Smart Rollator - Capstone Project Proposal

SYSC4907, Group 33

By:
Corbin Garlough - 101101493
Isabelle Bryenton - 101077788
Kenny Deng - 101122713
Mark Johnson - 101110080
Yunas Magsi - 101115159

Supervised by: Dr. Adrian Chan

Department of Systems and Computer Engineering
Carleton University
Ottawa, Canada

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SYSC 4907 Project Proposal: Smart Rollator

C. Garlough, I. Bryenton, K. Deng, M. Johnson, Y. Magsi

1 Introduction

The Smart Rollator is a mobility aid that collects data about how a patient uses and moves with a rollator through multiple onboard sensors. A medical professional can continuously monitor and adjust patient rehabilitation using collected data streamed to a cloud service for remote access. This project aims to add sensors to a rollator, such as a Nexus rollator shown in fig:1, to add functionality without modifying the design of the traditional rollator.

Figure 1: Nexus rollator

1.1 Justification of suitability

Group 33 is a team composed of members with unique engineering backgrounds and skills well suited to the diverse requirements of the Smart Rollator project. Corbin, Kenny, and Yunas are Computer Systems Engineering students, Mark is a Software Engineering student, and Isabelle is a Biomedical and Electrical Engineering student.

The computer systems degree is helpful in this project because the degree focuses on the ability to integrate software and hardware into a functional system. Since this project has multiple sensors, a cloud-based data storage system, and software to process data, the system integration skills learned in the computer systems degree will significantly assist in creating a final product.

Similarly, Software engineering focuses heavily on the methodological aspects of writing software, including requirements engineering, system design documentation, verification and validation, and software quality management; these are essential aspects of engineering and delivering correct and complete software systems.

Finally, a Biomedical and Electrical engineering degree will provide greater insight into the project's biomedical aspects. This medical device utilizes multiple electrical sensors to acquire biomedical data and microprocessors to process and visualize the data.

1.2 Team Member Tasking

fig:2 shows the distribution of the tasks for the project deliverables for each team member of group 33.

Team member	Tasks
Corbin	Sensor hardware development and database management
Kenny	Testing and sensor hardware
Yunas	Python app development for data display and database management
Mark	Requirements management, data processing and microprocessor software development
Isabelle	Data acquisition system, Sensor integration and testing

Figure 2: Team member Tasking for Project Deliverables

1.3 Milestones

- Read data from sensors
- Mount sensors and required hardware to rollator frame
- Export sensor data to cloud storage service
- Generate a summary of data viewing
- Have a patient use the rollator to collect data about a short period of activity

The milestones above have been documented in Jira and assigned to the appropriate team member.

2 Methodology

Group 33 proposes that the project be implemented to meet the following requirements: the microprocessors, sensors and power supplies, cloud data storage, and analysis detailed in the following Implementation section of the proposal.

2.1 Requirements

Functional Requirements
The functional requirements are the features that provide the data of the rollator usage. These include motion sensing, usage time tracking, heart rate monitoring, weight sense applicator, power capacity to last a full day, local data storage, and cloud upload. Diving into motion sensing, the rollator must be able to track the speed at which the patient moves throughout the day, along with the distance travelled and average acceleration within it. The rollator will also include a Photoplethysmography-based (PPG) heart rate sensor, with which measurements will be recorded when the device is in use. The rollator usage time is logged for the medical practitioner to see the frequency of use, and movement patterns, such as whether they are seated, actively walking or stopped. The three pressure sensors placed on the handles and the rollator's seat provide insight into the patient's weight distribution tendencies and passive use time spent sitting on the seat.

The addition of the sensors and Raspberry pi to the rollator creates a requirement for a power supply on the device. Ideally, this power supply should support at least one full day's use before needing a charge to have no extra burden on the patient. Furthermore, the data collected can be stored locally on the rollator for up to 5 days before it exceeds storage capacities. Local data storage is not ideal, and this has just been added as a failsafe backup measure in case there is no internet available to push the data to the cloud. **Non-Functional Requirements**
The power consumption patterns of the Smart Rollator will be similar to those of consumer cell phones, with battery drain during the day when in use and battery charging required at night while idle, allowing more inexpensive charging solutions to be considered without impacting daily use. The rollator will require wired charging to minimize the technical barrier to entry for using the rollator and maximize the system's ease of use. The Smart Rollator sensor modules and wiring will be implemented without changing the visual appearance of a standard rollator since it is intended to be as unobtrusive as possible for the patient. The data analysis report will be designed for medical practitioners and will require patient-specific authentication to access. This report will be created using a Python app and summarizes all relevant data collected from the patient's rollator into a visually appealing and informative document.

