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IBEHS 5P06 – Capstone Design Project
Faculty of Engineering – McMaster University – Undergraduate Studies
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The SureStride: An Intermediate Mobility Device for Seniors in Long-Term Care

Submitted by: Team 02
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Summary

In conversations with stakeholders, wellbeing representatives from *Amica Dundas*, the team is interested in developing a design solution for seniors in retirement homes who require the use of assistive mobility devices (AMDs) to mitigate risks associated with falling. The most used AMDs are walkers and wheelchairs. However, both devices have significant limitations; walkers are limited in stability, while wheelchairs limit the autonomy of the user and decrease use of the lower limbs. Using a walker increases fall risk, and can be more unsafe, while using a wheelchair increases comorbidities associated with lower physical activity and the general quality of life of the user.

Due to the prioritization of user safety, those who do not have the stability for walkers are directed to use wheelchairs despite having enough strength to not need one. The team is specifically interested in addressing the needs of seniors who fall within this category and **developing an intermediate mobility device** to mitigate fall risk while providing sufficient mobility. Seniors in nursing homes who use AMDs and have an increased risk of falling require an intermediate AMD without the stability limitations of a walker or autonomy limitations of a wheelchair to increase their quality of life, physical activity, and safety.

Approximately 25% of seniors in nursing homes use wheelchairs; wheelchair-use is correlated with an increased risk of depression, possibly due to restricted mobility and ability to socialize with others. The **social impacts** of the design are to increase the autonomy of users, and consequently, their quality of life. 35% of seniors have an abnormal gait, and the annual prevalence of falls is estimated to be 28%. Postural instability also increases with a reduced level of physical activity. The **safety and health impacts** of the design are therefore to decrease fall risk for users and allow for physical activity.

The proposed solution is the *SureStride*, an intermediate mobility device between a walker and a wheelchair that stabilizes the upper body and maintains the center of mass within the base of support, reducing postural instability and providing more support than a traditional walker.

Seniors in nursing homes who use assistive mobility devices (AMDs) and have an increased risk of falling require an intermediate AMD without the stability limitations of a walker or autonomy limitations of a wheelchair to increase their quality of life, physical activity, and safety.

Declaration of Academic Achievement and Consent

As a future member of the engineering profession, the student is responsible for honestly performing the required work without plagiarism and cheating. Submitting this work with my name and student number is a statement of understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario. Submitted by [Taylor Kramer, kramet1, 400245824]

As a future member of the engineering profession, the student is responsible for honestly performing the required work without plagiarism and cheating. Submitting this work with my name and student number is a statement of understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario. Submitted by [Namya Mehan, mehann1, 400247184]

As a future member of the engineering profession, the student is responsible for honestly performing the required work without plagiarism and cheating. Submitting this work with my name and student number is a statement of understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario. Submitted by [Elizabeth Evans, evanse10, 400259424]

As a future member of the engineering profession, the student is responsible for honestly performing the required work without plagiarism and cheating. Submitting this work with my name and student number is a statement of understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario. Submitted by [Meera Moorthy, moorthym, 400244635]

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LIST OF ABBREVIATIONS AND SYMBOLS

Term	Abbreviation
Assisted Mobility Device	AMD
BNO055 Absolute Orientation Sensors	BNO055
Computer-Aided Design	CAD
ESP32 PICO-KIT	ESP32
Fault Tree Analysis	FTA
Finite Element Analysis	FEA
Liquid Crystal Display	LCD
Time-of-Flight Sensor	ToF

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Chapter 1: Proposal

1.1 Team Charter

Team Number: 02

Full Name:	**MacID:**
Elizabeth Evans	evanse10
Namya Mehan	mehann1
Meera Moorthy	moorthym
Taylor Kramer	kramet1

Roles and Responsibilities
• Meeting minutes shall be recorded for every formal meeting with the team and/or with stakeholders and/or instructors. • Team members shall refer to the Gantt chart to find their responsibility for the weekly meeting. • For meetings scheduled outside of the weekly meeting, the roles will be according to the weekly meeting for that week. • For meetings with disciplinary co-instructors where students from only on discipline are in attendance, they shall alternate taking notes versus leading the discussion.

Expectations of Behavior, Work Ethic, and Professionalism
• Team members shall be committed to the successful completion of the project. • Team members shall make a reasonable attempt to complete all action items identified during the weekly meeting prior to the next week's meeting. • Team members shall respect one another during meetings and outside of formal meetings. • Team members shall communicate with instructors and stakeholders in a professional manner. • Team members shall communicate with the rest of the team when they encounter an issue/potential issue.

Communication and Documentation Management
• Team members shall keep meeting minutes for all internal and external meetings. • Team members shall communicate with each other in a timely manner via Facebook messenger group chat. • All team members shall attend the weekly meeting (in person). • Team members shall attend meetings with their respective disciplinary co-instructors (optional meetings if not their discipline). • All project documents shall be shared with the team OneDrive.

• The team shall schedule bi-weekly or monthly meetings with each of: stakeholder, disciplinary co-instructors, co-instructors. • Communication with stakeholders and instructors shall include all team members (CC).

Other Commitments
• Reading week: no commitments. • Winter break: no team commitments, receiving parts.

Conflict Management and Accountability
• Potential conflicts shall be presented during weekly meetings before they arise. • Should a potential conflict turn into a conflict, all group members shall discuss the conflict to arrive at a solution by consensus.

By signing below, all team members certify agreement with the team charter as outlined below.

Full Name:	**Signature:**	**Date**
Elizabeth Evans	*Elizabeth Evans*	October 1, 2023
Namya Mehan	*Namya Mehan*	October 1, 2023
Meera Moorthy	*Meera Moorthy*	October 1, 2023
Taylor Kramer	*Taylor Kramer*	October 1, 2023

1.2 Motivation and Impact

1.2.1 Motivation

In conversations with our stakeholders, wellbeing representatives from *Amica Dundas*, we are interested in developing a design solution for seniors in retirement homes who require the use of assistive mobility devices (AMDs) to mitigate risks associated with falling. The most commonly used AMDs are walkers and wheelchairs. However, both devices have significant limitations; walkers are limited in stability, while wheelchairs limit the autonomy of the user and decrease use of the lower limbs. Using a walker increases fall risk, and can be more unsafe, while using a wheelchair increases comorbidities associated with lower physical activity and the general quality of life of the user. These limitations are further discussed in *Background Research & Literature Review*.

Due to the prioritization of user safety, those who do not have the stability for walkers are directed to use wheelchairs despite having enough strength to not need one. We are specifically interested in addressing the needs of seniors who fall within this category and developing an intermediate mobility device to mitigate fall risk while providing sufficient mobility. Seniors in nursing homes who use AMDs and have an increased risk of falling require an intermediate AMD without the stability limitations of a walker or autonomy limitations of a wheelchair to increase their quality of life, physical activity, and safety.

Seniors in nursing homes who use assistive mobility devices (AMDs) and have an increased risk of falling require an intermediate AMD without the stability limitations of a walker or autonomy limitations of a wheelchair to increase their quality of life, physical activity, and safety.

1.2.2 Impact

Approximately 25% of seniors in nursing homes use wheelchairs, limiting their physical activity, and leading to dependence on others [1]. Wheelchair-use is also correlated with an increased risk of depression, possibly due to restricted mobility and ability to socialize with others [1]. The social impacts of our design are to increase the autonomy of users, and consequently, their quality of life.

35% of seniors have an abnormal gait, and the annual prevalence of falls is estimated to be 28% [2]. Postural instability also increases with a reduced level of physical activity [3]; there is a 30 to 50% reduction in motor neurons in the lower limbs, which can be exacerbated with low physical activity [4]. The safety and health impacts of our design are therefore to decrease fall risk for users and allow for physical activity.

1.3 Background and Literature Review

1.3.1 Rollators

Among AMDs, rollators are one of the most prescribed devices [5]. They are recommended to individuals suffering from various medical conditions that adversely affect lower limb strength and/or balance [6]. AMDs for seniors are governed by ISO/TC 173/SC 1 (which outlines standardization in products and services aimed at assisting individuals in compensating for reduced abilities) [7] and CAN/CSA-B659-08 (R2018) which provides standards for device designs tailored to the aging population [8].

To increase the user’s stability, walkers and rollators work by enlarging the base of support, redistributing some of the user’s weight from the lower limbs to the upper limbs, and providing additional somatosensory feedback to the user [9]. Although many rollator users are satisfied with the device [5], they have many limitations.

Walkers are increasingly being prescribed to seniors. This may be in part due to the growing proportion of the population that they contribute, but the rate of injuries due to walkers appears to be increasing at a greater rate than the number of users [10]. This may indicate that walkers are used as mobility aids for longer than they should be, causing the device to become a hazard and increasing the risk of falls.

Walkers and rollators can increase the risk of falls if the device prevents the user from compensatory stepping when they lose balance, especially in the lateral plane [6]. Furthermore, the user’s environment can make the device less effective by creating obstacles for the device to get caught on or surfaces on which it can slip [11]. To control the walker and use the mobility device correctly, the user must have enough cognitive capacity to move the device in synchrony with their movements [6]. However, aging related health and medications have a negative impact on the cognitive function of older adults [12]. As a senior ages, rollators and walkers become less suitable as AMDs, resulting in a transition to wheelchair use instead.

1.3.2 Wheelchairs

Wheelchairs address a wider range of mobility needs and reduce the risk of falls, particularly in seniors and individuals with severe mobility limitations [13].

They are recommended to seniors in nursing homes, including patients who lack lower body strength, balance, or endurance for ambulation or those dealing with conditions such as arthritis, stroke, or injuries that significantly affect their mobility [13]. They also serve as a preventive measure for falls and allow seniors to navigate their environment safely [14].

Manual wheelchairs are lightweight and easy to maneuver [15]. They rely on user and caregiver propulsion, making them cost-effective and straightforward, but increasing dependence on the caregiver [15]. Electric wheelchairs employ battery-powered motors, offering greater independence to seniors with limited upper body strength. Power-assisted wheelchairs combine manual control with electric assistance, allowing users to switch between modes as needed [16].

Despite their advantages, wheelchairs limit freedom of movement. Improper fitting or adjustment of the device can lead to discomfort and discourage seniors from using the wheelchair [17]. The lack of full wheelchair accessibility in many nursing homes and indoor environments can restrict seniors' movement [13]. Some seniors may perceive using a wheelchair as a sign of dependence or loss of autonomy, which can have psychological impacts on their perceived freedom of movement [14].

While wheelchairs and rollators are increasingly favored for their significant mobility benefits to seniors in nursing homes, there are several limitations that decrease their effectiveness in providing increased mobility and an improved quality of life.

1.3.3 Intermediate Solutions

There are several current solutions that may be used to bridge the gap between walkers and wheelchairs. Standing frame rollators function similarly to the traditional rollator. They include four wheels on the frame to make the device easy to maneuver as well as brakes to stop the device when performing transfers (e.g., walking to sitting). The benefit of a standing frame rollator to the traditional rollator/walker is that it maintains an upright posture for the user, thereby decreasing the pressure on the upper body.

The standing wheelchair puts the user in a locked leg position, securing the legs to the frame of the wheelchair while leaving the upper body to move freely. The benefits of the standing wheelchair include reducing pressure sores, reducing muscle soreness, and slowing down the degradation of bone. Although the device slows down bone degradation, it does not prevent all the muscle degradation in the lower limbs because they are not being used to propel the body.

The innovative Second Step Gait Harness System Standing Frame Walker [18] is a therapy tool used to rehabilitate people who have suffered from issues such as stroke, brain injury, spinal cord injury, and lower extremity amputation. Although the device provides balance support, it is a custom device that is not mass manufactured and therefore, inaccessible for many seniors. Furthermore, the footprint is large, and transitions would require the assistance thereby reducing the user's independence.

1.3.4 Characterizing The End User

Increasing physical activity causes adaptations within neuromuscular and cardiopulmonary systems which can improve clinical outcomes and reduce the risk of developing cardiovascular and metabolic diseases. Consistent loading of the lower limbs also increases bone mineral density and decreases the risk of fracture if a fall does occur [4].

Postural instability has been shown to increase with age and a reduced level of physical activity [3]. As well, gait disorders have a prevalence of 35% among adults aged 70 years and older [2]. Deficiencies in both balance and gait are associated with an increasing risk of falls, resulting in a 28% annual prevalence of falls among seniors [2].

Physiologically and neurologically, the pathways that allow for balance and coordination change with age. Older adults tend to have reduced muscle strength, an inclined posture, impaired cognitive functioning, declined motor responses, deteriorated visual systems, and a decreased sense of orientation and proprioceptive awareness [3]. Older adults are more affected by the loss of visual information when maintaining balance and rely more heavily on vision to provide guidance for movements [2].

Stooped posture is characterized by carrying the head and neck forward relative to the torso and is more common in older adults [19]. Stooped posture is associated with a higher risk of falls, since the center of mass is displaced forward, and core muscular strength decreases with age, preventing seniors from accounting for this displacement [2].

1.4 Design Criteria

To accomplish the project objectives, an intermediate mobility device will be created. This device will provide the user with more support than a walker but more independence/mobility than a wheelchair. The project objectives and constraints are outlined in Table 1 below. This list was developed with help from co-disciplinary instructors and project stakeholders. To achieve these objectives/constraints, careful consideration will be given to each engineering design decision.

In terms of biomechanics, it is important that the design is stable and supports the user's center of mass (COM). It is important that the device engages the user's legs to promote muscle activity and prevent the loss of bone density. Lower body engagement will also allow the user more independence. Dr. Quenneville explained how walkers do not allow the user to maintain a proper posture, so it is also critical that the developed device allows the user to maintain upright posture that is healthy for the natural curvature of the spine. The device also must be adjustable to various members of the population, with the minimum size representing the 5^{th} percentile female and the maximum size representing the 95^{th} percentile male. Dr. Quenneville explained how typically assisted mobility devices for seniors are sized specifically for the user. For this reason, in-lieu of having an adjustable device, it is reasonable to have various size options available for the device.

As a mechanical objective, the design must be lightweight so that the user can operate it independently. To select the dimensions of the design, stress analysis will be performed, which will determine material selection. The design will require a moderate to large factor of safety to ensure it is safe for the user to operate, which will also be accounted for in stress analysis. All mathematical optimization processes will determine that the device is sufficiently supportive and feasible.

As an electrical objective, the device will monitor the user's movements and act accordingly. To achieve this objective, sensors will be programmed to collect data on the user's movement patterns and stored for processing. An algorithm will be developed to use the collected data to make predictions on the user's movement patterns and mobility habits. This information will be useful to the user care team and help them make informed decisions about their healthcare plan.

Table 1: Outlined Objectives and Constraints

Objective
Constraint

Technical	Economic	Environmental	Societal	Ergonomic
Capable of withstanding cyclic loading	Affordable material selection	Sustainable materials	Increased independence	Safe
Intuitive (easy to use and operate)	Accessible repairs/part replacement (ANSI/ASME)	Recyclable components	Increaser user quality of life (QOL)	Comfortable
Rechargeable	Decrease expenses caused by fall related injuries	Sustainable manufacturing practices	Avoids stigmatization (subtle, inconspicuous)	Appropriately adjustable
Capable of integrating mechanical and electrical components	Affordable			Lightweight
Serves as an assisted mobility device	Insured device by Health Canada			Easy to transport
Increases user independence				Supportive
Increases user stability				Maintains proper healthy human posture
Decreases user fall risk				
Adjustable				
Adaptable functionality				
Independent operation				
Durable materials				
Comprised of standard parts (ANSI/ASME)				
Feasible design				

1.5 Project Planning and Design Process

The Gantt chart is attached below. It includes scheduled stakeholder/ disciplinary co-instructor meetings, and administrative due dates. This chart will be updated throughout the project. To structure the Gantt chart, the major milestones of the Fall semester were outlined and assigned a timeline for the latest possible completion date to identify the critical path. The Winter semester was delegated for prototyping. A Fall progress plan is shown below, in Figure 1. Project milestones were divided by sub-team (Mechanical/Electrical).

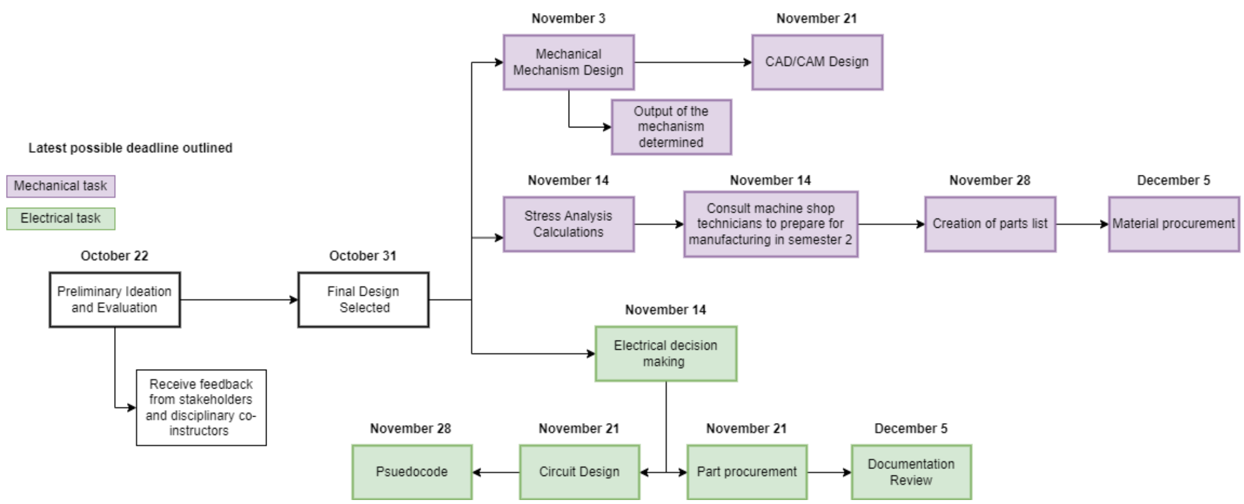

Figure 1: Critical Path Items with Latest Possible Deadline

The Gantt chart divides each week of the semester into separate meetings and goals. Each week, a different member of the group is assigned to be the notetaker and the meeting host. The meeting host is responsible for preparing the meeting agenda and governing the discussion.

To select the best possible design, independent and group preliminary design/evaluation sessions are scheduled, which can be seen in the Gantt chart. At the October 3rd meeting, preliminary designs will be generated in a group discussion and brainstorming session. Following this, each team member will have 2 weeks to independently create solutions. Advice received from community stakeholders, Jessica (AMICA Dundas), Parinda (AMICA Dundas), and Dr. Quenneville (McMaster University) will be incorporated into each design. At the October 17th meeting, each team member will present one design solution to the team that adheres to the outlined criteria, constraints, and project objectives. To identify the best solution, a decision matrix will be used, including the 10 most relevant design criteria weighted by importance. Each design will be evaluated and ranked based on its performance in the decision matrix. The results of the matrix will be presented in meetings with the disciplinary co-instructors, Dr. McDonald, and Dr. Shirani, on October 18th/19th for feedback on the chosen design. The final design solution will be selected by October 31st at the latest.

From this point forward, the team will separate into the designated sub-teams for the remainder of the semester.

On the mechanical team, Taylor and Meera have divided their work into two roles:

- Computer Aided Design (CAD) – Taylor

- Numerical optimization – Meera

Taylor and Meera will collaborate to create the mechanical mechanism. They will seek advice from their community stakeholders, disciplinary instructor, and McMaster machine shop technicians to ensure that their design is feasible, both for user interaction and manufacturing. Taylor will create the CAD model of the design, and Meera will perform the numerical optimization to determine the material selection and required dimensions for a safe device. The latest completion dates for both are outlined in Figure 1, and in the appended Gantt chart. In the winter semester, Taylor and Meera will both contribute to the manufacturing processes in the McMaster Mechanical Engineering Undergraduate Project Library.

On the electrical team, Namya and Liz will perform their work collaboratively. Their first milestone is to perform the decision-making process for the electrical considerations of the project. This will involve selecting a programming language and outlining the major electrical objectives. They will then begin to design their circuit and procure items. They have delegated the Winter semester to programming /debugging and will spend the Fall semester preparing pseudocode and reviewing documentation of electrical parts.

Aside from administrative assessments, in the Fall semester the sub-teams will not have much collaboration. Mechanical/electrical components will be integrated in the week of March 24-30th, 2024, at the latest, once all manufacturing and coding is complete. Throughout the year, the entire team will continue to meet weekly for updates on progress, challenges, and group expectations.

