Rayan • Rayan • Both • Both
October 19th – 25th	• Replace Arduino with ESP32 and test PCB using ordered components • Finalize analog acquisition subsystem	• Both • Both
October 26th – November 1st	• Complete PCB audit • Submit PCB design for 4th Round • Start firmware for signal processing and Bluetooth communication	• Both • Tyler • Tyler
November 2nd – 8th	• Assemble physical sensing pad with all layers • Progress Demo with TAs • Individual Progress Reports	• Both • Both • Both
November 9th – 15th	• Solder final PCB with all components • Finetune assembly of physical pad • Establish threshold for pressure vs. no pressure tests • Team Contract Assessment	• Tyler • Rayan • Both • Both
November 16th – 22nd	• Account for last minute issues unforeseen in this schedule • Mock Demo with TA • Mock Presentation with TA	• Both • Both • Both
November 23rd – 29th	• Fall break, relax!	• Both
November 30th – December 6th	• Practice our Demo and create Presentation documents • Final Demo with everyone	• Both • Both
December 7th – 13th	• Final Paper due • Lab Notebook due	• Both • Both

4. Ethics, Standards, and Safety

The IEEE Code of Ethics dictates that engineers should hold the safety and health of the public as the highest priority and disclose any potentially harmful side effects thoroughly before sharing with the public [4]. Due to this project's use case residing primarily in the medical field, preserving patient safety and welfare is chief among ethical considerations, and we intend to adhere to that.

Our ethical design choices consist of incorporating a foam pad above the sensing pad to ensure patient comfort is maximized, even if it will make sensing pressure over time more difficult. Additionally, we will ensure that the alarm that goes off to signal excessive prolonged pressure is not needlessly embarrassing or shaming, only alerting the caregiver in charge of that patient. This system is to be treated as nothing more than a monitor and alert aid, to be supplemented by expert clinical judgement before any action is taken. This system will not replace the caregiver but rather help in their care and assessment of their patients, ensuring we follow the IEEE requirement that our project is honest and realistic when stating our technical claims and capabilities [4].

Several engineering standards provide relevant guidance for the design process and self-evaluation of this project that we must follow. “IEC 60601-1, Medical Electrical Equipment—Part 1: General Requirements for Basic Safety and Essential Performance”, addresses electrical and other safety considerations for medical electrical equipment [5]. These principles are relevant when considering the power supply, electrical isolation, and potential hazards associated with equipment used near patients in hospital or healthcare settings, like our device. We will use a risk management approach to identify any hazards, including electrical faults, pressure-measurement errors, mechanical discomfort, or missed alerts, and adapt as we go for how our design and testing can address them.

Several safety features must also be addressed during the development of our project. We will ensure that all components utilize a low-voltage power source, and any exposed conductive materials are secured inside of the plastic covering. This enclosure will also prevent the patient from being poked, prodded, or otherwise made uncomfortable by any electronic components we develop. All materials that contact the patient or the patient's bed will be encased in foam to further maximize comfort and prevent potential damage to the bed itself. Furthermore, the system will be non-obstructive insofar as its existence will not prevent the normal repositioning tactics employed by the caregivers. Additionally, we are under no false idea that this system will operate forever under extensive and intense use. We would be sure to thoroughly explain to anyone using this system that the lack of an alarm does not guarantee the safety of the patient, and that normal checkups would still be required as if the system was not in place. This is only to catch preventable pressure-related injuries before they happen, and in the event of a failure in our

system and the inability to alert a caregiver of the situation, normal procedures must stay in effect. We can develop a simple LED display to identify the caregiver when the system is operational to prevent such a situation from happening.

The nature of our project will be simply a research prototype and not a clinically approved device. All testing will be done strictly on the members of our team and with expressed, informed, and verbal consent prior to trials.

As for the societal impact of our project, the upside is rather intriguing. Firstly, it will improve the working lives of the caregivers in charge of bedridden or mobility-impaired patients, serving as an aid in ensuring their patients receive the best care possible. Needless to say, it will also benefit the patients themselves, as millions of patients per year could avoid a pressure-related injury and greatly improve their quality of life. As discussed before, the economic impact could also be quite significant, with healthcare costs reducing massively and benefiting the overall healthcare system. This low-cost platform would provide the monitoring capabilities of much more expensive machines while using relatively simple components, granting this aid to areas of the country/world previously unable to implement it. During our development process, we will ensure to reduce waste and develop a prototype capable of being reproduced with non-harmful substances to prevent any negative impact on the environment.

5. Citations

- [1] Agency for Healthcare Research and Quality, “Preventing Pressure Ulcers in Hospitals: Overview,” U.S. Department of Health and Human Services, Oct. 2014. Available: <https://www.ahrq.gov/patient-safety/settings/hospital/resource/pressureulcer/tool/intro.html>. [Accessed: Sep. 18, 2026].
- [2] W. V. Padula and B. A. Delarmente, “The national cost of hospital-acquired pressure injuries in the United States,” *International Wound Journal*, vol. 16, no. 3, pp. 634–640, Jun. 2019, doi: 10.1111/iwj.13071.
- [3] Interlink Electronics, Inc., “FSR® 400 Series Data Sheet,” document PDS-10004-C. [Online]. Available: <https://www.interlinkelectronics.com/downloads/datasheets/fsr-400-series-datasheet.pdf>. [Accessed: Oct. 2, 2026].
- [4] IEEE, “IEEE Code of Ethics,” IEEE, Jun. 2020. [Online]. Available: <https://www.ieee.org/about/corporate/governance/p7-8.html>. [Accessed: Sep. 18, 2026].
- [5] International Electrotechnical Commission, IEC 60601-1:2005+AMD1:2012+AMD2:2020, Medical Electrical Equipment—Part 1: General Requirements for Basic Safety and

Essential Performance. Geneva, Switzerland: IEC, 2020. [Online]. Available: <https://webstore.iec.ch/en/publication/67497>.