3 Implementation

The requirements outlined above will be met by implementing the following hardware and software components as shown in the system diagram in fig:3.

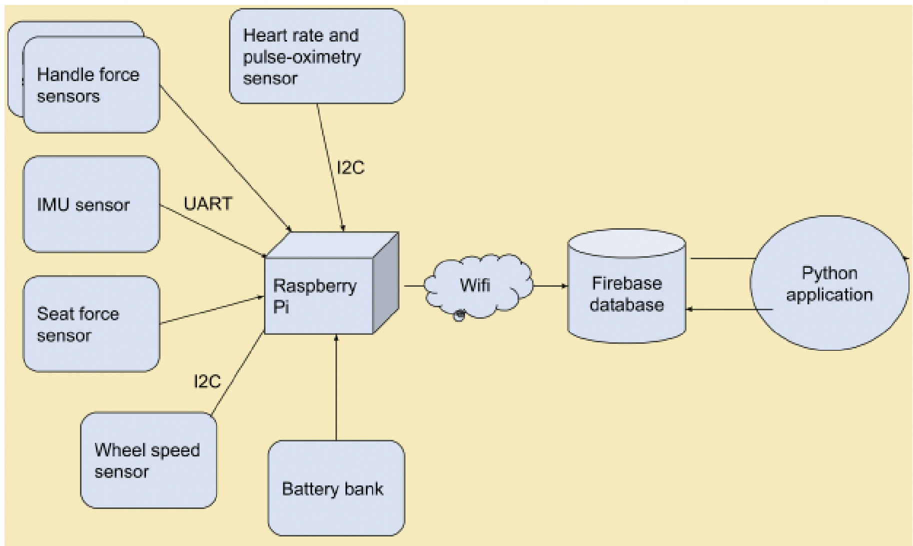

Figure 3: RollSmart System Diagram

3.1 Sensors

Multiple sensors have been selected to be mounted to the RollSmart in order to accomplish the requirements of the project. An overview of these sensors is provided in Table:2 along with an in depth review of each in the following section of the proposal.

3.1.1 Heart Rate Monitoring

An important aspect of the rollator is to track and monitor the heart rate of the user to aid a medical professional in tracking rehabilitation progress and overall health. A wired MAXREFDES117 PPG sensor has been chosen to measure users' heart rate while using the rollator. This sensor has to be non-intrusive to the user while providing accurate heart-rate information with little noise.

The MAXREFDES117 sensor is a PPG optical heart-rate sensor (red and IR LEDs) that communicates using I2C. This sensor was chosen because of its low power consumption, small form factor (able to be mounted and placed on hand/finger), open-source heart rate and blood oxygen saturation level algorithm, and easy to connect terminals. PPG sensors are very reliable and accurate in determining heart rate. With a non-intrusive sensor, there is minimal

Sensor Type	Primary	Alternative	Data Type	Description
Heart Rate	https://www.digikey.ca/en/products/detail/analog-devices-inc-maxim-integrated/MAXREFDES117/6165562		I2C	Measure heart rate of user
IMU Sensor	https://www.digikey.ca/en/products/detail/dfrobot/SEN0373/13590881	https://www.digikey.ca/en/products/detail/bosch-sensortec/BNO055/6136301	UART	9-axis Accelerometer, Gyroscope, & Magnetometer
Speed Sensor	https://www.digikey.ca/en/products/detail/pic-gmbh/MS-332-5-4-0500/9687474		I2C	Measure wheel and rollator speed
Pressure Sensor	https://www.digikey.ca/en/products/detail/uneo-inc/GHF-10/15657152		I2C	Measure force exerted from user

Table 1: Sensor Overview

Figure 4: Sensor Overview Table

interference to the user (the user places a hand over the sensor, not mounted to the user like a chest-mounted monitor, and the user does not have to exert any additional effort to use the sensor). The sensor provides flexibility in terms of mounting to the rollator (able to mount wherever the user has skin contact with the rollator). The sensor is readily available to ship at online vendor DigiKey.