1.6 Updates according to feedback

Design criteria such as requiring 10 million cycles to failure minimum will be included to provide additional quantitative criteria for designing.

Stress analysis will be performed with target masses ranging from the 5th percentile female size to the 95th percentile male. This data will be obtained from anthropomorphic studies and ensures that the device is suitable for the majority of the population.

1.7 References

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CHAPTER 2: DESIGN CONFIGURATION

2.1 Design Investigation

2.1.1 Core Objectives

The full list of objectives and constraints identified in Chapter One were narrowed to those that are the most relevant to fulfilling the core purpose of the device, as follows:

1. The device must support the user's center of mass while providing more stability than a traditional walker.
2. The device must promote muscle activity in the legs.
3. The device must be able to be operated independently (after the initial training and fitting of the device).
4. The device must be comfortable for the user.
5. The device must be able to monitor the user's movements. This will provide feedback to the user's healthcare team.
6. The device must be able to identify falls and alert appropriate personnel.

A full list of the objectives and constraints can be found in Appendix A. Because economic, societal, and environmental objectives were not included as core objectives, the team will use these objectives in future iterations on the final design.

2.1.2 Design Ideas

From the core objectives, multiple solutions were created. Because most mechanical solutions would be able to accommodate device functionality added through the electrical components, the team focussed preliminary ideas on the physical design of the device. From discussions with disciplinary instructors and stakeholders, the team narrowed down the number of proposed solutions to three.

The first proposed design is a cage-walker design. The user steps into the device from the back and uses the arm supports to assist them while walking. The design features a flip-up seat for the user to rest on if they become fatigued. This design uses tri-wheels that swivel for the user to steer the device. The benefit to this device was its intuitive functionality. However, the device did raise some concerns about fall risk given that the user must step over a bar to enter it. As well, the team felt the device did not sufficiently address the need statement in terms of providing more stability than a traditional walker.

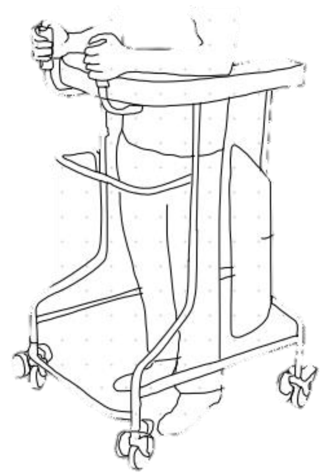


Figure 2: Cage walker design

The second proposed design combines a tricycle and strider bike. In this design, the user is seated on a bicycle seat and uses their legs to propel themselves and the device forward. The device has handlebars to provide steering and brakes to slow down the device. The design puts the two wheels in front of the user so that they can step into the device from the back, then take a seat and move forward. Similarly, to the first design, there were safety concerns with introducing a fall risk while the user is entering the device. As well, the comfort of the user and compression of the groin area for an extended period was brought up as a concern during a project stakeholder meeting.

Figure 3 Reverse tricycle design.

The third design is a combination of a crutch and walker. In this design, the user enters the device from the rear and rests their forearms on an armrest and their armpits rest on the under-arm rests. The under-arm supports stabilize the upper body while the user is walking and maintains the center of mass within the base of support. The forearm supports are intended to bear the weight of the user. The device uses caster wheels on the front along with handles on the armrests to allow the user to maneuver the device. One potential concern with this device was its size and difficulties associated with transporting or storing it.

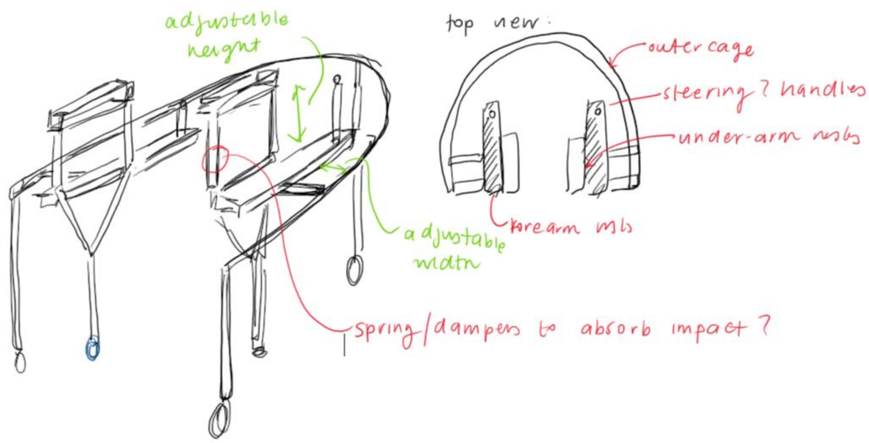


Figure 4 Crutch-walker design.

Because these design ideas satisfied most of the core objectives, a decision matrix was used to objectively evaluate the ideas against the criteria and each other.

Table 2: Decision matrix used to evaluate three preliminary ideas.

		Cage Walker		**Reverse Tricycle**		**Crutch-Walker**	
Criteria	Weight	Score (x/10)	Weighted score	Score (x/10)	Weighted score	Score (x/10)	Weighted score
Supports center of mass	3	5	16	6	19	9	29
Promotes leg muscle activity	2	10	21	8	17	10	21
Safe independent operation	3	4	10	8	20	9	23
Affordable	1	6	4	7	5	6	4
Comfortable	1	8	11	4	6	8	11
Monitors user's movements	0		0		0		0
Identifies falls	0		0		0		0
Total Score	**10**		**63**		**67**		**89**

The decision matrix features the core objectives with assigned weights. The most highly weighted criteria were that the device supports the center of mass and that it is operated independently. Through discussions with stakeholders, these aspects of the design were deemed the most important for user adoption of the device. The objective to promote leg muscle activity was ranked second to support the center of mass and independent operation because this feature would set this design apart from a traditional wheelchair. Finally, affordability and comfort were both assigned weights of one because they are important to consider for user acceptance of the device. The team allocated a weight of zero to the objectives that would be implemented using the electrical elements because their implementation would be similar regardless of the mechanical configuration. Furthermore, because the designs would have similar environmental impact, it was not included in the decision matrix.

The result of the decision matrix indicated that the crutch-walker design best satisfies the set of objectives. Therefore, the team pursued with iterations on this design.

2.1.3 Final Design

From the initial crutch-walker design, the team iterated to improve the device. First, the team added gyroscope sensors that would be able to measure the user's speed, acceleration, and changes in relative angles. From this data, the device would be able to provide feedback to the user's healthcare team about their mobility habits. Next, brakes were added and would be controlled by user input and automatically through a decision-making algorithm based on the sensor data. The brakes will operate using a hydraulic hose with one junction going to a mechanical brake lever that is on the user's handles, and the other junction going to the linear actuators that will carry out the automatic braking mechanism. Upon consultations with stakeholders, the next feature that was added was a collapsible mechanism. This makes the device more portable, and thus more likely to be integrated into users' lifestyles.

The device was also made to be adjustable. From discussions with stakeholders, the team decided to take this approach instead of a one-size-fits-most or a small/medium/large sizing. This means that the device would need to be fitted to the user at the initial use, which is common for most current assistive mobility devices. The device is adjustable for the user's height via the adjustments from the floor to the forearm rests. It can also be adjusted for the user's width by adjusting the poles connecting the forearm and under-arm rests to the supporting poles. Finally, it can be adjusted for the user's armpit to forearm length. These adjustments will allow the device to fit most users comfortably.

Figure 5: Computer-Aided Design (CAD) model of final design.

2.2 Final Design Concept: Modelling and Analysis

2.2.2 Mechanical Engineering Modelling and Analysis

Analysis of the device from a mechanical perspective was completed in 4 stages, as follows:

1. Defining the overall dimensions of the device and maximum load being supported using anthropometric tables.
2. Identifying critical failure locations in the device based on regions of structural weakness.
3. Conducting a stress analysis on critical locations in the device and calculating:
    a. Yield factor of safety
    b. Fatigue factor of safety
    c. Number of cycles to failure
4. Selecting a material that has a yield factor of safety greater than 5, fatigue factor of safety greater than 1, and infinite life (i.e., can withstand more than 1,000,000 cycles-to-failure)

2.2.2.1 Defining Overall Dimensions and Maximum Load

Dimensional data for the device was taken from the 2012 Anthropometric Survey of U.S. Army Personnel [1]. Relevant parameters are summarized in

Table 3 below, along with the corresponding locations on the device in Figure 6. The overall width of the device was chosen based on the maximum width of a doorway [2], such that the device can be maneuvered between rooms without being collapsed.

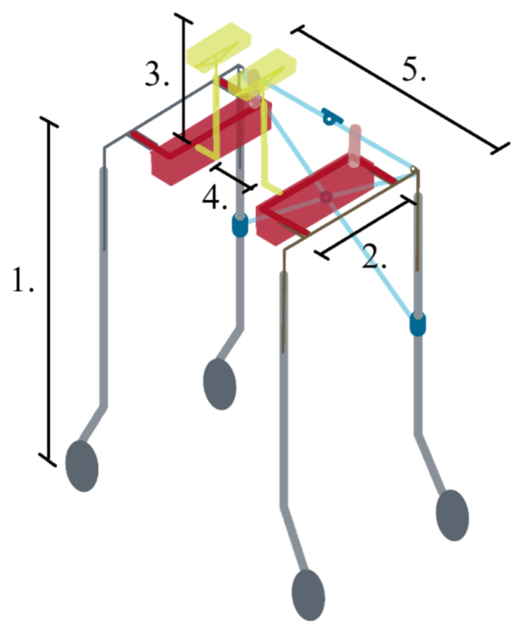


Figure 6: Corresponding structural dimensions based on anthropometric dimensions and standard door-size in

Table 3

Table 3.

Table 3 Dimensions of device based on anthropometric dimensions and standard door-sizing.

	Description	Dimension (cm)	
		5^{th} Percentile Female (cm)	95^{th} Percentile Male (cm)
1.	Elbow rest height (standing), distance from standing surface to bottom of elbow [1]	93.20	116.70
2.	Forearm-hand length, distance between elbow to tips of fingers [1]	40.40	52.00
3.	Shoulder-elbow length, distance from top of shoulder to elbow [1]	30.70	39.40
4.	Chest breadth, maximum horizontal distance between medial edges of arms [1]	24.10	32.00
5.	Minimum average North American door size [2]	61	

From the 2012 Anthropometric Survey of U.S. Army Personnel the mass for the 5^{th} percentile female and 95^{th} percentile male was also taken to be 51.30kg and 110.7kg, respectively. It should be noted that the anthropometric data used to construct the device and the subsequent stress analysis is limited by its applicability to an older demographic; army personnel can be presumed to have a significantly different fitness level and body composition than a senior.

Based on the anthropometric dimensions defined in

Table 3, the adjustable levels of the device were defined in Table 4Table 4 corresponding to locations defined in Figure 7

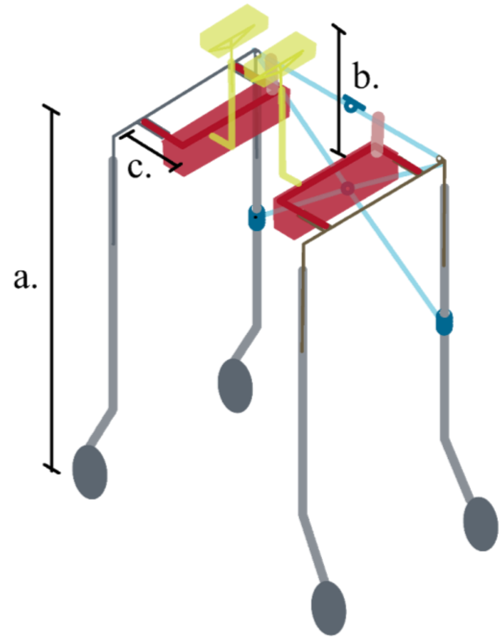


Figure 7 Corresponding adjustable structural dimensions in Table 4.

Table 4 Adjustable dimensions of device based on anthropometric dimensions.

	Description	Dimension (cm)			
		Minimum Distance (cm)	Number of Increments	Increment (cm)	Maximum Distance (cm)
a.	Elbow-height adjustment	90	10	3	120
b.	Under-arm height adjustment	30	5	2	40
c.	Internal width adjustment	14	4	1	18

2.2.2.2 *Identifying Critical Failure Locations*

Once the device dimensions were identified, some critical locations for failure were identifiedbased on failure prevention techniques described in *Shigley's Mechanical Engineering Design* [3] textbook. The failure modes and corresponding textbook chapters and sections are outlined in Table 5 below. The location of the failure modes is defined in Figure 8, below.

Table 5 Failure modes and associated Shigley's chapters and sections for conducting an analysis.

	Failure mode	Textbook Chapter/Section	Description
1.	Transverse holes in bending	6-10	Fatigue Failure Resulting from Variable Loading – Stress concentration and notch sensitivity
2.	Curved beam in bending	3-18	Load and Stress Analysis - Curved beams in bending
3.	Pin shear	3-4	Load and Stress Analysis - Stress
4.	Weld group in shear	9-5	Weld, Bonding, and the Design of Permanent Joints - The Strength of Welded Joints
5.	Single weld in shear	9-5	Weld, Bonding, and the Design of Permanent Joints - The Strength of Welded Joints
6.	Column buckling	4-12	Deflection and Stiffness - Long columns with central loading

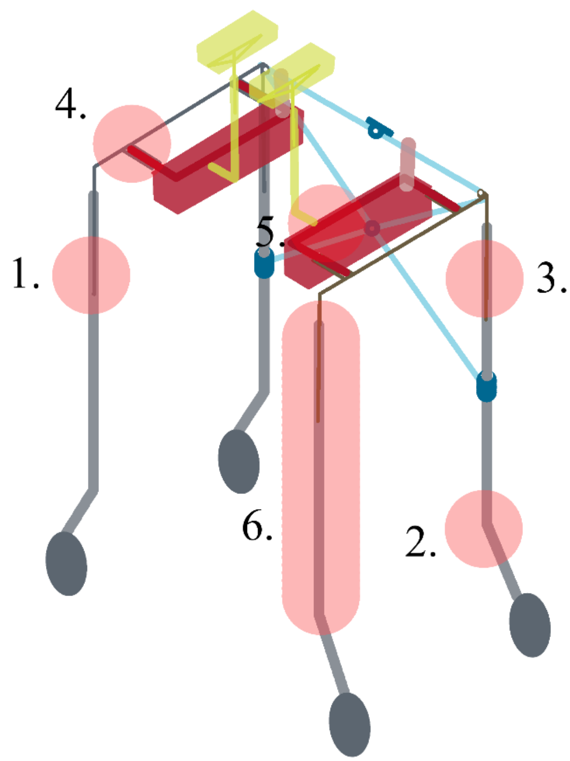


Figure 8 Locations of failure mode on device corresponding to Table 5.

2.2.2.3 *Stress Analysis*

Specific stress analysis calculations, dimensions, and parameters can be found in Appendix **Error! Reference source not found.**. Table 6Table 6 Summary of failure mode, analysis assumptions, and loading conditions. below defines the loading conditions and assumptions for failure modes 1 to 5. **The goal of the stress analysis was to support a body mass of 120kg** (95^{th} percentile male) or body weight of approximately 1200N.

Table 6 Summary of failure mode, analysis assumptions, and loading conditions.

	Failure Mode	**Loading Condition**	**Assumptions**
1.	Transverse holes in bending	Bending	1. Each column supports the body weight (BW) equally, the force along each column is BW/4 2. The bending moments generated in each column are the same. 3. The reduced section modulus is the same along both the x and y axis. 4. The surface finish is machined or cold-drawn. 5. There are no temperature, reliability, or miscellaneous effects.
2.	Curved beam in bending	Bending	1. Each column supports the body weight equally – the force along each column is BW/4. 2. The bending moments generated in each column are the same. 3. Stress due to bending along x is modelled as a curved beam in bending. 4. Stress due to bending along y is modelled as a straight beam in bending. 5. No fatigue stress concentration (Kf=1) 6. Surface finish is machined or cold-drawn. 7. There are no temperature, reliability, or miscellaneous effects (kd=ke=kf=1)
3.	Pin shear	Shear	1. Shear force experienced by a pin in each column is BW/4 2. Pin is purely in shear (no bending) 3. Ultimate strength in shear is 0.67*Sut 4. Yield strength in shear is 0.67*Sy

4.	Weld group in shear	Shear and bending	1. Shear stress on each side is V = BW/2 2. Shear stress in each weld is V'=V/N where N is the number of welds 3. Surface finish is as-forged 4. Fatigue concentration factor is taken as highest value, regardless of type of weld 5. There are no temperature, reliability, or miscellaneous effects (kd=ke=kf=1)
5.	Single weld in shear	Shear and bending	1. Shear stress on each side is V = BW/2 2. Surface finish is as-forged 3. Fatigue concentration factor is taken as highest value, regardless of type of weld 4. There are no temperature, reliability, or miscellaneous effects (kd=ke=kf=1)
6.	Column buckling	Normal, compressive	1. Column is loaded centrally 2. One end of the column is fixed and the other is free.

Once material stresses were calculated, a variety of materials were analyzed, and the yield factor of safety (FOS) was calculated. Due to the structure being cyclically loaded, the fatigue FOS and number of cycles-to-failure (CTF) were also calculated. The yield FOS, fatigue FOS, and number of CTF are only shown for the final selected material in Table 7, which will be discussed in greater detail later. As shown in Table 7, the failure mode with the lowest yield factor of safety and fatigue factor of safety is 1 - Transverse holes in bending. To increase these factors of safety, future design updates will increase the diameter of the structural columns to increase the area moment of inertia of the beam and will decrease the diameter of the holes to increase the cross-sectional area of the beam. The failure mode with the lower number of cycles to failure is 5 – Weld group in shear. Future design updates will consider adding internal t-connections to reinforce the region or increasing the throat thickness of the weld.

The stress analysis was also limited by the assumption that loads would be applied purely vertically, and that the device is in static equilibrium. Dr. Quenneville recommended analyzing loads on an angle and at different points on the device to determine factors of safety for misuse cases as well. It should be noted that the large number of assumptions made for each failure mode also limit how accurate the calculated design stresses are, and a finite element analysis will be conducted on a future model to verify the accuracy of the manual calculations.

Column buckling (failure mode 6) was analyzed in terms of the **maximum compressive load** that could be applied concentrically to the column without buckling occurring; no FOS or cycles-to-failure were calculated. The critical load calculated was approximately 10000N, which is significantly higher than the maximum body weight supported by the device (1200N).

Table 7 Failure modes and corresponding stresses, FOS, and cycles to failure.

Failure Mode	Design Stress (MPa)	Yield FOS	Fatigue Stresses (MPa)		Fatigue FOS	Number of CTF
			Midrange Component	Amplitude Component		
1.	142.747	8.455	159.172	159.172	1.965	653e6
2.	109.222	11.05	54.611	54.611	5.728	6013e6
3.	14.988	53.96	7.494	7.494	25.36	8824e12
4.	12.623	39.11	17.04	17.04	4.23	430e6
5.	8.524	57.93	4.262	4.262	6.269	2077e6

As shown in Table 7, the failure mode with the lowest yield factor of safety and fatigue factor of safety is 1 - Transverse holes in bending. To increase these factors of safety, future design updates will **increase the diameter** of the structural columns to increase the area moment of inertia of the beam and will **decrease the diameter of the holes** to increase the cross-sectional area of the beam. The failure mode with the lower number of cycles to failure is 5 – Weld group in shear. Future design updates will consider adding internal t-connections to reinforce the region or increasing the throat thickness of the weld.

The stress analysis was also limited by the assumption that loads would be applied **purely vertically**, and that the device is in **static equilibrium.** Dr. Quenneville recommended analyzing loads on an angle and at different points on the device to determine factors of safety for misuse cases as well. It should be noted that the large number of assumptions made for each failure mode also limit how accurate the calculated design stresses are, and a **finite element analysis** will be conducted on a future model to verify the accuracy of the manual calculations.

2.2.2.4 Material Selection

Criteria for a successful material were as follows:

1. The material must result in a yield factor of safety greater than 5.
2. The material must result in a fatigue factor of safety greater than 1.5.
3. The material must result in infinite life (must have greater than 1,000,000 cycles to failure).

After a thorough literature search, and in consultation with Dr. Quenneville, the team found there is no current standard for the factor of safety for assistive mobility devices. Devices are typically marketed by their ability to support a certain user-weight or mass. However, a yield factor of safety of 5, fatigue factor of safety of 1.5, and infinite life was deemed appropriate for a preliminary stress analysis by Dr. Quenneville. Further research will be conducted on safety standards for future design updates and for risk assessments.

Material properties were taken from *Shigley's Mechanical Engineering Design* textbook and are summarized below in

Table 8. The material chosen for the structure itself is a titanium alloy (Ti-13 V-11 Cr-3 Al) and the material chosen for the weld has an ultimate tensile strength of 120kpsi.

Table 8 Material properties for selected structure and weld materials

	Structure	Weld
Designation	Ti-13 V-11 Cr-3 Al	E120xx
Yield Strength (MPa)	1207	737
Ultimate Strength (MPa)	1276	827

2.2.3 Electrical Engineering Modelling and Analysis

The analysis of the device from an electrical perspective is based on the following steps:

1. A focus on fall resistance and automatic braking,
2. Incorporating a sophisticated system of sensors, microcontrollers, motor drivers, linear actuators, and other essential components.
3. Selecting components and providing a comprehensive solution for ensuring user and device safety.

2.2.3.1 Mechanism for Fall Resistance and Automatic Braking

The device's electrical components prioritize fall resistance and automatic braking. It will detect potential falls and initiate braking to prevent or mitigate impacts. It senses unusual acceleration and deviations in orientation, automatically engaging brakes to counter undesired acceleration. The design seamlessly integrates electrical actuators and mechanical braking, ensuring user safety through both voluntary and sensor-triggered braking. Utilizing two accelerometer/ gyroscopic sensors, the device captures data and transmits to a microcontroller, which assesses fall risk and directs a motor driver to operate linear actuators connected to mechanical hydraulic brakes. The device logic flowchart and desired electrical objectives found below were discussed with and approved by the project stakeholders.

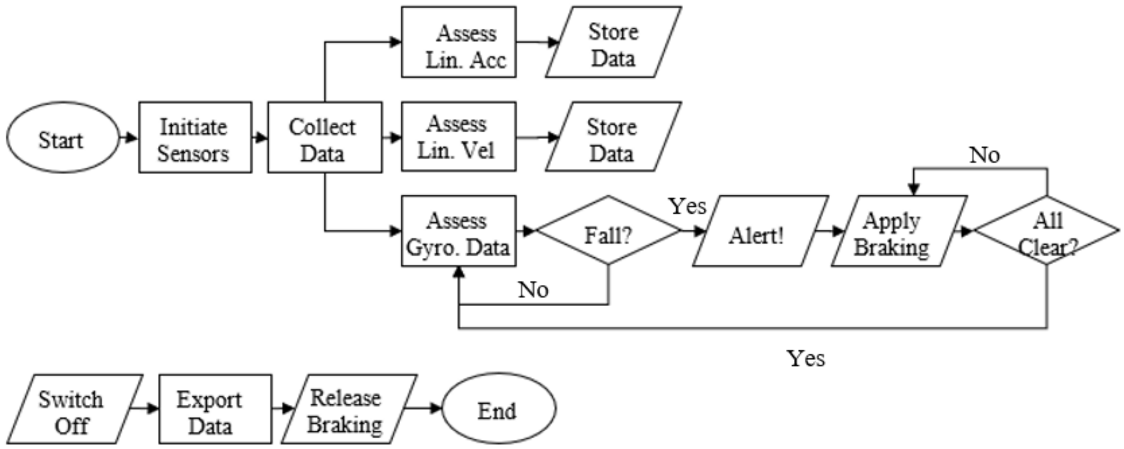


Figure 9 Device logic flowchart

Table 9 Desired electrical objectives.

	Objective
1	Integration of sensors and microcontroller for decision-making
2	Integration of linear actuators, motor driver and microcontroller for initiation of physical braking
3	Incorporating incremental resistive braking
4	Transferring stored sensor data to external device
5	Implementation of power switches and user interface components
6	Integration of a 12 V battery with a DC/DC step-down converter

2.2.3.2 Incorporation of an Integrated System

The key components needed to achieve the objectives defined above were decided based on existing literature and knowledge from previous courses. Following are the components selected to be used in the design:

Table 10 List of components required for proposed design.

	Component	Function
1	**Accelerometer/Gyroscope Sensors**	Two sensors are responsible for collecting acceleration and angle data to assess the user's movements. The dual sensor setup enhances accuracy in detecting falls and movement patterns.
2	**Microcontroller**	The microcontroller processes the data from the sensors and declares fall risk based on predefined algorithms. It serves as the brain of the system, making real-time decisions about whether to engage the braking system.
3	**Motor Driver**	This component is crucial for controlling the operation of the linear actuators. It interprets the signals from the microcontroller and regulates the movement of the actuators, ensuring a timely and precise response to potential fall situations.
4	**Linear Actuators**	These actuators are connected to the mechanical hydraulic brakes, providing the physical mechanism for braking. The linear actuators allow for a controlled and smooth application of the braking force, enhancing user safety and comfort.
5	**Mechanical Hydraulic Brakes**	These brakes are the final point of action, physically engaging to prevent falls when triggered by the linear actuators. The hydraulic system ensures a reliable and responsive braking mechanism.
6	**Power Switch**	A power switch is integrated to control the overall power supply to the system, enabling users to turn the device on or off as needed.
7	**User Interface**	Additional user interface components, such as buttons, indicators, and displays, are incorporated for user interaction. These elements contribute to the overall usability and accessibility of the device.

2.2.3.3 Selection of Electrical Components

The selection of each component is based on its compatibility with the system specifications, ensuring seamless integration and optimal performance in achieving the device's fall resistance and automatic braking objectives. Each component has been chosen with attention to their individual and collective contributions to system reliability. By adhering to specified voltage, current, and functionality requirements, this selection ensures the device can perform its task safely.

Table 11 Selection of electrical components and bill of materials

	Component	Reasoning	Cost
1	**Sensors** Absolute Orientation Sensor (Adafruit BNO055) [4]	Incorporates gyroscope, accelerometer, and geomagnetic sensor for comprehensive motion tracking. Compatible voltage supply (2.4 – 3.6V) aligns with the system requirements. Multiple digital interface options (UART, I2C) provide flexibility for integration. Moderate current supply (12.3 mA) balances power consumption.	$100.70
2	**Microcontroller** Expressiff ESP32 Pico Kit [5]	Suitable operating voltage (3.3 – 3.6V) for seamless integration with sensor components. Adequate operating current (80 mA) ensures stable performance. Versatile I/O options (PWM, ADC, DAC, I2C, I2S, SPI) support diverse functionalities. USB-UART bridge with 1Mbps speed facilitates efficient data communication.	$15.36
3	**Motor Driver** DBH-12 Dual H-bridge [6]	Compatible voltage range (5 – 12V DC) aligns with the system specifications. Supports operational current up to 30A, providing ample power for linear actuator control. Compatibility with 3.3V, 5V, and 12V systems enhances flexibility.	$26.96
4	**Artilife Linear Actuator [7]**	Rated voltage of 12V matches the power supply of the system. Appropriate speed (10 mm/s) and load capacity (900N) for efficient braking performance.	$83.18
5	**MK Battery 12-Volt 10 Ah SLA** [8]	Battery voltage of 12V aligns with the system requirements. Adequate capacity (19Ah) ensures prolonged device operation.	$38.01
6	**DC/DC Step Down Converter** P YB10-Q24-S3-T [9]	Wide input voltage range (9-36V) accommodates variations in the power source. Provides a stable output voltage of 3.3V for the microcontroller.	$33.97
7	**Battery Charger** [10]	Compatible with chosen battery	$64.98
8	**Breadboard Kit** [11]		$19.99
Final Cost of Electrical Components (incl. tax)			**$432.96**

2.2.3.4 Limitations and constraints

1. **Power Consumption:** The electric components of the device may have a high-power consumption which can limit the operational time of the device between battery charges. One of the future steps would be to optimize the power efficiency to enhance the user experience.
2. **Sensor Inaccuracies:** Errors in the device’s sensors may lead to false positives or negatives in fall detection. Therefore, reliability of the sensors is critical for the overall effectiveness of the device. A proper fall sensitivity threshold may help limit this.
3. **Cost Limitations:** Cost limitations may restrict the inclusion of advanced sensors or features that could enhance the device's performance. A balance between cost-effectiveness and functionality is essential.
4. **Maintenance:** Mechanical components, such as the linear actuator and braking system, may require regular maintenance, and wear and tear could impact the reliability of the device over time.
5. **User Interface:** The simplicity and effectiveness of the user interface components need to be carefully assessed to ensure ease of use for the elderly population in long-term care.

2.3 Final Decision Concept: Proof of Concept

2.3.2 Mechanical Engineering Proof-of-Concept

For the SureStride mechanical proof-of-concept, a CAD model was created in SolidWorks. The model was created according to the outlined design objectives and mechanical constraints. Figure 10 below highlights a large-scale image of the final design, with certain features magnified.

Figure 10: Large Scale Mechanical Proof-of-Concept

2.3.2.1 Accounting for Height Adjustability

1. <u>Elbow-height adjustment</u>

To account for variation in user height, a telescoping pole design was implemented to make the design adjustable from the base to elbow supports, as shown in Figure 11.

Figure 11: Telescoping Pole Design Allowing for Elbow Height Adjustment

The design will be one-time measured and fixed for the user's height through a nut and a bolt. The modelling and analysis calculations required a 30cm range of adjustability (Table 4). To account for this, 10 holes were modelled, with a center-to-center distance of 3cm between each hole (Figure 12). Currently, the hole diameter is modelled as 13mm for an M12 close fit clearance hole [12]. These dimensions/fitting types serve as current place holders and will be optimized in future calculations to minimize stress concentration and improve safety. This will be verified in design validation through finite element analysis (FEA) performed in SolidWorks.

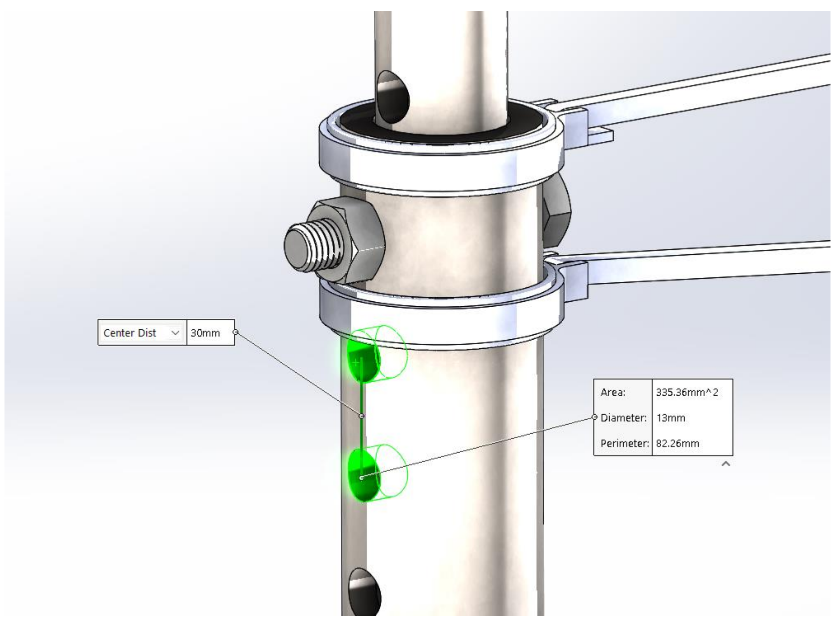


Figure 12: Ground-to-Elbow Height Adjustability

2. <u>Under-arm height adjustment</u>

A total adjustment range of 20cm was required, so 5 holes distanced 2cm apart were implemented into the design (Table 4Figure 7). Similar to the elbow adjustability, a close fit clearance fit was selected for an M5 nut and bolt, making the hole diameter 5.3mm [12]. The bolt size will be calculated to ensure minimal stress concentration (Figure 13, Figure 14).

Figure 13: Telescoping Pole Design Allowing for Armpit Height Adjustment

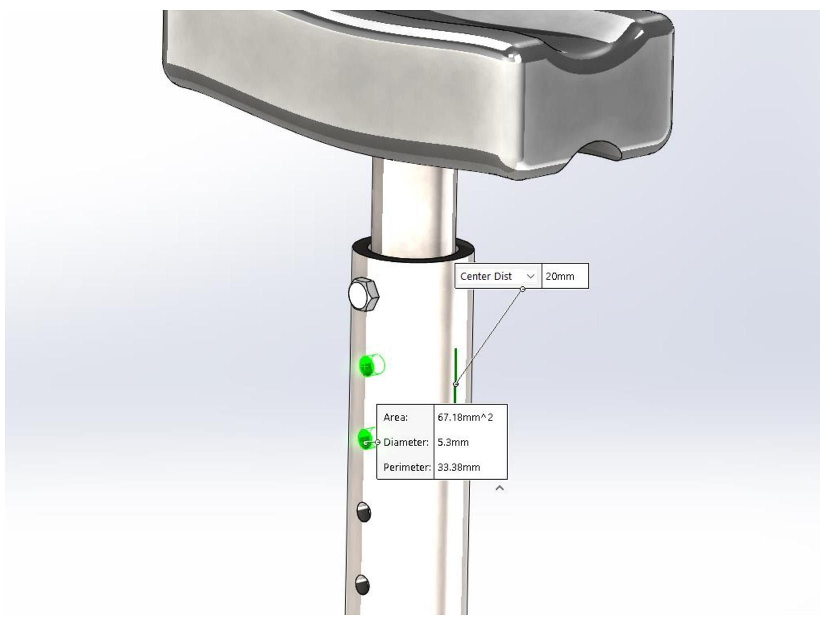


Figure 14: Armpit Height Adjustability

3. <u>Internal width adjustment</u>

The range of variation was required to be 4cm based on anthropomorphic dimensions, and a 5.13mm hole was created for a close clearance fit based on an M5 bolt (Table 4, Figure 15, Figure 15) [12]

Figure 15: Telescoping Pole Design Allowing for Elbow to Armpit Width Adjustment

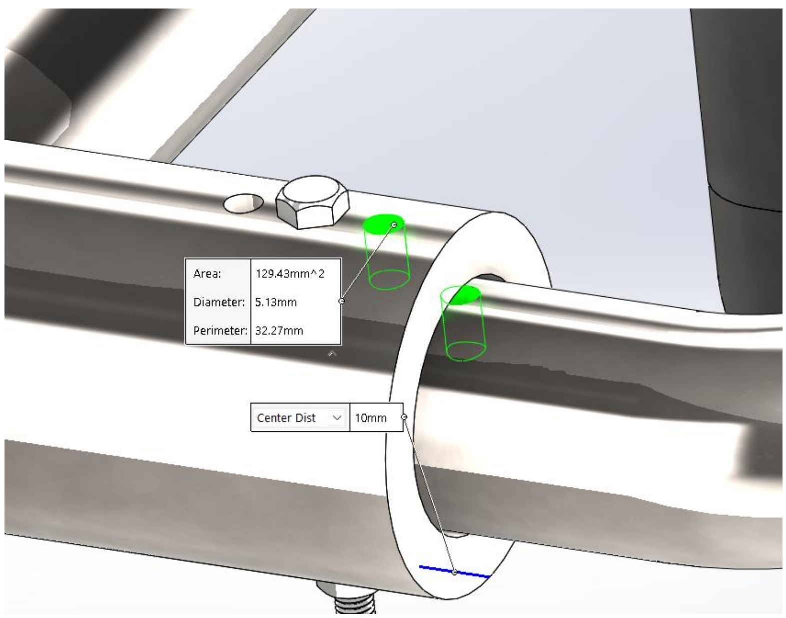


Figure 16: Elbow-to-Armpit Width Adjustment

2.3.2.2 Collapsible Mechanism

To allow the design to be easily transportable, a collapsible mechanism was implemented (Figure 17).

Figure 17: Collapsible Device Mechanism

This design includes four concentric cylinders that are fixed to allow for two sets of motion:

1. Upwards motion of the hinged bar
2. Downward motion of the sliding concentric cylinders connecting the X-bars

To allow for the walker to fold together, Figure 18B is assembled into Figure 18A, and that sub-assembly is fixed where it does not interfere with the M12 nut/bolt assembly, creating Figure 18C on one side of the structure, and Figure 18D on the other side of the structure (Figure 10). When the walker is fully expanded in the active position, both components of the central hinge are flush with one another, allowing the hinged bar to make an angle of 0° with the ground (Figure 18E, F). When in this position, an interference is created between the hinged bar and the base of the concentric cylinder fixed on each pole, prohibiting the bars from falling past the 0° position.