When a heart beats, capillaries contract and expand, these contractions and expansions alter the volume of blood in the capillaries. The PPG heart-rate sensor emits red and IR LED light to detect and calculate these changes in blood volume and translates these changes into a heart rate. One heart rate sensor will be mounted on each of the rollator's handles and constantly monitor the user's heart rate through measurements of the user's fingers/hands. The heart-rate sensor will be physically wired to the microprocessor.

3.1.2 Position Measuring

An essential feature of the rollator is its ability to track the users and usage patterns, and total use times. Medical rehabilitation devices such as a rollator will only deliver desired therapeutic effects if they are used by the patient as long as intended. The rollator will allow medical professionals to monitor the usage times of their patients, offering better insight into their patient's recovery. A sensor that determines the rollator's movements in time is required to determine these metrics.

The momentum sensor chosen is an IMU sensor, it will be used primarily

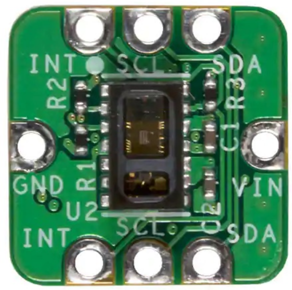

Figure 5: MAXREFDES117: Heart-Rate and Pulse-Oximetry Monitor

to detect movement to track usage time, orientation and relative movement. The Bosch BNO055 IMU sensor shown in fig:5 consists of multiple integrated sensors: an Accelerometer, Gyroscope and Magnetometer to function as a 9 axis sensor using I^2C. This sensor was chosen for its small form factor, low power requirement, and having been recommended by Dr. Chan. The sensor is readily available to ship from the online vendor DigiKey.

Figure 6: Bosch 9-Axis BNO055 IMU Sensor

3.1.3 Speed Detection

An aspect of the rollator is tracking and monitoring the rollator's movement speed. Monitoring and tracking the speed of the rollator over time to create a trendline will aid a medical professional in determining if the user is progressing positively in rehabilitation through an increase in average and peak movement speed. To measure the speed of users while the users are using the rollator, a wired MS-322-5 Reed style speed sensor has been chosen for the task of measuring movement speed. Such a sensor would ideally be non-intrusive to the user while providing accurate speed information.

A speed sensor will be used aboard the rollator to determine the distance and speed travelled by the user during their rollator activity. The existing rollator has a speed sensor attached to the wheel/chassis. Since a sensor already exists, we could reuse the old sensor and/or purchase a new one. We chose the MS-322-5 sensor because it is simple, small, compact, readily available on DigiKey and has two pre-existing mounting holes (easier to place in tight/small wheel well).

The magnet is attached to the rollator's wheel(s) and detects each wheel's (s) revolution. The magnetic field produced by the magnet induces a current in the sensor wires, and the sensor detects the induced current. A speed can be derived with a predetermined measured circumference of the wheel. An option is to use two-speed sensors to detect the direction of travel. This can work with the BNO055 (9-axis IMU) for more accurate distance and rollator usage monitoring.

Figure 7: MS-332-5: Mains Switching Reed Sensor Flatpack

3.1.4 Pressure Measuring

An aspect of the rollator is to measure the pressure that a user exerts onto the handle grips and also measure and detect pressure on the rollator's seat. Measuring the pressure exerted onto the rollator's handle grips over a period of time to create a trendline will aid a medical professional in determining if the user is progressing positively in rehabilitation through a decrease in pressure exerted onto the handle grips. Pressure will also be measured on the seat to detect rollator misuse. To measure the pressure exerted by the user while using the rollator, a wired GHF-10 flex sensor has been chosen for the task of measuring pressure. Such a sensor would ideally be non-intrusive to the user while providing accurate pressure information.

Three force sensors will be placed on the rollator to gain important information on the user's weight distribution when using the device. The first two force sensors will be placed under each handle grips of the rollator to monitor the weight distribution across the rollator as pressure is applied to the surface of the sensor, the resistance of the metal decreases. The relationship between the resistance and pressure applied to the sensor allows the quantification of the force applied by the varying output voltage. Interesting data, such as the user's Left/Right balance, can be determined by comparing the force recorded at the left and right handle sensors.

The third force sensor will be larger and placed under the seat of the rollator. The data from this sensor will be used to determine the amount of time the user spends sitting down during a rollator' activity'. This force sensor, along with the BNO055 IMU will also determine if the user is misusing the rollator by scooting and pushing themselves around while being seated.