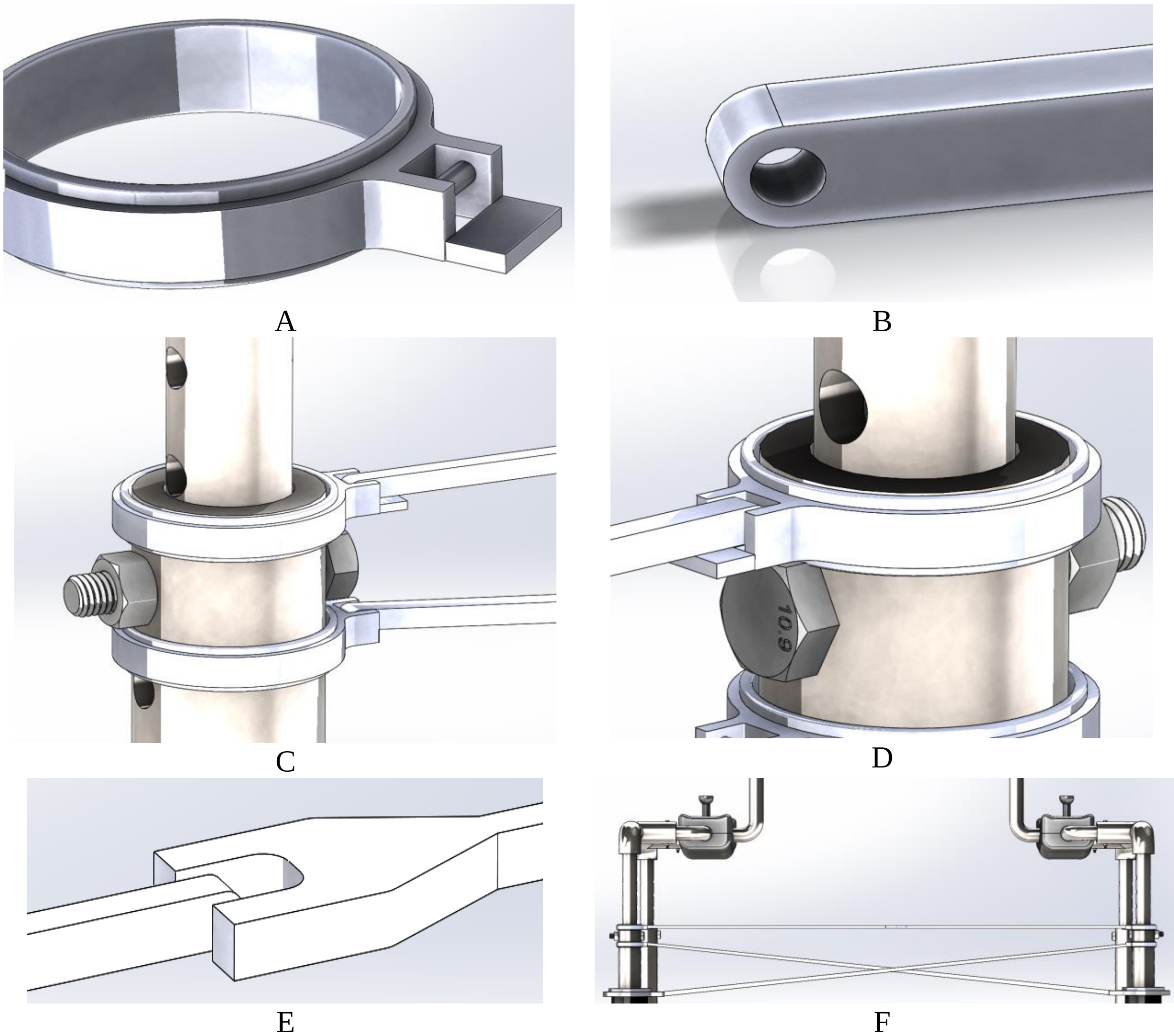
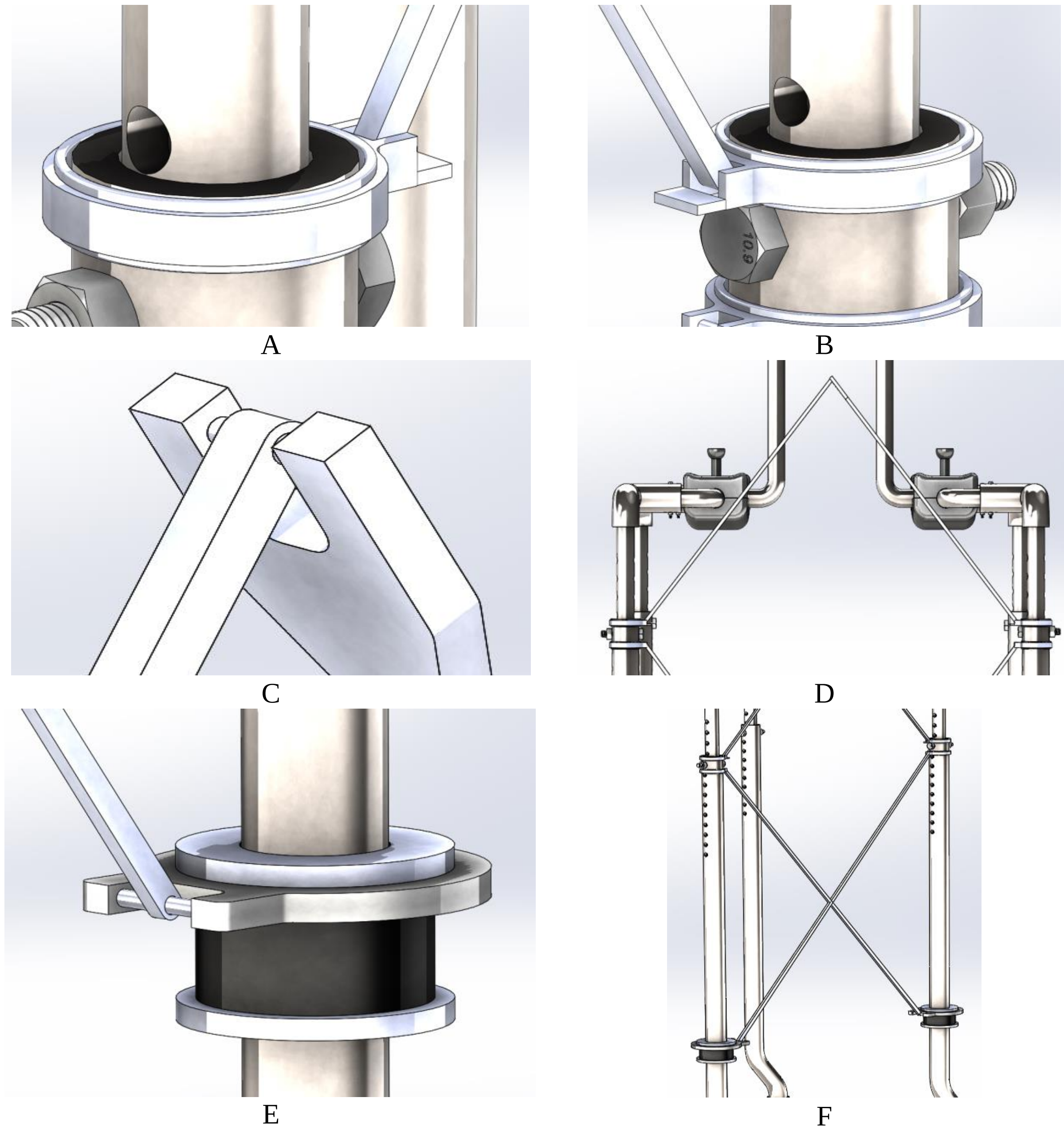


Figure 18: Fixed Poles Highlighting Hinging Mechanism – Walker Fully Open

When collapsing the device, the interference on the fixed pole is removed (19A, B), and the central hinge (19C, D) is allowed to fold upwards. The sliding poles move downwards (19E, F) which allows the device to fold inwards.



19: Fixed and Sliding Poles Highlighting Hinging Mechanism – Walker Closed

At this stage, to attempt to verify the design, a 1:10 scale model was 3D printed (Figure 20) and a Bill of Materials (BOM) was generated (Table 12).

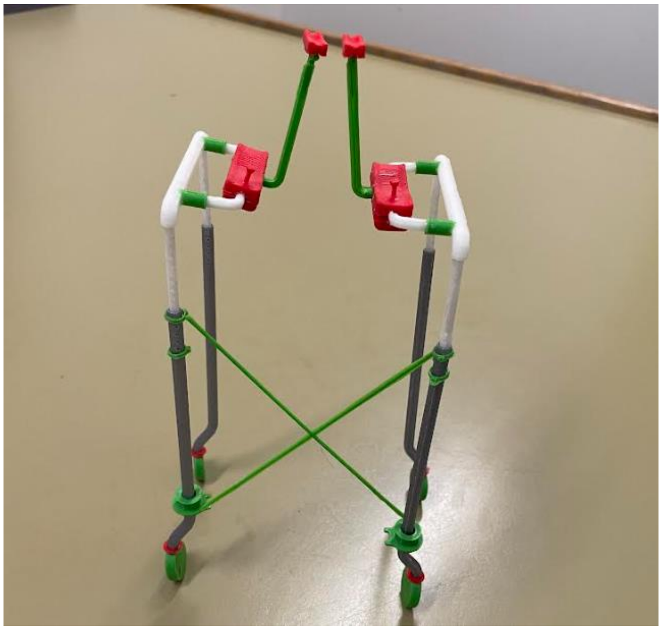


Figure 20: 3D Printed SureStride 1:10 Scale Model

Table 12: Bill of Materials for Prototype Development

Material	Quantity	Cost
PLA Plastic	0.5* meters	0.03**
Krazy Glue	1 package	1.695

Total Cost: 1.725

**0.5 meters serve as an estimation of how much PLA was used during the 3D printing process*
***$0.03 was estimated from 1 roll costing $19.98*1.13 for 350m, and 0.5m being used representing 0.14% of the total cost [13]*

2.3.2.3 Next Steps

The scale model revealed that the design was unstable in some regions, so some features will need to be further iterated before mechanical assembly begins. The scale model experienced difficult in standing independently. It is believed that this occurred due to the generation of a bending moment at the wheels and curvature in the base of the design (Figure 21).

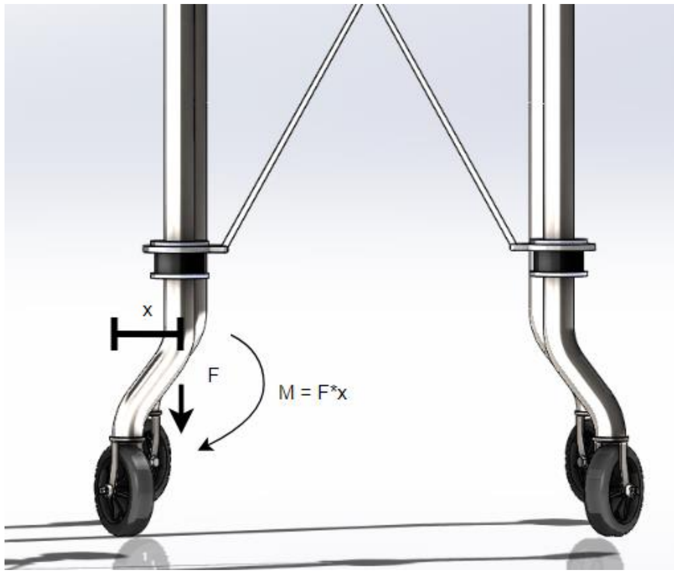


Figure 21: Bending Moment Generation Contributing to Instability of Design

In the initial design stage, it was believed that the symmetry of the design would cancel these moments (Figure 22).

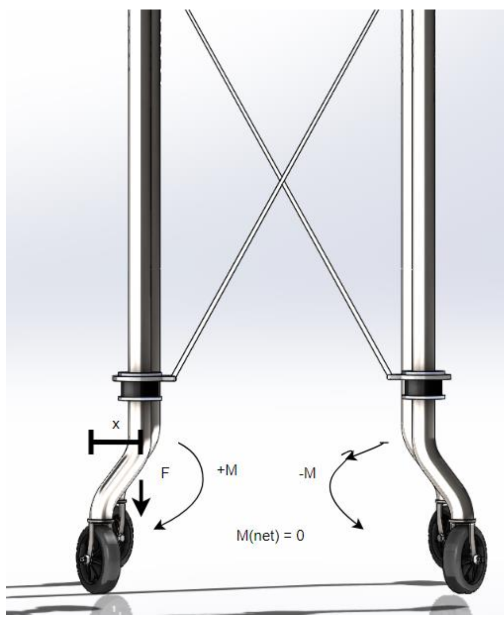


Figure 22: Theorized Moment Cancellation

However, after printing the design, it was found to be very unstable, insinuating that additional support will be required in the final prototype. These supports will be implemented through creating a **stronger** support mechanism at the **top hinging bar** (increase thickness, optimize cross-sectional profile), through adding material to the sides of the structure (Figure 23), and through potentially adding additional wheels to widen the base of support, while ensuring that they do not interfere with the user's stride upon entry and exit of the device.

Figure 23: Potential Mechanism to Increase Design Support

Additionally, it was noticed that the CAD model does not allow for adjustability of the handle, which does not account for variation of elbow length in each user and will need to be updated in further iterations (Figure 24).

Figure 24: Handle Placement

To validate the final model, FEA will be performed in SolidWorks for fatigue analysis and behavior under static loading. This analysis will aim to confirm results obtained from stress analysis.

Comparing the proof-of-concept to the modeling and analysis of the design, certain changes were made. When the CAD model was constructed, anthropomorphic measurements and optimized dimensions had not been calculated, so the proof-of-concept is not dimensionally representative of the analysis. Stress analysis was performed using only an outer diameter of 30mm, and a wall thickness of 4mm, serving as the smallest measurements present in the prototype (regions of stress concentration). Based on the stress analysis outcome, the yield and fatigue FOS had potential to be improved. Intuitively, larger dimensions would make for a stronger and safer design, so the overall CAD dimensions were increased and **do not** reflect those listed in the Appendix of this report. Additionally, in the stress analysis 5mm holes are used for each height-adjustable location. In the CAD model, one section has 13mm holes. The CAD model has larger holes, which create larger areas of stress concentrations, so those will need to be minimized in future iterations.

2.3.3 Electrical Engineering Proof-of-Concept

2.3.3.1 Objective

The primary objective of the proof-of-concept is to validate the theoretical models and analysis presented in Section 3. Specifically, the team will assess the real-world performance of the electrical components in fall detection and automatic braking scenarios.

2.3.3.2 Methodology and Documentation

1. Prototype Assembly: The low-fidelity prototype was assembled according to the following wiring diagram.

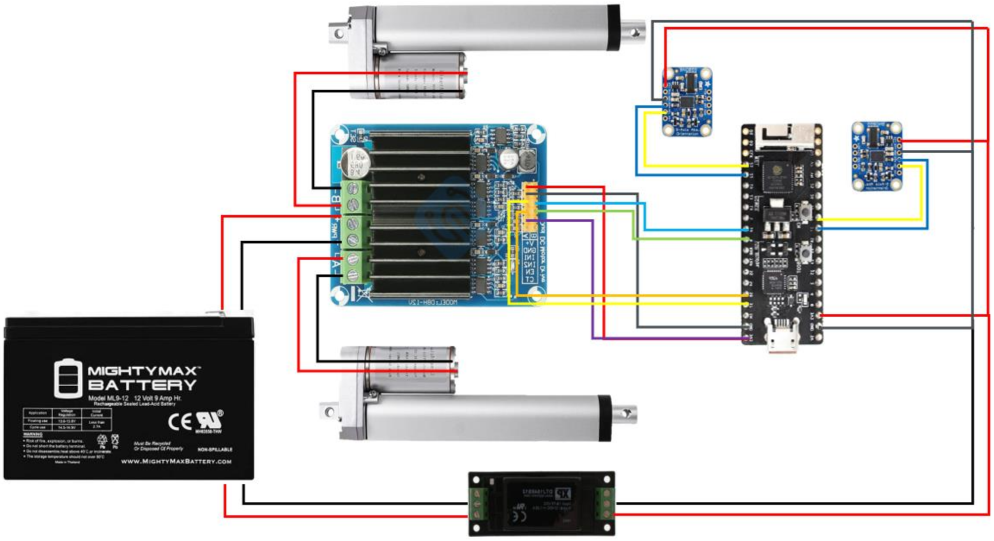


Figure 25 Prototype wiring diagram.

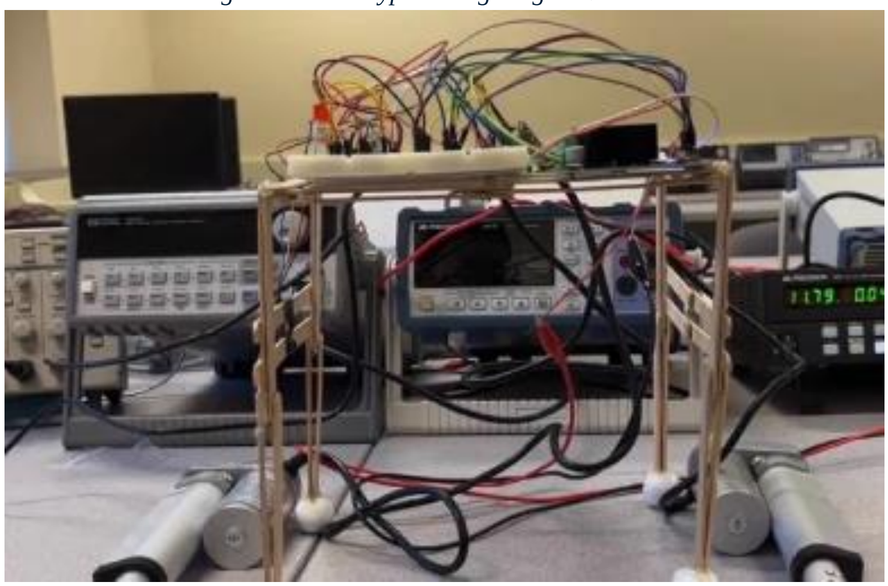


Figure 26 Prototype set-up.

A bill of materials for all components used in the device can be found in Table 11 under *Selection of Electrical Components*.

2. Programming: A high-level block diagram of the device logic was implemented as shown in the figure below. The device function was classified into a three-step mechanism: measure, assess and intervene.

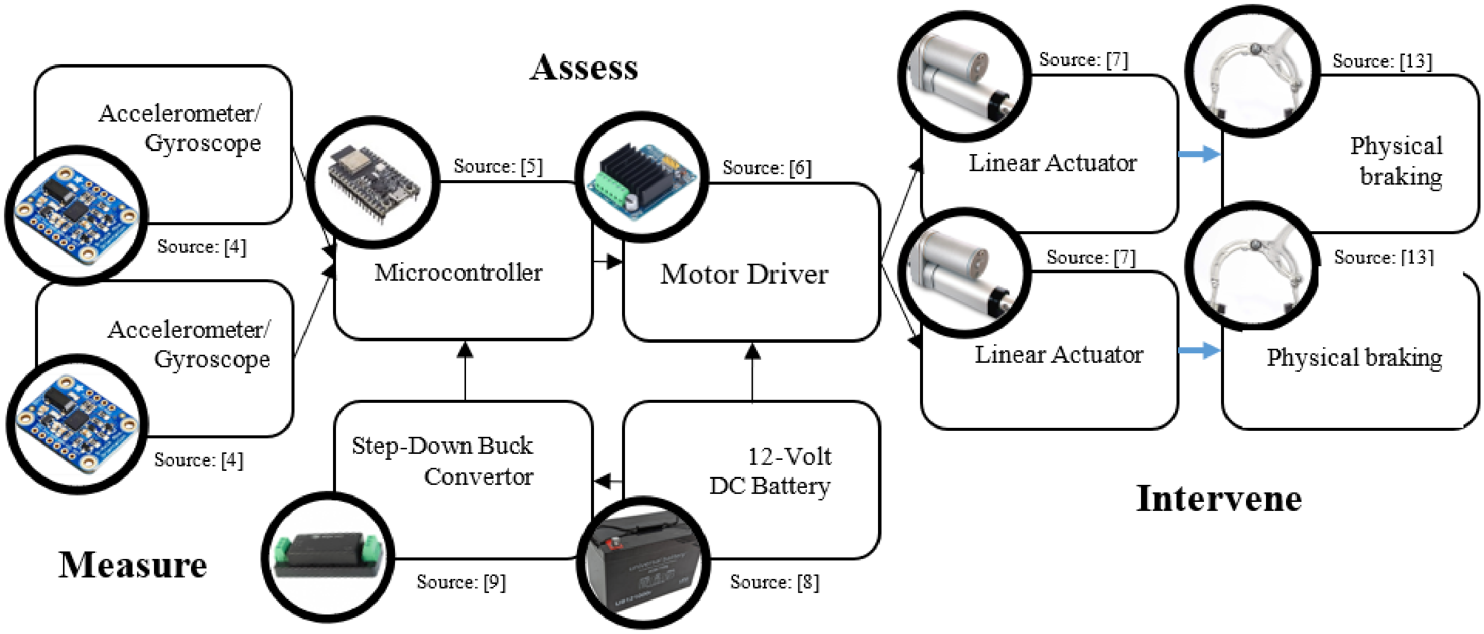


Figure 27 High Level Block Diagram.

3. Testing and Validation: To test the low-fidelity prototype and assess the function and connection pertaining to individual components, the team developed a separate test for each component:

Table 13 Connections and Validation Plan.

	Component	Connection	Validation/Test Plan
1	**Sensors (BNO055 x2)**	• Vin, GND to ESP32 • SDA, SCL to 21, 22, 32, 33 on ESP 32	• Isolated sensor-microcontroller operation, • Validation: verify for a 30o angle change in the x-direction using a protractor, • Check connection using communication command in Arduino C code (see pseudocode)
2	**Microcontroller (ESP32)**	• Pins 21, 22, 32, 33 to BNO055 • Pins 9, 10, 25, 26 to Motor Driver • Powered by buck converter output	• Check connectivity using in-built ESP32 Pico Kit on Arduino IDE, • Confirming accurate data output by producing a sample output pin voltage with the help of an oscilloscope, • Checking LED status by uploading sample code
3	**Motor Driver**	• Vin, GND to ESP32 • IN1A, IN2A (Actuator 1) IN1B, IN2B (Actuator 2) to 9, 10, 25, 26 on ESP32 • Pin A to linear actuator 1 • Pin B to linear actuator 2 • Powered by 12 V DC	• Confirming the operation of the motor driver when powered by through the LED status, • Setting varying microcontroller outputs to drive motors in both directions. • Tested with a sample input waveform generated signal.
4	**Linear Actuators**	• Actuator 1: Pin A on Motor driver • Actuator 2: Pin B on Motor driver	• Check functioning by supplying voltage directly to move in the backward direction, • Flipping polarity to move in forward direction, • Changing the input voltage to control speed.

4. Pseudocode:

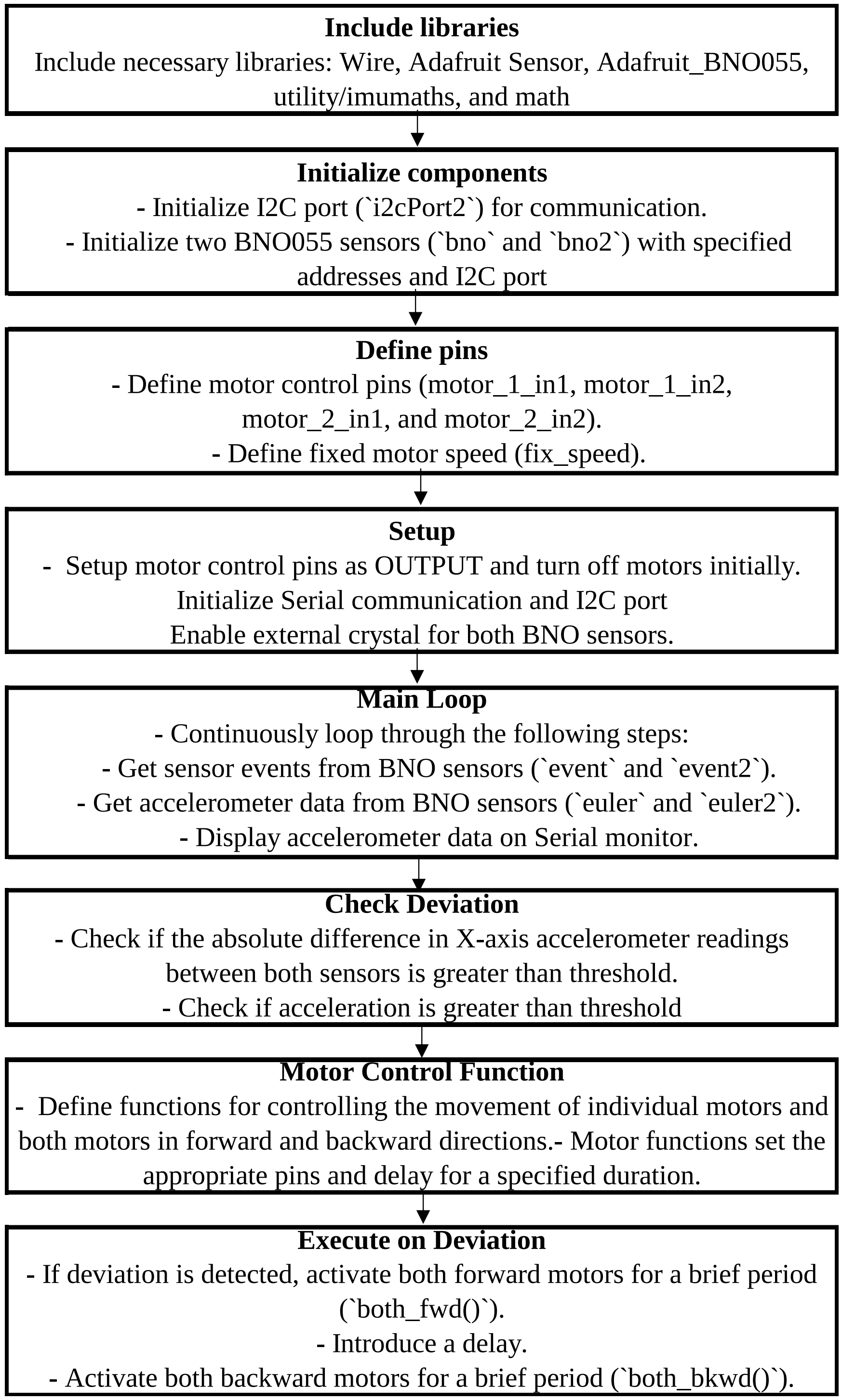


Figure 28 Pseudocode for proof-of-concept.

2.3.3.3 Comparative Analysis and Results

In the above proof-of-concept demonstration, the testing was primarily done by assessing gyroscope data. A low threshold (= 5) is chosen to demonstrate the working of the device. For future iterations of the prototype, scientific data pertaining to fall risk angles and acceleration will be used to determine the risk or occurrence of fall, resulting in the execution of incremental, resistive braking. Further, the team will be implementing a common 12 V battery source (instead of a 12 V source currently used for the motor driver and 3.3 V source for the microcontroller supplied through a micro-USB connected to a computer) along with a DC/DC step-down converter. A power switch button and other user interface components will be added. The proof-of-concept prototype **passed all validation tests** conducted and the comparison of the originally defined electrical objectives given in

Table 9 compared to the achieved objectives can be found below:

Table 14 Intended objectives and progress status.

	Objective	Status
1	Integration of sensors and microcontroller for decision-making	Achieved
2	Integration of linear actuators, motor driver and microcontroller for initiation of physical braking	Achieved
3	Incorporating incremental resistive braking	In progress
4	Transferring stored sensor data to external device	In progress
5	Implementation of power switches and user interface components	In progress
6	Integration of a 12 V battery with a DC/DC step-down converter	In progress

2.3.3.4 Proof-of-Concept Video

Link to proof-of-concept demonstration: https://www.youtube.com/watch?v=DNNm8QqmmAU

2.4 Updated Project Plan

The Gantt chart is attached below and has been continuously updated throughout the duration of the project. Completed tasks are highlighted in grey, and tasks in colour are to be completed throughout the winter semester. To structure the Gantt chart, the major milestones of the Winter semester were outlined and assigned a timeline for the latest possible completion date to identify the critical path. This progress plan is provided below:

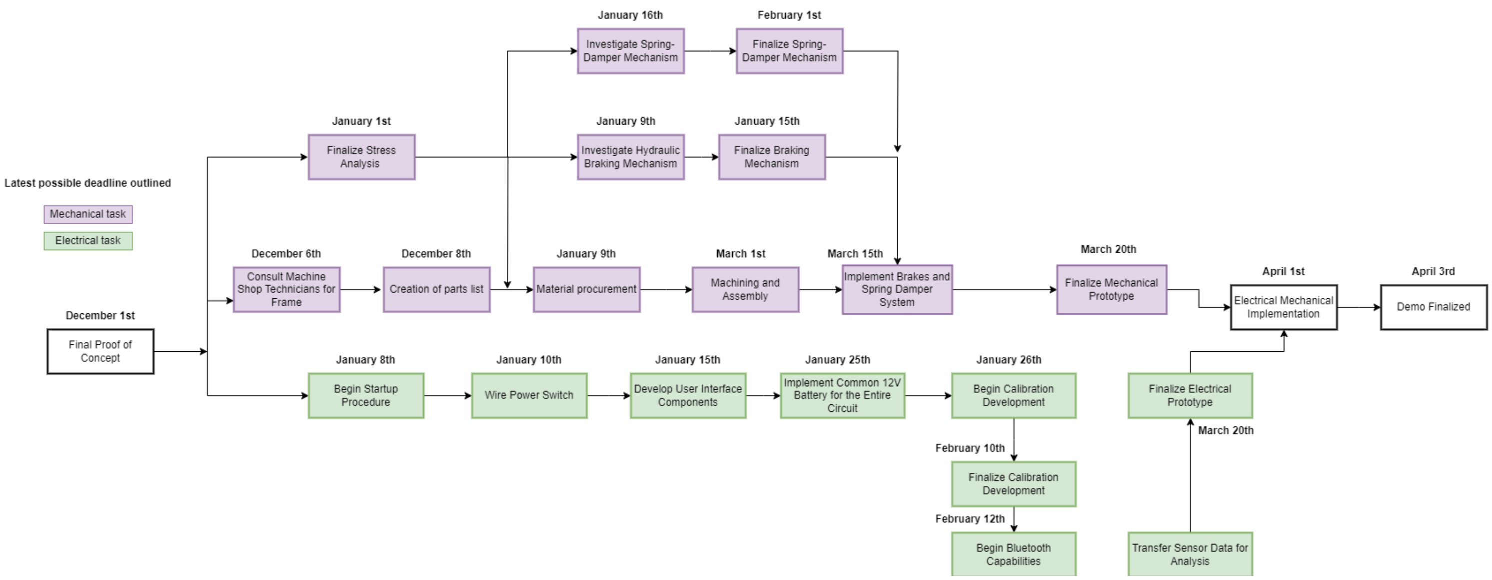


Figure 29: Critical Path for Winter Semester.

Like the Fall semester, the Gantt chart separates the semester into various tasks with their target completion dates. At this stage, meetings with co-disciplinary instructors and project stakeholders have not yet been scheduled. In the coming weeks, regular meeting times for the new year will be established, and these dates will be added to the project chart.

Many objectives were achieved in the Fall semester, which will be built upon in the Winter semester. On the Mechanical sub-team, Taylor and Meera will focus largely on two critical aspects of the project this winter:

1. Implementation and design of mechanical hydraulic braking system
2. Manufacturing of the design

In the Fall semester, Taylor and Meera split work between modeling and analysis (Meera) and proof-of-concept prototype generation (Taylor). In the winter, they plan to work collaboratively to perform the brake design and machining/assembly. They will begin the winter semester with their dimensions finalized so that they can order parts by December 8th. Before ordering parts, the FEA will be performed by Taylor to ensure that the structure behaves well throughout cyclic loading. While waiting for materials to arrive, Taylor and Meera will determine how to construct the hydraulic braking mechanism. Time permitting, they are also going to investigate the implementation of a spring-damper system at the armpit support to soften the impact of the user entering the device. They will have completed the mechanical component of the prototype by March 20th in preparation for integration of prototypes with the electrical team.

On the electrical sub-team, Liz and Namya will focus on further developing the electrical circuitry of the design. This will largely consist of further elaboration of the fall prevention mechanism. First, they plan to begin the startup procedure, including wiring the power switch and developing the user interface. They plan to finish this by January 15th. Following this, they will begin to implement the common 12V battery for the device. One of their major goals for the semester is to implement user calibration and Bluetooth capabilities. They plan to finish this by February 10th and March 1st, respectively. After transferring sensor data for analysis, Liz and Namya will plan to finish the independent electrical prototype by March 20th in preparation for integration of prototypes with the mechanical team.

Once both teams have finished their independent prototypes, they will perform prototype integration and begin working on their demonstration in preparation for the capstone showcase. They plan to have all elements finished by April 3rd.

In terms of major changes from Chapter 1, the mechanical sub-team faced some challenges in the Fall semester with selecting their final design, which caused them to fall behind schedule. To ensure that the design will still be completed on time, the mechanical sub-team plans to meet with the machine shop technicians on January 8th to discuss manufacturing and search local hardware stores for their components so that they do not need to wait for long periods of time to receive online orders. They also plan to accelerate the FEA and hydraulic brake design processes in attempt to get ahead of schedule to prepare for potential delays throughout the semester. The fatigue simulation and applied mass FEA will be used to validate the design.

For the electrical team, the deviation from the initial plan in Chapter 1 increased the speed of prototyping. This included selecting all device components, testing them, and integrating them into a simple algorithm for the proof of concept. This will leave additional time in the Winter semester for design validation and debugging.

2.5 Updates according to feedback

None

2.6 References

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CHAPTER 3: IMPACT AND RISK

3.1 Ethical Concerns

Designing a smart mobility device presents several ethical concerns within the intersection of innovation, user well-being and social impact. Some of the ethical considerations related to the use of the proposed device include:

3.1.1 Privacy and Data Sharing

The SureStride is designed to relay collected sensor data and user information to the healthcare provider to assess the fall risk over time. This data may include sensitive information about the user and must be handled carefully. To mitigate the risk of compromising patient privacy, the data (anonymized and encrypted) must only be shared with the healthcare provider. Further, explicit consent will be obtained from users, clearly defining the goals and the process of data sharing. Ethical mitigation strategies will involve safeguarding user privacy while enabling proactive risk assessment and personalized care.

3.1.2 Equity and Accessibility

Given the diverse population that may use the SureStride to address their mobility needs, the device should be accessible and equitable. We aim to advocate for policies, including government support, to promote the affordability of the device. The device is designed to be intuitive and simple such that diverse user needs (including physical abilities and cognitive differences) are addressed. The device will also be marketed across diverse populations through community outreach. Ethical mitigation strategies will promote inclusivity, ensuring that all individuals, regardless of socioeconomic status are benefitted. Societally, this will foster a more inclusive and accessible environment, reducing disparities in healthcare access.

3.1.3 Transparency

To mitigate the ethical risks associated with the working of the device, users should be educated about the device's capabilities and limitations. Providing clear, easy-to-understand documentation and labeling potential risks on the device will promote its proper use. Societally, this encourages transparency in technology development and usage, and empowers users to make informed choices.

3.1.4 Healthcare Professional Responsibility

The continuous sharing of information may be lined with overdiagnosis and unnecessary interventions. Open communication between users, professionals and manufacturers can promote informed analysis and responsible interpretation of data. Ethical mitigation strategies involve promoting collaborative decision-making. Societally, this cultivates a culture of responsible healthcare practices, where technology complements clinical judgment, bettering patient outcomes.

3.2 Health and Safety Risks

There are certain risks that may arise for the end-user when operating the SureStride. The SureStride is a mechatronic device, meaning it collects signals from its environment and reacts accordingly.

The electrical components of the SureStride include inertial measurement unit sensors (IMUs) and linear actuators, as well as various output devices. The linear actuators are a critical component of the design, as they are the mechanism behind the automatic braking system. When the IMU sensors detect a sudden extreme change in acceleration, the actuators will extend at 10mm/s to drive the disc brake and decelerate the wheels [1]. The prototype uses a BNO055 IMU accelerometer. This sensor has acceleration ranges of ±2g/±4g/±8g/±16g and will exert a braking force through the linear actuators that is proportional to the experienced change in acceleration [2]. Although this sensor has reliable accuracy, there is a risk that the linear actuators spontaneously extend, or that the IMU sensors report an incorrect measurement, prompting the actuators to extend. This would result in unanticipated automatic braking that may alarm the user. To mitigate this risk in the existing prototype, coding with temporal safeguards will ensure that the sensor readings accurately represent reality. Furthermore, the speed of braking can be controlled by the speed of the linear actuators which can operate at 10 mm/s or below according to the signal received from the microcontroller. In the final prototype, high accuracy sensors would be used to minimize the possibility of incorrect values being reported. Additionally, since electrical components are present there is a risk of overheating. Since heating cannot be feasibly controlled, electrical components will be housed in cases, not in contact with human skin.

In terms of the mechanical design, a stress analysis was performed to locate structural weaknesses. As structural supports, there are 6 bars connected to the device through welded joints (Figure 1).

Figure 30: SureStride Solid Model Skeleton

Bends in the device present as regions of stress concentration. If these regions were to experience a loading condition that exceeded the selected material’s yield stress, the device would begin to plastically deform, and could experience brittle fracture. To mitigate the risk of failure, maximum loads were calculated to select the correct material and dimensions that keep the loading scenario in the elastic range.

During the prototyping process, certain risks were present. From a mechanical perspective, many of the machining processes were hazardous. The CNC milling machine, lathe, horizontal bandsaw, tube bending apparatus, acetylene torch, and sandblaster were used. Each of these machines have their own associated hazards. To mitigate injury in the prototyping process, the McMaster Mechanical Engineering Technical Staff was consulted, and proper personal protective equipment (PPE) was worn.

When performing the tube bending, some tubes fractured (Figure 2). They experienced fast, brittle fracture accompanied by a large noise. To avoid fracture, lubricating oil was placed inside the bending die and the pipe was heated with an acetylene torch (Figure 3).

Figure 31: Fractured Aluminum Tube

Figure 32: Operation of the Acetylene Torch in Tube Bending

When operating the acetylene torch, a face shield and gloves were worn as PPE. The die used to bend the pipe could only be used for pipes of 1-inch outer diameter. Since the procured pipes were 1.05-inches in diameter, excess material was removed using the lathe. Each bend in the aluminum pipe requires an additional 12 inches of material, so certain segments of pipe were very long. When the long pipes were inserted into the lathe, vibration was introduced. After consulting with the mechanical engineering technical staff, it was concluded that the best method to prevent this chatter in machining was to secure the workpiece to the chuck through duct tape.

Figure 33: Lathe Operation

This presented as a hazard in the prototyping process, as the lathe rotates at very high velocities and duct tape is not a mechanically sound vice mechanism. It was decided that since this machining process was quick, this temporary mechanism would suffice. In the future, 1.00’’ outer diameter pipes would be specially sourced to mitigate the hazards associated with the lathe. Additionally, the device would be fabricated of aluminum alloy 3003, as this alloy is more ductile and the acetylene torch would not be needed to reverse anneal the material [3].

Finally, this device is aimed to interact with a vulnerable population, which presents inherent risks. It has been designed to remain stable, however if misuse occurs and the user experiences a fall, electrical engineering principles could be implemented to have the device alert emergency services.

3.3 Environmental Risks

Environmental risks are crucial to identify and mitigate, as they are present throughout the entire life cycle of the device, from development to deployment and end of usable life. Risks to the environment include aspects such as raw material procurement, energy use, and recycling unusable devices.

In terms of environmental risks to consider during the design phase, power consumption is the main concern. The device should minimize the amount of power it uses and draw this power from a rechargeable battery. Strategies to minimize the device power consumption include using highly efficient linear actuators and user interface components. The team’s prototype phase of the design is implemented with a rechargeable lead-acid battery; however, a lithium-ion battery would be more efficient. Future prototypes can further reduce the need to recharge the device by implementing a renewable energy source on board. For example, a micro-inverter could be used to generate electricity while the wheels are turning.

Once the device is ready to be marketed, numerous environmental considerations arise in the production and manufacturing sectors. Acquisition and processing of raw materials can involve large amounts of water and energy. The waste byproducts can contain dangerous chemicals. To minimize these impacts to the environment, the device will be built using standardized parts sourced from environmentally and ethically responsible companies. Any waste generated from the manufacturing process will be disposed of responsibly to minimize environmental impacts. The device will be shipped partially assembled to minimize emissions per device delivered, and it will be assembled at the user’s fitting appointment. Shipping the device partially assembled will also reduce the packaging required. The packaging will be made of recyclable materials.

An important aspect to consider in terms of environmental impact is the end-of-use phase of the product. Because the device is adjustable, it can be refitted to another user if it is still in working condition. If certain parts of the device show wear, such as wheels or armrests, they can be replaced without replacing the whole device. Finally, if the device cannot be restored to working order, it can be sent back to the manufacturer to be recycled into a new device.

3.4 Standards and Codes

3.4.1 International Safety Organization (ISO) Standards

The International Safety Organization uses the ISO 11199-2:2021 policy to specify requirements and test methods for rollators. However, this policy is not applicable for devices with horizontal forearm supports, which are further subclassified as 'walking tables' and instead require policy ISO 11199-3:2005. A walking table is defined as a walking aid with three or more legs and a supporting table or horizontal forearm supports pushed forward by the upper arms, possibly in combination with the upper body. Marking requirements include: product identification, use and adjustment instructions, user weight limit, maintenance instructions, relevant safety precautions, and compliance with standards. The standard specifies the following test methods: mechanical strength tests, durability tests, stability tests, braking system tests, and adjustment mechanism tests. Mechanical strength tests include: the static load test (assess ability to support a static load without deformation or failure) and the dynamic load test (assess ability to withstand dynamic loads characteristic of normal use). Durability tests include: the load cycling test (assess ability to withstand cycles of loading and unloading) and the drop test (assess ability to withstand impact by dropping it). Stability tests include tip-over tests that assess the resistance of the walker to tipping over from a forwards, backwards, and sideways force. The brake performance test evaluates the effectiveness of the braking system and ensures enough resistance is provided when engaged. Adjustment mechanism tests include: the adjustment force test (assess force required to make an adjustment) and the adjustment stability test (assess stability after adjustment is made) [4].

3.4.2 International Electrotechnical Council (IEC) Standards

IEC 80601-2-78:2019 specifies requirements for the basic safety of medical electrical equipment. General requirements in the standard are that the equipment must be designed to ensure safety and minimize potential hazards. As well, adequate information must be provided to ensure the safe operation and maintenance of the device. Electrical safety requirements are that the device must provide for protection against electrical shock, fire, and comply with general electrical safety standards. Electrical circuits must be appropriately insulated to ensure user safety. Mechanical safety requirements are that the design of the device must consider hazards related to moving parts. The device must be electromagnetically compatible; in the presence of an electromagnetic disturbance, the device should not respond in a way that is hazardous to the user [5].

3.4.3 **Standards Council of Canada** *(SCC) Standards*

Within Canada, the Standards Council of Canada uses the CAN/CSA-Z604-03 (R2008) policy to specify requirements and test methods for transportable mobility aids. The standard specifies the general design requirements, product marking and labeling, test procedures, and performance requirements [6].

3.4.4 Plan for Compliance

The aforementioned standards require purchase to view; as such, specific quantities in testing and dimensions were not referenced in the design and conception of our product. To comply with the standards, the device would be made to match the dimensions and device requirements. As well, the team would test the device according to all testing methods specified in the design validation phase of our product. Due to the prototype being composed of aluminum piping rather than our previously specified titanium alloy, stress tests conducted on the prototype would not accurately represent its ability to withstand certain loading conditions. Risks of non-compliance would include the inability to market the product as an assistive mobility device, and the inability to assure its safety to nursing homes, care providers, and physicians who would be responsible for acting as an intermediary in selecting the device for use. Also, ethically, it would be against the professional engineering code of conduct to construct and sell a device that has the potential to do harm.