In brief, the force sensor will be used to determine if the smart rollator user has an equal Left/Right distribution when using the device and how much time is spent sitting when operating the device. This data can be compared over time for interesting clinical applications, such as monitoring the progression of a patient over time to determine the efficiency of current treatment/rehabilitation protocols.

Figure 8: UNEO Inc, GHF-10 1cm Diameter Ultra Thin Flex Sensor

3.2 Microprocessor

The microprocessor chosen for the Smart Rollator is the Raspberry Pi 4. After extensive research on various micro-controllers and microprocessors. It became clear that the Raspberry Pi offers a substantial amount of GPIO pins, computational power, Wifi/Bluetooth connectivity, can be used for threading operations more simply, and many more features. The Pi offers the best performance and flexibility. If wireless sensors are used, the Pi is more than capable of handling the new task. The Pi has a built-in real-time clock, which many other microprocessors do not offer. The Raspberry Pi runs its operating system, which is Linux based, meaning we can use the device as a regular computer if desired.

An overview of the Raspeberry Pi GPIO and how it interfaces with the chosen sensors for the rollator is provided in fig:8

fig:12 shows a rough sketch of a RollSmart unit, where the small rectangles represent the location of the sensors and microprossesors which were described in the proposal. fig:12 highlights **101**, the location under the seat where the

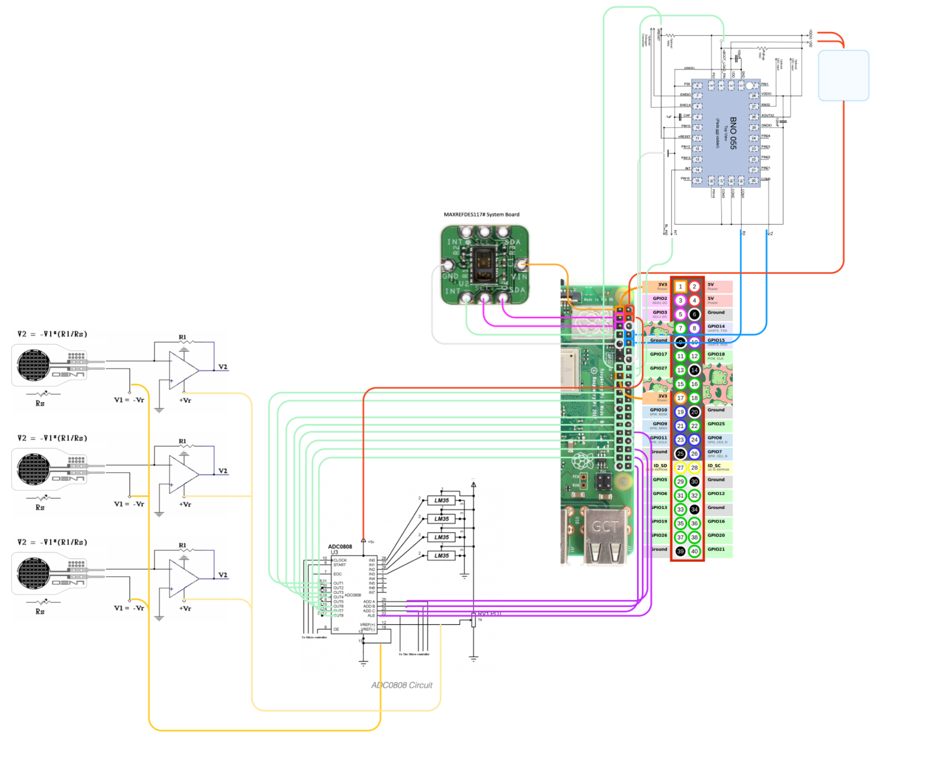

Figure 9: RollSmart System Diagram

raspberry pi and IMU are located, along with the seat force sensor. The remaining two force sensors along with the MAXRESDEF117 PPG sensor are shown on the handles at **102**.

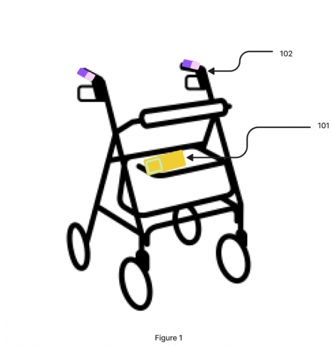

Figure 10: Sketch of Rollator to illustrate location of sensors

3.3 Powering The Rollator

The rollator requires an independent power source to supply power to the microprocessor and the various connected sensors. An analysis of the power consumption of the desired sensors for the rollator is shown in fig:9. What kind of battery and recharging system should it entail? We must consider form factors, ease of use, repairability, and upgradability.