3.5 Updated Project Plan

The attached Gantt chart represents the target deliverables for the remainder of the semester and was updated from Chapter 2 to represent current project progress. Completed tasks are in grey, and tasks in colour are incomplete. To structure the Gantt chart, major milestones were outlined and assigned a timeline to create a critical path (Figure 34).

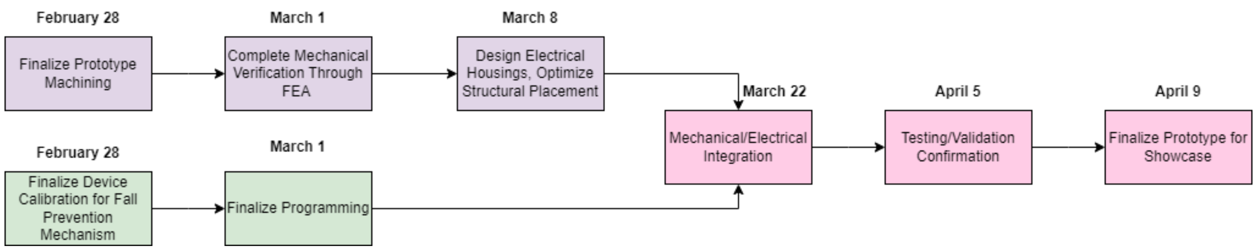

Figure 34: Remaining Validation Plan

Many changes have been made since the submission of Chapter 2. Originally, the SureStride included a collapsible mechanism. Upon discussion with the Mechanical Engineering Technical Staff, it was concluded that within the desired timeline it would not be possible to machine the collapsible mechanism, so the hinging component of the design was replaced with rigid bars. After performing a cost analysis, it was determined that it was less expensive to purchase a mechanical walker and absorb its components than to purchase wheels and mechanical disk breaks. Upon receiving the walker, Meera noticed that it is manufactured from hardened steel. Hardened steel cannot be cut with the horizontal bandsaw in the machine shop, thus the walker had to be returned and the wheel mechanism had to be rethought. Since this, Meera has procured a new walker with wheels attached by fasteners.

Taylor and Meera have completed the majority of their checklist for the manufacturing stage of the project (Figure 6). As mentioned above, they plan to finish manufacturing by the end of February to allow sufficient time to create housings for the electrical components. In the final stages of the project, Meera plans to focus on the integration of the mechanical wheels while Taylor focuses on the design and mounting of the electrical components.

Part A

- ☐ Cut holes
- ☐ Cut to size
- ☐ CAD and 3D print underarm support

Part B

- ☐ Cut to size
- ☐ Side punch THRU
- ☐ Cut holes

Part C

- ☐ Cut holes
- ☐ Add foam for forearm support

Part D

- ☐ Cut holes
- ☐ Cut to size

Part E

- ☐ Cut holes

Part F

- ☐ Cut holes
- ☐ Attach wheels
- ☐ Cut to adjust height of the device

Part G

- ☐ Cut to size

Part H

- ☐ Cut to size
- ☐ Configure internal dimensions

**Drill additional holes in specified locations for electrical housing mountings*

Figure 35: Manufacturing Checklist

From the electrical sub-team, this semester they experienced some challenges with obtaining the correct components. The key buck converter that allows the microcontroller to be powered with the same battery as the 12 V linear actuators did not arrive as ordered. This issue was resolved when the distributor sent the correct item. Further challenges included trying to implement a liquid crystal display (LCD) for the user interface. Because this item was not specifically chosen for this project, it did not communicate via 3 V logic, like the other peripherals on the same I2C bus. Although the LCD was made operational on the system, it was ultimately abandoned to ensure the protection of the other peripherals from this higher voltage.

Once both teams have completed their prototypes, integration will begin. Following advice from their co-supervisors, they plan to integrate in early March.

3.6 Updates according to feedback

3.6.1 Environmental risks

Feasible environmental risks were identified and mitigated. Such risks included minimizing materials required and minimizing energy processing materials. For example, soldering was done in such a way that all wires were prepped prior to turning the iron on to minimize the time that the solder station was consuming energy. Furthermore, materials that were damaged during manufacturing will be recycled.

3.6.2 Standards and codes

Compliance strategies will be implemented for the device entering the next iteration provided that sufficient funds are available to purchase such standards and codes.

3.7 References

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[3] C. Jönsson et al., “Here are the best aluminium alloys for bending,” Shapes by Hydro, https://www.shapesbyhydro.com/en/material-properties/here-are-the-best-aluminium-alloys-for bending/#:~:text=Aluminium%20alloy%203003.,between%20yield%20and%20tensile%20 strength. (accessed Feb. 16, 2024).

[4] *Iso.org*, 2021. https://www.iso.org/obp/ui/#iso:std:iso:11199:-3:ed-1:v1:en (accessed Feb. 14, 2024).

[5] *Iso.org*, 2024. https://www.iso.org/obp/ui/en/#iso:std:iec:80601:-2-78:ed-1:v1:en (accessed Feb. 14, 2024).

[6] “CAN/CSA-Z604-03 (R2008),” *Standards Council of Canada - Conseil canadien des normes*. https://www.scc.ca/en/standardsdb/standards/18693 (accessed Feb. 14, 2024).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Design Development, Analysis and Optimization of Final Design

4.1.1 Final Design: Mechanical Analysis

4.1.1.1 Design Reviews and Consultations

Before the winter proof of concept presentation, our team made a 1:10 scale model of our prototype, shown in Figure 36 below:

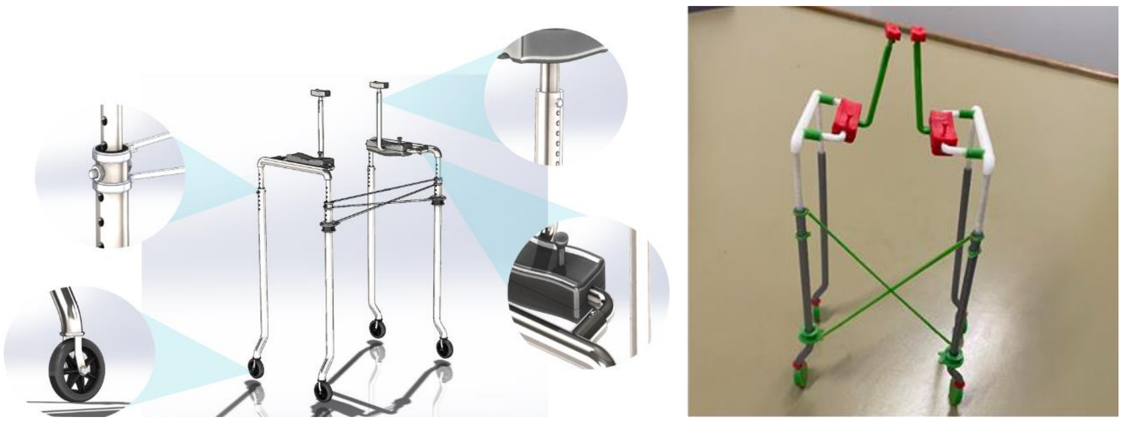


Figure 36: CAD and Scale Model of Design Iteration 1

We noticed after printing that the design was very unstable. To better ascertain why the structure may be unstable, our team had performed a finite element analysis in SolidWorks. The FEA stated that the structure failed under two 25 kg loads applied at the armpit supports. Following these results, our team met with the Mechanical Engineering Undergraduate Project Library Technicians on December 8th. They informed us that this design was not a structure, and if we were to begin manufacturing it would likely collapse. Throughout the month of January, we extensively discussed many alternative geometries, materials, manufacturing methods, and more. Some examples of the many discussed design alternatives are listed in the table below. *It should be noted that every design moving forward required support bars welded into the structure, so this was not discussed in strengths of design as it was a non-negotiable feature required for mechanical integrity.*

Table 15: Alternative Designs Discussed with Technical Staff

Alternative	Strengths	Limitations
Manufactured from copper	• Could solder components together to remove the need for welding	• Very little room for design optimization (strict limitations on wall thickness, outer diameter) • Weak (material and manufacturing method)
Manufactured from PVC piping material	• Very inexpensive	• Weak • Less aesthetically pleasing
Manufactured from aluminum extrusion	• Allows for infinite combinations of adjustability	• Extremely expensive • Unfamiliar material with specialized fittings that enhances product cost
Buy an existing standard walker and focus only on brake design	• Much easier route • Reasonable within time and cost constraint	• Less opportunity to learn manufacturing skills in IBEHS 5P06 • Less opportunity for mechanical design
Collapsible mechanism, angled legs, Aluminum 6061, telescoping poles for adjustability	• Angled legs provide wider base of support • Support bars will enhance structural integrity • Telescoping poles allow for adjustability at a lower cost	• May not be reasonable within time or cost constraint • Collapsible mechanism is a large point of structural weakness that will be challenging to design and manufacture • Aluminum 6061 is a less ductile alloy (bending may be a challenge, especially for two opposing bends separated by a short distance)
Remove collapsible mechanism, remove angled legs, Aluminum 6061, telescoping poles for adjustability	• Reasonable within time and cost constraint • More structurally sound • Reasonable within manufacturing constraints • Telescoping poles allow for adjustability at a lower cost	• Non-collapsible mechanism is less user-friendly • No angled legs provide smaller base of support • Aluminum 6061 is a less ductile alloy (bending may be a challenge)

The final alternative listed in Table 15 was selected, and further design iteration was performed throughout the course of the semester. The final design CAD model is shown in Figure 37 below:

Figure 37: Final Design

This design includes the following features that were updated from our initial design:

- Rigid support bars welded to the front and sides of the device to reduce bending moments on vertical bars.
- Aluminum 6061 material – within constraints for weight and cost
- No collapsible mechanism.
- Mechanical hand brakes that can be independently actuated by the user to stop the device when in motion or lock the device in place.
- Disc brakes connected to a linear actuator (electrically driven) to automatically resist wheel rotation if the device experiences:
    - Excessive wobble *detected by BNO 055 gyroscope.*
    - Proximity to an obstacle (within 25 cm) *detected by time-of-flight sensor.*
    - Excessive acceleration (passed the threshold deemed safe) *detected by BNO 055 accelerometer*.
- Universal front wheels capable of 360-degree rotation, fixed back wheels

  Removal of angled device 'legs' due to foreseen challenges with double bends in Aluminum 6061 and presence of structural weakness

4.1.1.2 Finite Element Analysis (FEA)

To confirm the prototype would be mechanically sound, FEA was performed in Autodesk Inventor. The following FEA model was made:

Figure 38: SureStride Autodesk Inventor Model

Then a tetrahedral mesh was created:

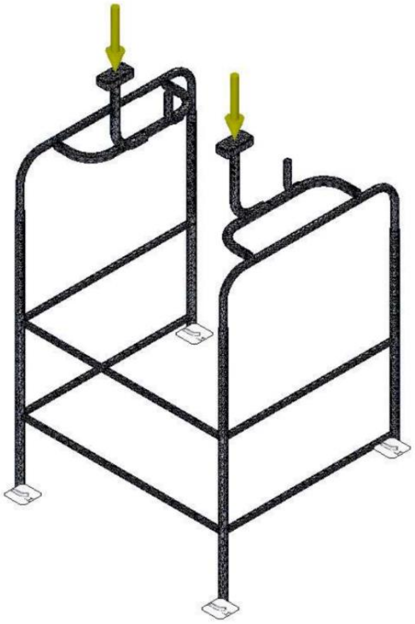


Figure 39: Model Mesh

Three different loading scenarios were applied to test the strength of aluminum. The loads were concentrated to the armpit supports as this represents the worst-case scenario loading application. The device is designed for the user to placed 20% of their body weight at this location. It is assumed that the user may incorrectly operate the design, by confirming its factor of safety for worst-case-scenario, we can conclude whether or not the design is safe. Pin constraints were added to the bottom of the device to represent that the device may not deform through the floor. Only the aluminum skeleton was modelled, as this is the main load-bearing component. Through FEA, the Von-Mises stress and factor of safety were evaluated. The results are shown below:

Table 16: FEA Results

Test Case	**Von-Mises Stress (ksi)**	**FOS**
1	3.44	15
2	6.32	15
3	8.42	15

When performing a structural analysis, regions with holes and bends are locations of structural weaknesses where we can expect to see high stress concentrations. Two examples are shown below:

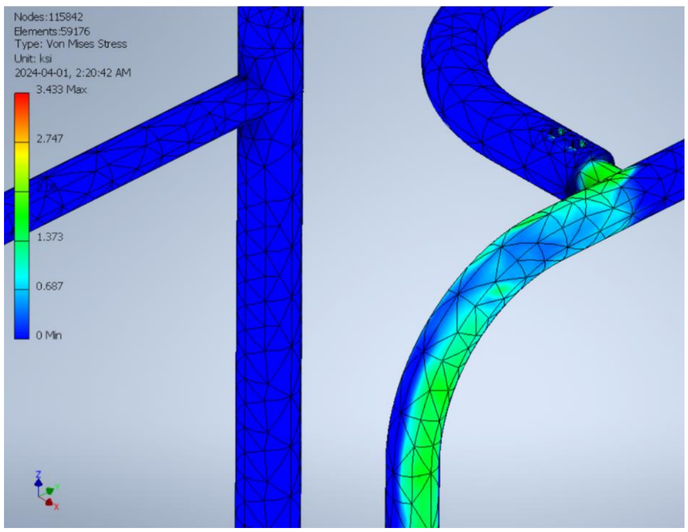


Figure 40: Stress Concentration at Bend

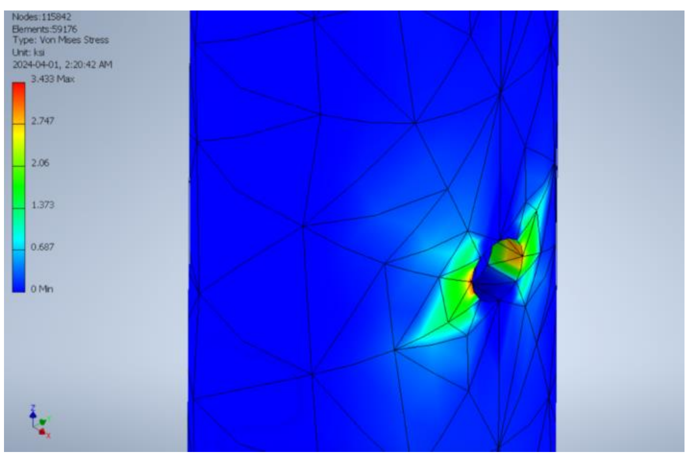


Figure 41: Stress Concentration at Hole

Although the greatest stress is experienced at these regions, the maximum stress is still far less than the yield stress of aluminum in each loading scenario, concluding that the device is safe from plastic bending under human load. The complete results for each test case can be found in Appendix B.

4.1.1.3 Stress Analysis with Design Modifications

As previously mentioned, the design from Chapter 2 was modified to include permanent, welded, horizontal bars across the front and sides of the walker frame. These bars ultimately reduce the moment that the vertical pipes experience when loaded by providing an opposing force to the applied moment. As well, the updated design does not include bent pipes to increase the base of support of the walker. To accomplish the same increase in area, the back wheels were mounted on the side. As well, the length of the beam subject to column buckling was reduced to the length in between welded supports. Overall dimensions and how the components were attached remained the same.

The failure modes from Chapter 2 is updated below in Table 17 to include the critical locations in the updated design. As in Chapter 2, these locations were chosen based on the failure prevention techniques described in *Shigley's Mechanical Engineering Design* textbook.

Table 17: Failure modes of updated design and associated Shigley's chapters/sections for conducting an analysis

	Failure Mode	**Textbook Chapter/Section**	**Description**
1.	Transverse holes in bending	6-10	Fatigue Failure Resulting from Variable Loading – Stress concentration and notch sensitivity
2.	Pin shear	3-4	Load and Stress Analysis – Stress
3.	Weld group in shear	9-5	Weld, Bonding, and the Design of Permanent Joints – The Strength of Welded Joints
4.	Single weld in shear	9-5	Weld, Bonding, and the Design of Permanent Joints – The Strength of Welded Joints
5.	Column buckling	4-12	Deflection and Stiffness – Long columns with central loading

Of the analysis conducted in Chapter 2, only failure modes 1 and 5 were changed due to the updated design. Specific stress analysis calculations, dimensions, and parameters can be found in Appendix B, Updated Stress Analysis. The goal of the stress analysis was to support a body mass of 120kg, or a body weight of approximately 1200 N, corresponding to the 95th percentile male. Table 18 below defines the loading conditions and assumptions for failure modes 1 to 5. For simplicity, the analysis neglected the impact of wheels and motion. The stress analysis was conducted on a frame in static equilibrium.

Table 18: Summary of failure modes, analysis assumptions, and loading conditions

	Failure Mode	**Loading Condition**	**Assumptions**
1.	Transverse holes in bending	Bending	• Each column supports the body weight equally – the force along each column is BW/4. • The bending moments generated in each column are the same. • Reduced section modulus is the same along both x and y axis. • Surface finish is machined or cold-drawn • There are no temperature, reliability, or miscellaneous effects (kd=ke=kf=1) • The moments created in x and y are applied to the center of the beam in z
2.	Pin shear	Shear	• Shear force experienced by a pin in each column is BW/4 • Pin is purely in shear (no bending) • Ultimate strength in shear is 0.67*Sut • Yield strength in shear is 0.67*Sy
3.	Weld group in shear	Shear and Bending	• Shear stress on each side is V = BW/2 • Shear stress in each weld is V'=V/N where N is the number of welds • Surface finish is as-forged • Fatigue concentration factor is taken as highest value, regardless of type of weld • There are no temperature, reliability, or miscellaneous effects (kd=ke=kf=1)
4.	Single weld in shear	Shear and Bending	• Shear stress on each side is V = BW/2 • Surface finish is as-forged • Fatigue concentration factor is taken as highest value, regardless of type of weld • There are no temperature, reliability, or miscellaneous effects (kd=ke=kf=1)
5.	Column buckling	Normal, compressive	1. Column is loaded centrally 2. The points in between each welded support is **fixed** 3. The length of the column is the distance between the welded supports

As in Chapter 2, once material stresses were calculated, the yield factor of safety (FOS) was calculated. Due to the nature of the loading being cyclical, the fatigue FOS and number of cycles-to-failure (CTF) were also calculated. The yield FOS, fatigue FOS, and number of CTF are shown for the material selected in Chapter 2 in Table 3. Table 19 also shows the difference between calculated values from the initial design to the current, revised design.

Table 19: Failure modes and corresponding stresses, FOS, and cycles to failure

Failure Mode	Design Stress (MPa)		Yield FOS		Fatigue FOS		Number of CTF	
	Initial	Updated	Initial	Updated	Initial	Updated	Initial	Updated
1	142.74	71.18	8.455	16.95	1.965	3.94	653e6	2396e8
2	14.98	14.98	53.96	53.96	25.36	25.36	8842e12	8842e12
3	12.62	12.62	39.11	39.11	4.23	4.23	430e6	430e6
4	8.524	8.524	57.93	57.93	6.27	6.27	2077e6	2077e6

As shown in Table 19, adding support bars across the sides and front of the frame only affects failure mode 1 in terms of design stress, FOS, and cycles to failure. The support bars improve the yield FOS and fatigue FOS by almost 200%. Failure mode 1 was the most critical mode with the smallest FOS of all other modes. Our design update improved it significantly, although it should be noted that there were also significant assumptions made in the stress analysis.

Column buckling (failure mode 5) was analyzed in terms of the maximum compressive load that could be applied concentrically to the column; no FOS or cycles were calculated. From the original design, a critical load of approximately 10000N was calculated. From the updated design, using a column length of the distance between the support bars, the critical load increases by almost 3-fold to 30000N.

In Chapter 2, our criteria for a successful material were: The material must result in a yield FOS greater than 5, fatigue FOS greater than 1.5, and infinite life (1,000,000 cycles to failure). With our design update, using the same material and dimensions, we increased each of these criteria by two-fold and met them. Our updated design has all critical failure modes with a yield FOS greater than 10, fatigue FOS greater than 3, and more than 2,000,000 cycles to failure. As in Chapter 2, we used a titanium alloy (Ti-13 V-11 Cr-3 Al) for the frame and E120xx for the weld material.

4.1.2 Final Design: Electrical Analysis

The final design of the SureStride employs electrical principles to provide **fall-preventative braking**. The device has three ways to initiate braking:

1. A distance sensor that prevents the user from walking into nearby tripping hazards.
2. An acceleration sensor prevents the device from straying; and
3. A gyroscope will measure the side-to-side wobble to detect and prevent any falls.