The easiest solution is to use an existing Lithium Polymer portable battery bank product available on the market with a micro USB cable directly powering the Raspberry Pi 4 microprocessor. One cable from the microprocessor to the power bank for supplying power. One cable from the power bank to the user for charging. This solution is very intuitive and can be easily modified in the future based on the increasing/decreasing power needs of the user. Portable battery banks are very readily available and easy to replace (batteries have a limited usable lifespan, and having a self-contained power unit makes them easy to replace).

An example of a readily available generic Lithium Polymer battery bank along with 36.6 Ah power capacity and input/output specs is shown in fig:8. (36.6 Ah, 36.76.$Solarpowered.4USB-Aoutput(5V, 2.1A).1USB-Cinput/output(5V, 3A)$).

Figure 11: Lithium Polymer battery Pack

For a worst-case scenario with maximum power draw and minimal idling from the microprocessor and sensor hardware selection with an ~36 Ah Lithium Polymer battery pack, we can expect ~12 hours of use between charges. For an average mixed use of light use and power draw along with a reasonable idle time, we can expect ~1.5 days of use between charges. For a best-case scenario with little use and power draw along with excessive idling, we can expect ~2.5 days of use between charges.

3.4 Data Acquisition

Data from the Smart Rollator sensor modules will be transmitted in several formats to the microprocessor for preprocessing, aggregation, and local storage

Device	Quantity	Power Consumption			
		Voltage (V)	Current (A)	Power (W)	Quantity * Ah
Raspberry Pi 4	1	5	3	15	3
Heart Rate Sensor	2	3.3	0.0015	0.005	0.003
Momentum Sensor	1	2.4-3.6 (3.3)	0.0137	0.04521	0.00137
Speed Sensor	1	3.3	0.01	0.033	0.01
Pressure Sensor	3	3.3	0.01	0.033	0.03
Total					3.044

Figure 12: Power requirements for all powered hardware on rollator

in anticipation of being uploaded to a cloud-based storage backend for data analysis.

3.4.1 Installation of sensors on Smart Rollator

All the sensors detailed above will be mounted to the Smart Rollator and hard-wired into the GPIO of the Raspberry Pi.

The Inertial Measurement Unit (IMU) supports both Inter-Integrated-Circuit (I2C) and Serial-Peripheral Interface (SPI) communication, of which we plan to use I2C due to its development simplicity and ease of integration with our chosen microprocessor. To ensure accurate data readings, the IMU will be mounted near the center of gravity of the rollator. The handle and seat strain gauges will transmit force readings as voltage differences between analog wire pairs, each connected to the GPIO pins of the microprocessor via Analog-to-Digital Converters (ADCs) in series with manufacturer-recommended LM358/LM324 operational amplifiers. This will translate the sensors' voltage output into a machine-readable 8-bit format.

The Reed switches will be mounted on the underside of the rollator wheel forks and connected to the microcontroller through analog wire pairs and ADCs, with readings transmitted as 500Hz current modulations induced by magnets embedded in the wheels for each fork. The Heart Oximetry Monitor (PPG) transmits data over I2C as well and will be connected to the I2C bus of the microcontroller shared with the IMU.

3.4.2 Collecting data from sensors

The goal of the data acquisition device is to collect all the data gathered by the sensors and package it into the desired format for processing and local storage. Once the data is stored, it will be pushed to the Cloud Database to be stored and analyzed.

Once the raw data inputs have been received in the microcontroller hardware buffers, they will be read by the Smart Rollator software and translated into a valuable format for storage and transmission. Frequency measurements from the Reed switches will be averaged to reduce noise before inputting into a wheel diameter-dependent equation to determine the speed of the rollator over its usage periods. However, the exact format of the strain gauge, PPG, and IMU readings have not yet been analyzed to determine what data preprocessing will be required prior to storage. Once an input data packet has been processed, it will be stored on a persistent flash storage medium connected to the microcontroller.

3.5 Cloud Data Storage Back-end

The Smart Rollator will use cloud-based storage to hold data collected about the patient and allow a medical professional to view the data from anywhere. The cloud storage solution will be hosted on Google Firebase. The Raspberry Pi located on the rollator will upload collected data once a day when the device is put on charge. When the doctor wants to view the data, they will launch a python application that will pull new data from the cloud database. The database will have tables dedicated to storing information for an individual rollator, and individual sensors, and all entries will have an associated time stamp. The system will require a username and password for anyone accessing patient data.

3.6 Data Analysis Application

Once the rollator detects an activity is done, the data acquired during the rollator activity is pushed to the cloud backend. This is when the data analysis begins. When a medical practitioner would like to view the patient's data, they can access a desktop application. The desktop application shall have a login screen where the practitioner enters a username and password. The username and password are compared to the cloud database, where the username and password are authenticated. Once the session has been validated, the practitioner will be asked to choose the patient's information they want to view. Upon selection, the data set will be presented. The practitioner can choose from visualized data of the patient's movement throughout the day, the average pressure the user applies on the handle, and their heart rate throughout the day. These data points can be cross-checked with other data points for the medical practitioner to see if there is any correlation in the patient's day-to-day recovery.

3.7 Testing

3.7.1 Unit Testing

RollSmart, Test Smart. To achieve all the functional and non-functional requirements set out earlier in this proposal, each component of the project must be continuously tested during every stage. Unit Tests will be implemented for each python script and integrated into GitHub CI in order to continuously test the project's code base.

3.7.2 Sample data for data analysis testing

In order to test the Data Processing portion of the project, test data will be generated for each of the sensors on board the rollator and used as input to the data processing sequence. The generated output will be tested to ensure it meets the requirements.

3.7.3 Continuous Integration, Delivery and Deployment (CI/CD)

The project code base is hosted on GitHub, allowing all of the members to work on the project simultaneously with version control. GitHub also supports continuous integration and delivery (CI/CD), allowing automation of building, testing and integration of code changes in the repository and its deployment. To improve CI efforts, a GitHub Pipeline has been implemented to pylint all files before they can be merged to main. This means that all code must comply with PEP8 standards before they can be incorporated into the main code base, ensuring that all the code submitted for this project is robust and of high quality.

3.7.4 RollSmart Test Fixture and integration into GitHub

A RollSmart unit that will reside in the Lab will be equipped with all the RollSmart sensors and constantly connected to power and ethernet. It will act as a remote test unit where we can test hardware and software requirements. Ideally, the RollSmart test unit will be integrated into GitHub CI as a worker, running the test sequence at desired intervals and when a merge request is triggered. This will allow the code to be continuously verified on the physical hardware with a simulated input, verifying any changes to new code which is getting committed to the code base.

4 Risk Analysis

4.1 Functional Safety

The Smart Rollator is not a safety-critical system, and it makes no claims of compliance or attempts at conformance to development standards regulating such systems, including IEC:61508, IEC:62304, and IEC:60601. Since the existing rollator design will not be modified by adding sensors, we can assume the sensors will not impact the rollator's functional safety. Conducting a Hazard and Operability Analysis (HAZOP), a Failure Mode and Effect Analysis (FMEA), or an equivalent risk analysis methodology on the Smart Rollator design is, therefore, not in scope now.

Given that such an analysis will not be performed, a Hazard and Risk Analysis (HARA) to document the hazards, risks, mitigations, and residual risks identified from such a risk methodology will not be developed, and no Safety Manual (SM) will be written to document the terms under which the Smart Rollator system can be used in accordance with its residual risks.

4.2 Quality Management

The Smart Rollator project is vulnerable to a variety of common problems that may impact the delivery of the system, including implementation and testing difficulties from poor requirements, misunderstood allocations of tasks, bugs in the software or the hardware, and interpersonal conflicts between team members. These risks are mitigated in the Smart Rollator project through the use of industry-standard project management techniques and tools to manage the scope, schedule and cost of the project, and the responsible application of engineering expertise to distribute project responsibilities and decide on the project design.

Project requirements are organized hierarchically through Atlassian's JIRA software, with stakeholder requirements created to document the intentions of the project, system requirements created for our design strategy to satisfy the stakeholder requirements, and software and hardware requirements created for the implementation details of each system requirement, all of which have bidirectional traceability between one another. Individual tasks are assigned to members of the project and are linked with specific requirements, allowing progress on the project to be tracked both from a high-level and low-level perspective and indicating gaps in either the requirements or the development efforts project members are engaged in. The project schedule is also integrated with the requirements and task tracking system to clearly indicate which tasks must be completed by what dates and keep the team on track.

5 Budget

A bill of materials is outlined in fig:10, listing all the components required to implement the intelligent rollator design.