Two BNO055 sensors were used to obtain linear acceleration and Euler angles. Linear acceleration is used to assess if the walker is accelerating at a faster rate than safe. If it is accelerating at a rate that is moderately too fast, the walker will initiate the minor braking procedure wherein the linear actuators pull on the brake wires and add some resistance to the motion, but do not stop it completely. If the walker is accelerating much faster than safe, it will initiate the major braking procedure wherein the linear actuators pull on the brake wires and create lots of resistance to the motion. When the linear acceleration drops down to acceptable levels, the braking is released.

The Euler angles are used to assess if the user's wobble could indicate a fall. If the walker detects angles that are greater than the typical variation, it will initiate the minor braking procedure. Once the angles return to normal, braking will stop.

The final design implements a time-of-flight sensor for obstacle detection. If there is an object approaching the walker and it comes within 25cm, the walker will commence minor braking to avoid a collision. When the path is clear, the walker will stop braking and the user can proceed forward.

The switches and LEDs form the basis for the user input and output interfaces. The switch near the base of the walker, by the battery, serves as an input to commence the calibration procedure. This switch was intentionally put out of the way because the calibration is meant to be done with the supervision of a trained professional.

The switch near the user's left arm rest serves as the input to power on the device. Furthermore, there are three LEDs near this switch to provide the user with feedback from the device. The LED colours are deliberately chosen as red, yellow, and green to match those of traffic signals to be easy to understand. When the walker is powered on, the green LED turns on. If minor braking is being applied, the yellow LED will turn on, whereas if major braking is being applied, both the yellow and red LEDs will turn on.

The walker's electrical components are all powered using a 12V battery. This is necessary because the linear actuators are powered by 12V. Thus, to limit the design to only require one power source, a 12V to 3.3V buck converter is connected between the battery and the microcontroller. Furthermore, a motor driver also connected to the batter and the microcontroller converts the microcontroller output to 12V which powers the linear actuators.

As part of the stop procedure, the walker uses Wi-Fi capabilities to offload the number of occurrences of braking to an external device. This Wi-Fi connection is formed via a 2.4GHz connection to the external device's network. From this, the external device can save the data and plot to analyse the user's trends.

Because the user's safety is of utmost importance, the walker is equipped with an emergency stop procedure. In the event of undesired automatic braking, the user can press the power switch and the walker will return to the unbraked position and power down.

KEY ELECTRICAL FEATURES

1. **Acceleration and angular sensors** (Adafruit BNO055 sensors) to detect falls and straying.
2. **Distance sensor** (Pololu Time-of-Flight sensor) to detect tripping hazards.
3. **ESP32 Microcontroller** to take input from the sensors and decide if the walker should commence preventative braking.
4. **DC-DC Converter** converts the 12V power from the battery to 3.3V which powers the ESP32 microcontroller.
5. **Switches** provide user input to power on the device and/or start calibration sequence.
6. **LEDs** show the user the walker status.
7. **12 V Lead Acid Battery** powers the device.

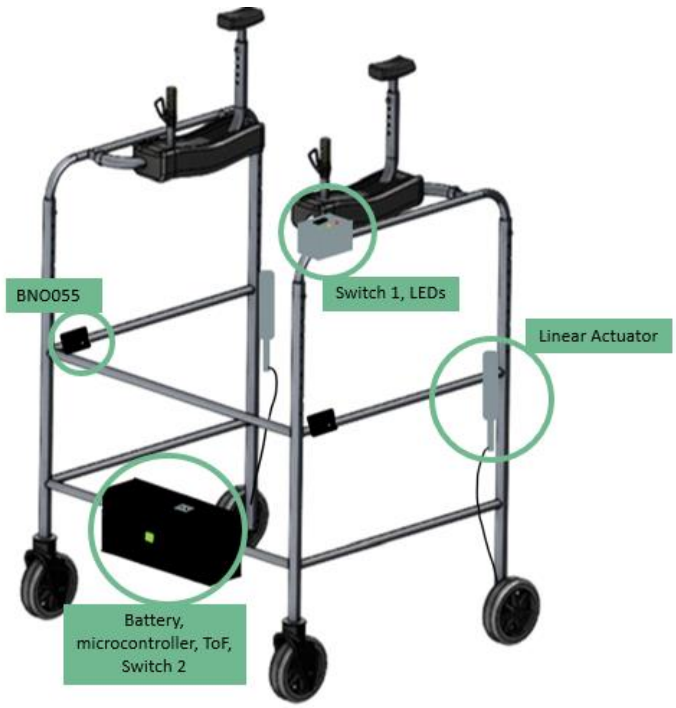


Figure 42. Placement of electrical components in design.

Further details of the selected electrical components are as follows:

Bosch BNO055 Intelligent 9-axis absolute orientation sensor [1]

The BNO055 sensor is a System in Package (SiP) solution that provides orientation data based on a 360° sphere, four-point quaternion output for more accurate data manipulation, three-axis of ‘rotation speed’ in rad/s, three-axis of acceleration in m/s², three-axis of linear acceleration data (acceleration minus gravity).

Table 20. Electrical characteristics of interest for the BNO055 sensor.

FEATURE	SPECIFICATIONS
OPERATING VOLTAGE	3.3V to 5V
LINEARITY	Highly linear
DIMENSIONS	Refer to datasheet
POLARITY PROTECTION	Yes (reverse polarity)
OPERATING RANGE	-40°C to +85°C
MIN/MAX VALUES	Orientation: 0° to 360° (yaw, pitch, roll)
VOLTAGE DROP	Varies based on load
NONLINEARITY	Minimal deviation from linearity
RESPONSE TIME	Fast response
HYSTERESIS	Ensures stability
TEMPERATURE RANGE	-40°C to +85°C
STORAGE TEMPERATURE	-55°C to +125°C

Table 21. Digital interface pin mapping for the BNO055 sensor.

PIN #	PIN NAME	DESCRIPTION
3	VDD	The main power supply for the internal sensors
2	GND	The common/GND pin for power and logic
20	COM0	I2C data pin that includes a 10K pullup resistor
19	COM1	I2C clock pin that includes a 10K pullup resistor

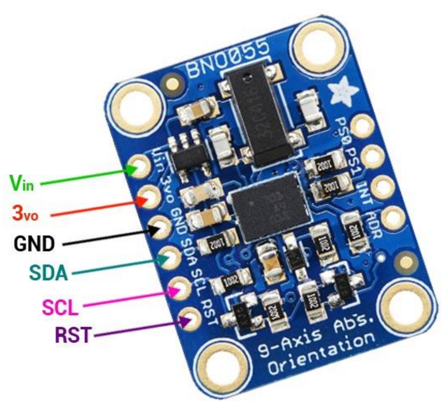


Figure 43. BNO055 sensor module.

Pololu VL53L1X Time-of-Flight Distance Sensor [2]

VL53L1X Sensor: A laser-ranging sensor capable of measuring distances up to 4 meters using time of flight (ToF) technology. It offers a programmable region of interest (ROI), operates in a range of 2.6 V to 5.5 V, and includes a 2.8 V regulator and level-shifters for easy interfacing.

Table 22: Electrical characteristics of interest for the time-of-flight sensor.

SPECIFICATION	DETAIL
RANGE	Up to 4 m
RESOLUTION	1 mm
LASER CLASS	Class 1 940 nm
SUPPLY VOLTAGE	2.6 V to 5.5 V
COMMUNICATION	I^2C interface

Table 23: Digital interface pins for the time-of-flight sensor.

PIN NAME	FUNCTION
VIN	Input voltage (2.6 V to 5.5 V)
GND	Ground
SCL	I^2C clock
SDA	I^2C data
GPIO1	Interrupt output
XSHUT	Shutdown input

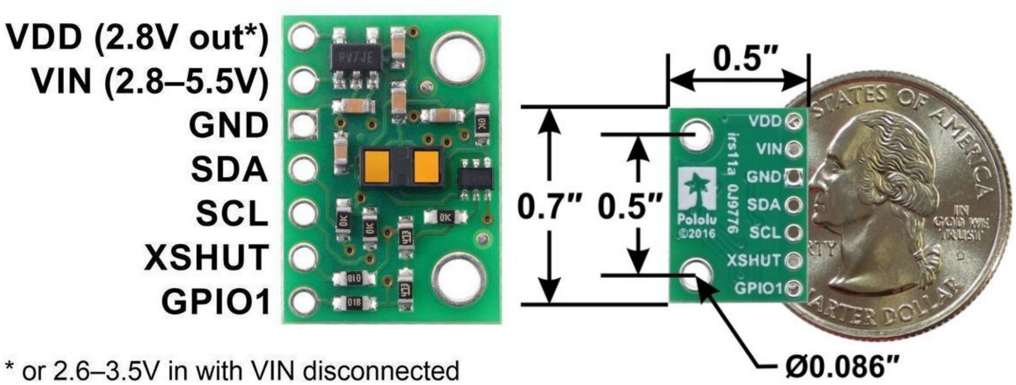


Figure 44: Pololu time-of-flight sensor module.

ESP32-PICO-KIT V4/V4.1 [3]

The ESP32-PICO-KIT is a microcontroller development board produced by Espressif. It features a System-in-Package (SiP) module with both Wi-Fi and Bluetooth capabilities.

Table 24: Key features of the ESP32-PICO-KIT

KEY COMPONENT	DESCRIPTION
MICRO USB PORT	One mode for power supply to the microcontroller. Communication interface for loading code onto the module.
GND	Ground
3.3/5 V POWER	Second option for power supply to the microcontroller. Power supply to the attached peripherals.
POWER ON LED	Indicates if the microcontroller is powered.
I/O	Many input and output pins to communicate with peripherals.
BOOT BUTTON	Download button
EN BUTTON	Reset button

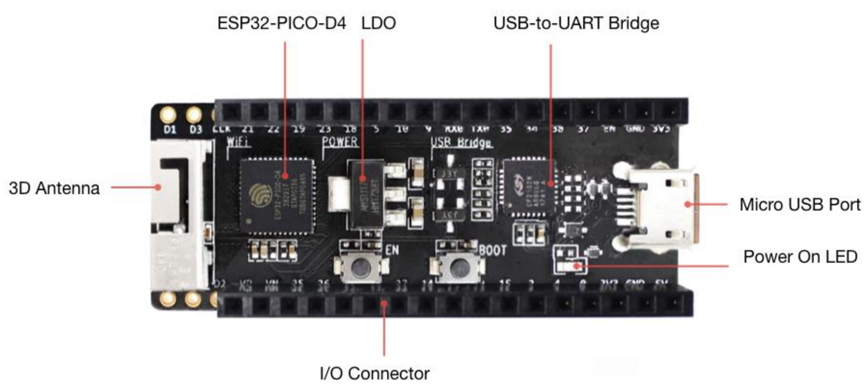


Figure 45: ESP32 PICO-KIT layout.

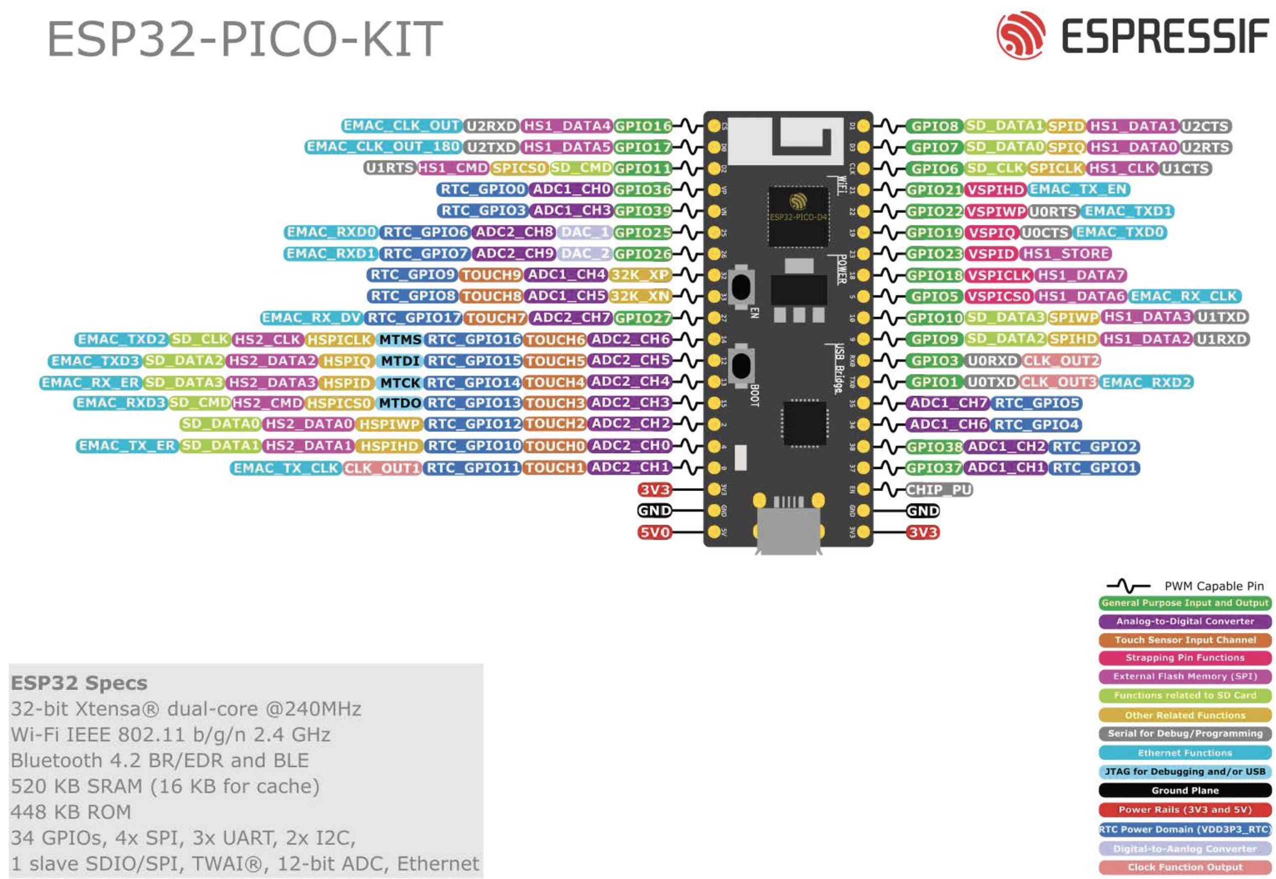


Figure 46: ESP32 PICO-KIT pin diagram.

The bill of materials for the electrical components of the project is outlined in the table below. The total cost of the project's electrical components is $320.29 (without tax), however multiple components were borrowed or reused, thus the total spending amount was less.

Table 25: Electrical bill of materials.

Item	Use	Cost (without tax)
Adafruit ESP32 Pico-Kit	Contains the code of the device to implement the logic. Takes input from the sensors and decides how to act.	$ 15.38 [4]
BNO055 Gyroscope	Senses relative angles and linear acceleration to detect falls or characteristics that could result in falls.	2 x $ 34.95 [5]

Polulu Time of Flight Sensor	Senses objects approaching the walker from the front of the device.	$ 14.95 [6]
Motor Driver	Takes the input from the microcontroller logic pins in combination with the 12 V power from the battery to actuate the motors when triggered by the microcontroller.	$ 26.96 [7]
2 Linear Actuators	Linear actuators pull on the brake wires, thus actuating the mechanical disc brakes.	2 x $ 41.59
Buck Converter	Reduces the voltage from the 12 V battery to 3.3 V which can be used by the microcontroller.	$ 64.98 [8]
12 V DC Battery	Power source for both the linear actuators and the microcontroller.	$ 38.01 [9]
Switches	Obtains user input for the power and calibration switch.	$ 6.66 [10]
LEDs	User output interface features 3 LEDs of different colours to communicate the status of the walker.	3 x $0.09 [11]

The components above were connected according to the following wiring diagram and pin connection tables.

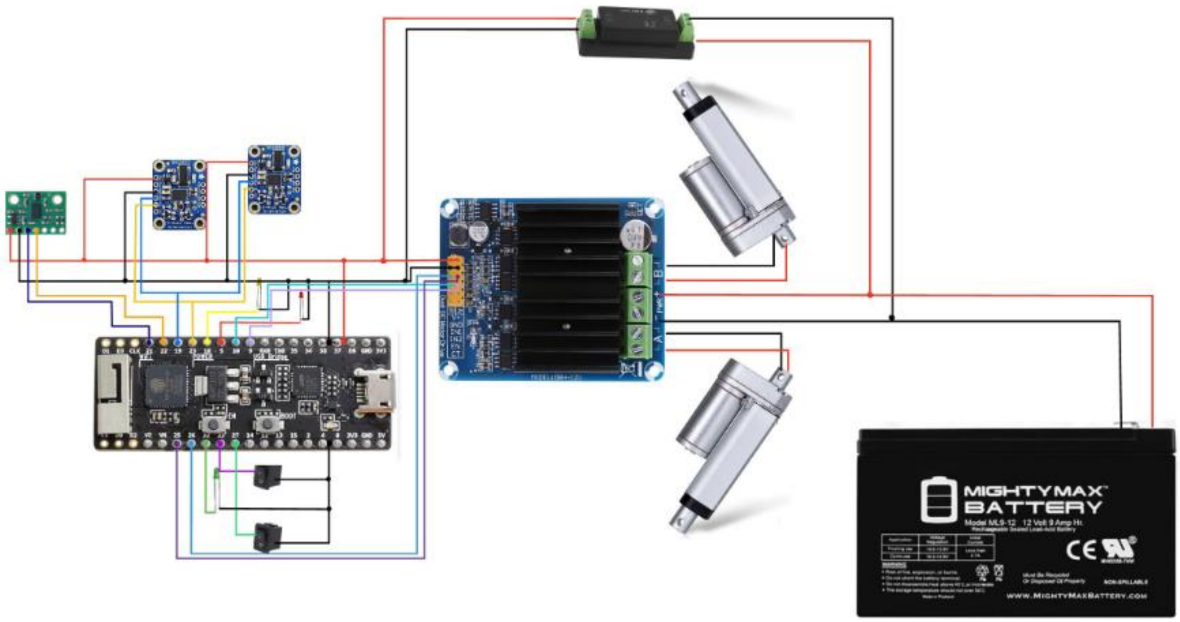


Figure 47: Wiring diagram of all electrical components.

Table 26: Pin layout connections of the ESP32 microcontroller.

ESP32 PIN #	CONNECTION
3V3	Motor drivers enable for motors A and B, BNO055 power, Time of flight power
GND	Switch 1 off pin, Switch 2 off pin, LED ground, Motor driver ground, BNO055 ground, Time of flight ground
5	Red LED power
9	Motor A IN2
10	Motor A IN1
18	Yellow LED power
19	BNO055 SDA
21	Time of flight SDA
22	Time of flight SCL
23	BNO055 SCL
25	Motor B IN1
26	Motor B IN2
27	Switch 1 (power user input)
32	Green LED
33	Switch 2 (calibration user input)

Table 27: Pin connections of the BNO055 sensor.

BNO055 PIN	CONNECTION
VIN	ESP32 pin 3V3
GND	Ground
SDA	ESP32 pin 19
SCL	ESP32 pin 23

Table 28: Pin connections of the ToF sensor.

TOF PIN	CONNECTION
VIN	ESP32 pin 3V3
GND	Ground
SDA	ESP32 pin 21
SCL	ESP32 pin 22

With all the components connected, the following logic flowchart was implemented. Each of the thresholds for the braking cases were determined experimentally by members of the team. Because this testing was not completed with the target demographic, further investigation is valuable to validate the braking thresholds.