Component	**Cost Per Unit**	**Quantity**	**Final Cost**
Raspberry Pi 4	$74.99	1	$74.99
Heart Rate Sensor	$28.14	2	$56.28
Momentum Sensor	$20.56	1	$20.56
Speed Sensor	$4.48	1	$4.48
Pressure Sensor	$7.92	3	$23.76
Portable Battery Bank	$36.76	1	$36.76
Misc. (Wire, Cables, Mounting Hardware, etc)	$34.56	1	$34.56
Total			$251.39

Figure 13: Bill of Materials for Smart Rollator

6 Project Timeline

The Gantt Chart in fig:11 displays the general timeline we aim to follow to accomplish the project.

These milestones have been assigned to a Team member who will act as the Milestone Lead. The lead for each milestone will be responsible for the organization of the work and for distributing tasks to other team members. Another vital role of the milestone lead will be to ensure that all the requirements outlined in this proposal are met. fig:12 shows a breakdown of the Milestones and their respective team leads.

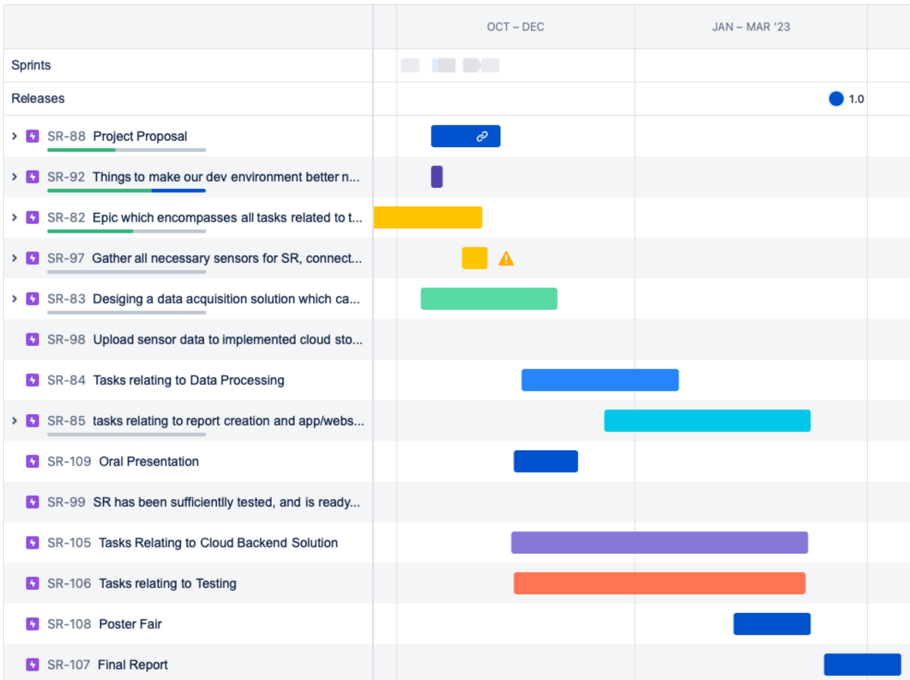

Figure 14: Smart Rollator Project Timeline

Milestone Description	Lead	Approximate completion date
Configure Raspberry Pi and connect sensors	Mark	November 18
Read data from wireless/wired sensors	Isabelle	December 31
Mount sensors and required hardware to rollator frame	Corbin	January 20
Export sensor data to cloud storage service	Kenny	February 24
Generate a summary of data viewing	Yunas	February 24
Have a patient use the rollator to collect data about a short period of activity	N/A	March 31

Figure 15: Breakdown of Milestones and team leads

7 Conclusion

The Smart Rollator is a project that explores various engineering principles, such as 3D printing, biomedical sensors and their implementations in microprocessor applications, cloud data storage, data processing and CI/CD. This project aims to add sensors to a rollator that provide valuable clinical data for Doctors to determine treatment efficiency and monitor patient health over time. These additional electronic components will be hidden as best as possible on the rollator to minimize the disruptions to the user and have been chosen to minimize the cost and energy requirements. The data provided by the intelligent rollator will allow doctors to better understand their patient's daily movements and exercise patterns and how their biometrics are affected by rollator usage. With its modular design, it can be retrofitted between different rollators, which will upcycle the rollator to sustain the environment. This project will offer the creators of the Smart Rollator an adventurous experience and training in engineering projects. With that, group 33 is proud to present the Smart Rollator.