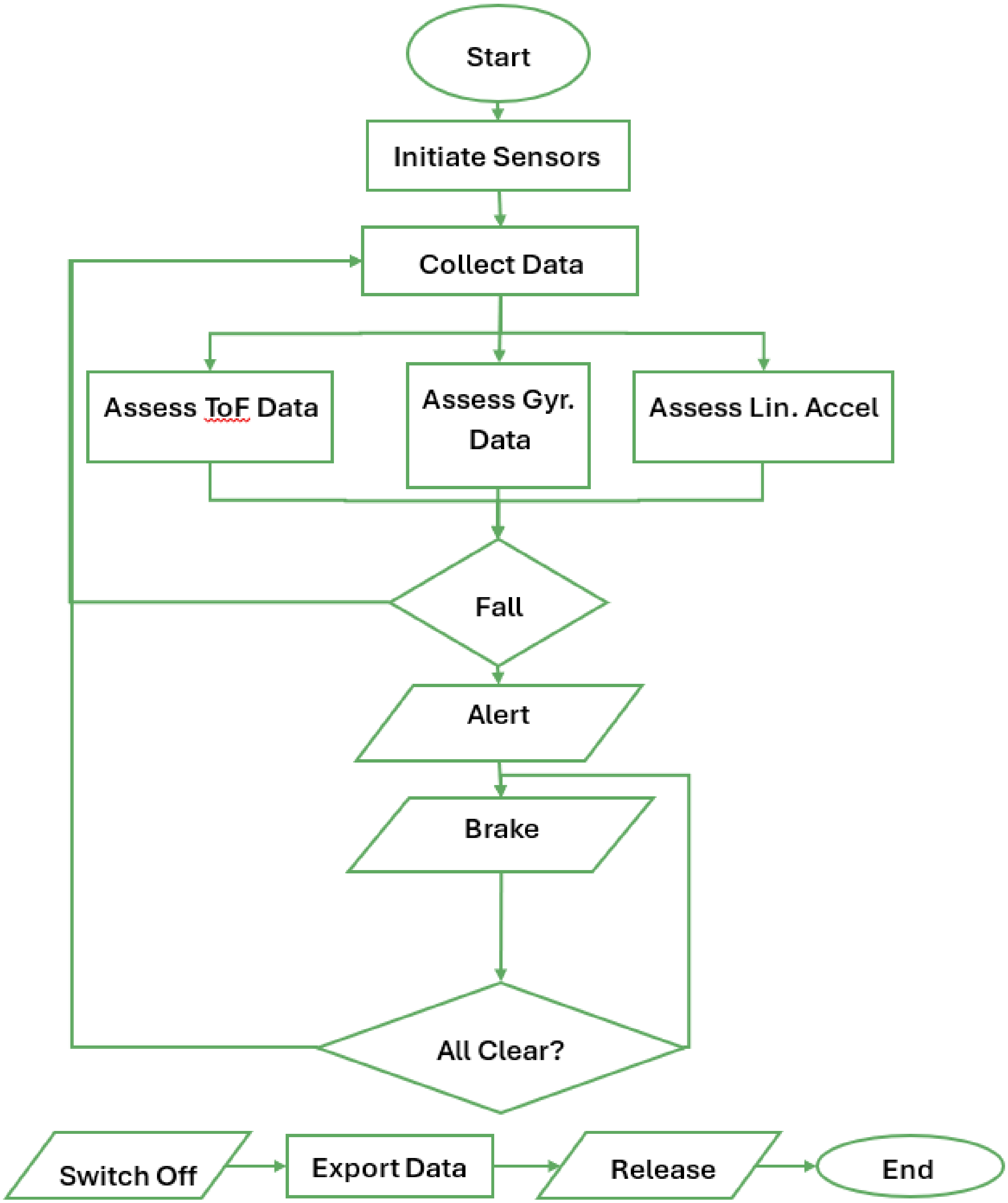


Figure 48: Device logic flowchart.

As part of the power off procedure, the SureStride utilizes its Wi-Fi capability to establish a wireless connection with a PC to offload the braking data. To demonstrate this capability, we utilized the PuTTY application on the PC to establish a serial connection with the SureStride device over Wi-Fi.

Once the Wi-Fi connection is established between the SureStride device and the PC via PuTTY, the microcontroller can transmit braking data in real-time. We configured Putty to log braking data to a text file on the PC, including both minor and major braking events.

After multiple sessions of walker use, the text file containing braking data from PuTTY serves as a valuable source for analysis. Using Python, we developed a script to parse the data from the text file and organize it into a structured format. Subsequently, Python libraries such as Matplotlib are utilized to generate graphical representations of the braking data for each session. These can then be shared with healthcare providers.

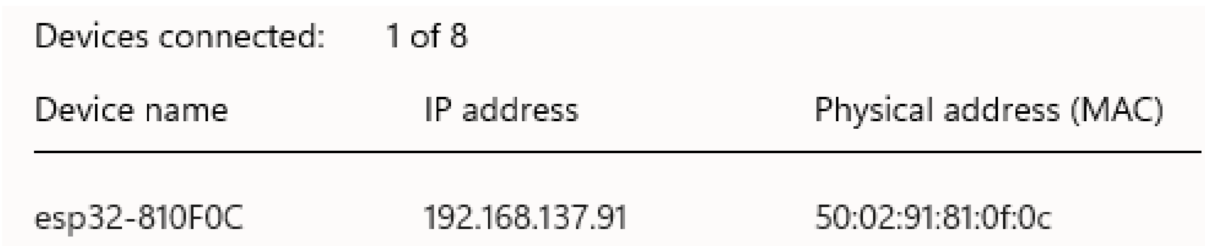
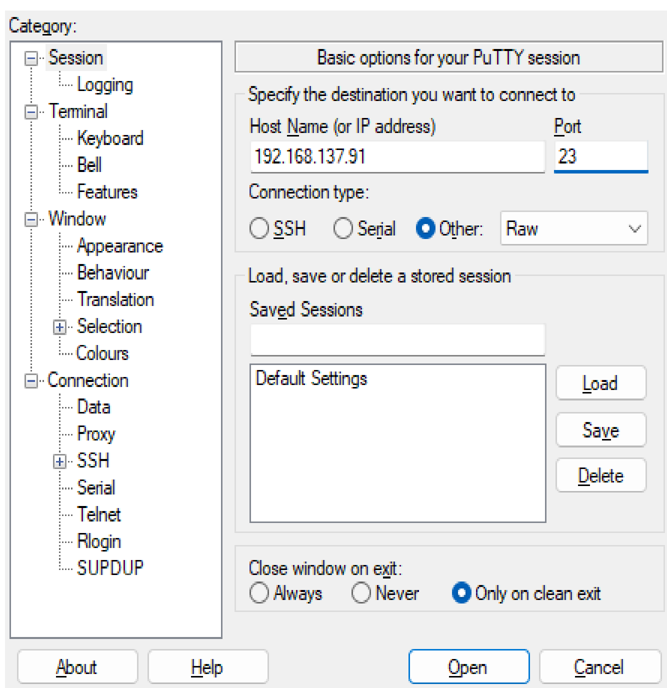


Figure 49: Device connection to PC via Wi-Fi.



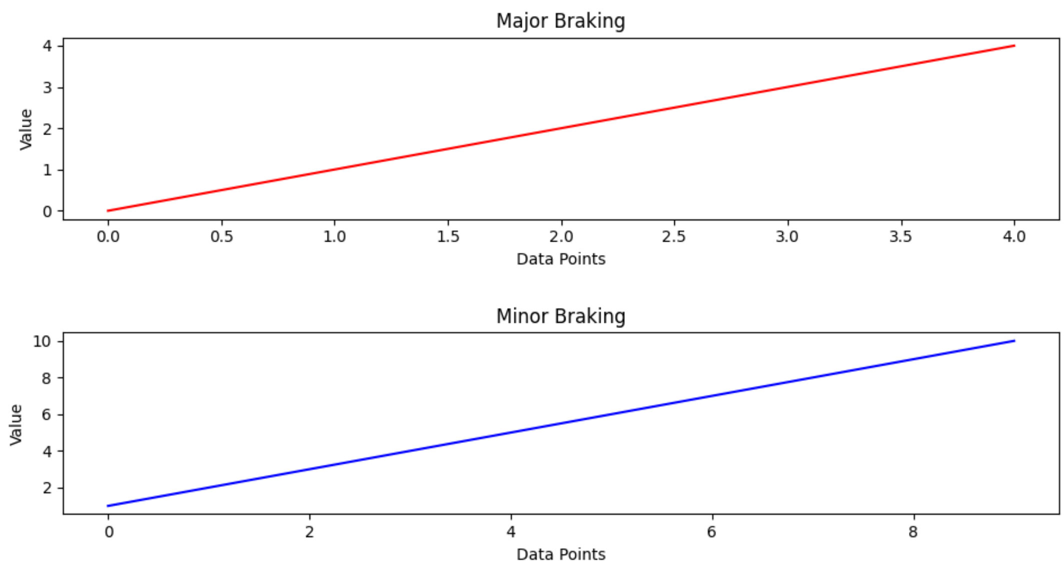


Figure 50: Storing and graphing braking instances.

The following figure outlines the purpose for each of the components and how they interact with each other.

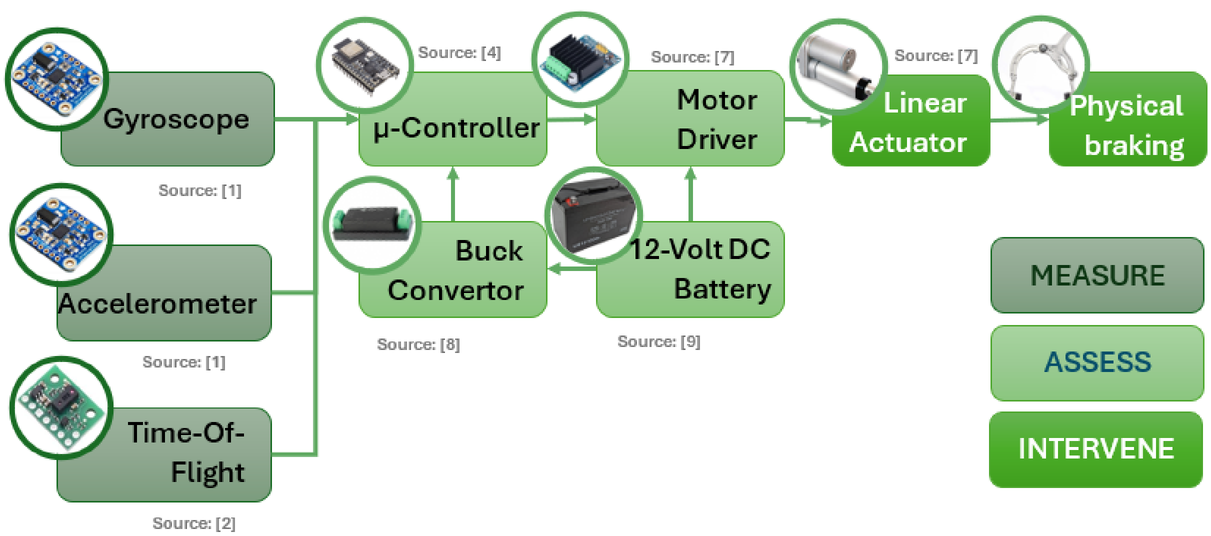


Figure 51: Device electrical component interactions.

To integrate the linear actuators controlled by the electrical circuit with the mechanical braking mechanism, the linear actuators pull on the brake wires of a mechanical disc brake that is securely fastened to the rear wheel.

To test the final design, the following tests were performed.

Table 29: Tests performed on peripheral devices and integration of final solution.

Test case	Description	Outcome
1	Switch	Switch was determined to be working because the voltage of the wire changed when the switch position was turned on from the off position.
2	LEDs	Each LED was tested individually using a 3.3 V power source to a 115 Ω resistor in series with the LED. All LEDs passed the test and are functional.
3	Linear Actuators	Linear actuators were tested by connecting directly to a 12 V DC power supply. Each direction was tested by reversing the polarity of the 12 V connections.
4	DC-DC Buck Converter	The input ends of the buck converter were connected to a 12 V DC power supply. The outputs were measured using a voltmeter and oscilloscope. The measured output was 3.3 ± 0.02 V with minor oscillations. This was deemed a pass.
5	Battery	The 12 V battery output was measured with an oscilloscope and voltmeter. The measured output was 12 ± 0.05 V with minor oscillations. This was deemed a pass.
6	Linear Acceleration	Acceleration was tested in the final implementation by jerking the device forward from rest. A strong push yielded a high linear acceleration whereas a soft push yielded a low linear acceleration. When the walker was used and velocity was kept constant, the linear acceleration was very low. Thus, the linear acceleration passed the tests.
7	Time of Flight	The time-of-flight sensor was tested by printing the measured distances then measuring manually and comparing to the serial output. The measurements were accurate to 1 mm. The time-of-flight sensor was tested again when implemented in the final design with the same procedure and yielded the same results.
8	Wobble	The wobble feature of the design is implemented using absolute Euler angles from the gyroscopes. To test the accuracy of these angles, each gyroscope was assessed individually in each of the 3 planes. Angles were displayed on the serial monitor and compared to an estimate of the actual angle of the sensor. Angles up to 90 degrees were only required to be tested because this is the maximum angle possible in the walker geometry. Each of the gyroscopes performed adequately, thus this method could proceed. To test wobble in the final design, the sensors were fixed on the walker and near-falls were simulated by moving the walker suddenly in oblique angles. The wobble detection successfully identified nearly all of these occurrences.

To analyze the potential hazards and their causes, a fault tree analysis (FTA) was performed. This analysis identified the root cause of potential issues in the electrical design. The primary root causes were component failure/degradation, manufacturing defects, and faulty wiring.

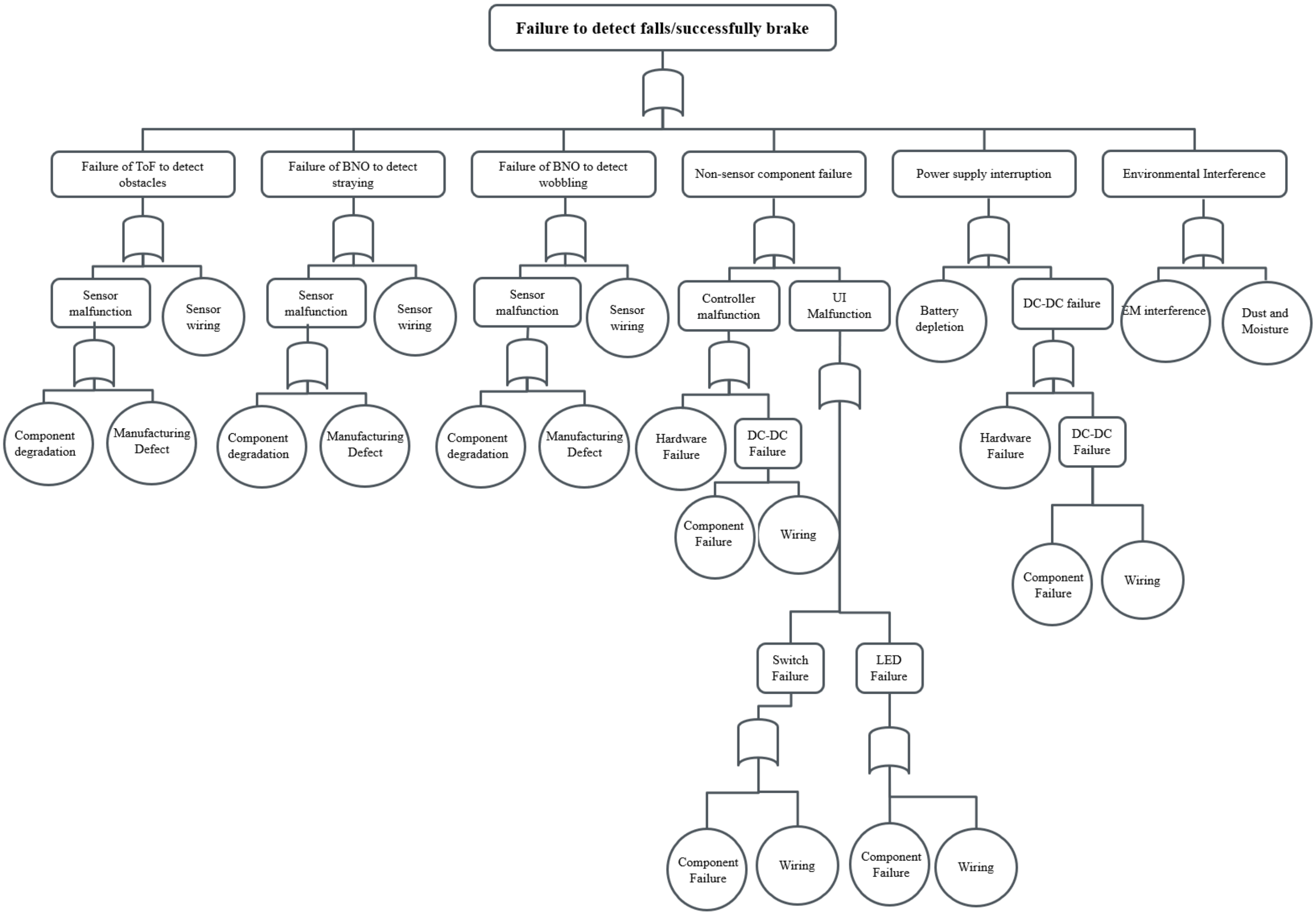


Figure 52: Fault tree analysis for automatic braking system.

4.2 Implementation

4.2.1 Mechanical Implementation

4.2.1.1 Manufacturing Plan

Prior to purchasing parts, the updated design was broken down into individual parts and CAD drawings were created for each part. This ensured that the manufacturing processes that would be applied were all determined prior to purchasing materials. As well, it would avoid not having sufficient material if problems were to arise during manufacturing. Each part was designated a letter, A through H, and was separated into a 'big' or 'small' category to distinguish which pieces would telescope. Each CAD drawing was annotated with: which other parts the piece would interface with and any manufacturing processes that would need to be performed. These drawings can be found in Appendix B. Table 30 summarizes the manufacturing processes for each part.

Table 30: Manufacturing overview for each part

Part	Quantity	Size	Details	Manufacturing Processes
A	2	Small	Interfaces with Part B via holes 4 holes required, 0.75'' apart, 0.25'' diameter	Cutting to size Drilling holes Countersinking holes Grinding edges of part
B	2	Large	Interfaces with Part A via holes 4 holes required, 0.75'' apart, 0.25'' diameter Interfaces with Part C via welds End-milling required to Part C diameter 1 bend at 90 degrees	Bending to 90 degrees Cutting to size Drilling holes Countersinking holes End-milling weld interface Grinding edges of part Welding to Part C
C	2	Large	Interfaces with Part D via holes 4 holes required, 0.5'' apart, 0.25'' diameter Interfaces with Part B via welds 2 bends at 90 degrees	Bending to 90 degrees (x2) Cutting to size – ensuring both bent edges are equal Drilling holes Countersinking holes Grinding edges of part Welding to Part B
D	4	Small	Interfaces with Part C via holes 4 holes required, 0.5'' apart, 0.25'' diameter Interfaces with Part E via welds End-milling required to Part E diameter	Drilling holes Countersinking holes End-milling weld interface Grinding edges of part Welding to Part E
E	2	Small	Interfaces with Part F via holes 6 holes required, 1.2'' apart, 0.25'' diameter Interfaces with Part D via welds 2 bends at 90 degrees	Bending to 90 degrees (x2) Cutting to size – ensuring both bent edges are equal Drilling holes Countersinking holes Grinding edges of part Welding to Part D

F	4	Large	Interfaces with Part E via holes 6 holes required, 1.2'' apart, 0.25'' diameter At opposite end of holes, interfaces with wheels Interfaces with Part G and H via welds	Cutting to size Drilling holes Countersinking holes Grinding edges of part Welding to Part G and H
G	4	Small	Interfaces with Part F via welds Welded on both ends	Cutting to size Welding to Part F
H	2	Small	Interfaces with Part F via welds Welded on both ends	Cutting to size Welding to Part F

The overall dimensions and length of each part was determined from Chapter 2. Parts that required a bend had 12 inches added **per bend**. This was recommended by the undergraduate laboratory machine shop technicians to account for uncertainties in the bend process – it was unsure how much material the bend would consume. Table 31 summarizes the size, quantity, and overall length of each part.

Table 31: Part-list for purchasing material including size designation, quantity, and length of part

Part	Size (Diameter)	Quantity	Length Per Piece
A	Small	2	6''
B	Large	2	24''
C	Large	2	64''
D	Small	4	10''
E	Small	2	76''
F	Large	4	36''
G	Small	4	28''
H	Small	2	30''

4.2.1.2 Procuring the Components for the Aluminum Frame

Based on the stress analysis, the FEA, and our design reviews with the mechanical technicians we concluded that the aluminum tubing should meet certain size requirements. We decided to procure two different tube sizes that could be telescopic. The technicians informed us that for a clean, sliding fit, a minimum of 1/8'' clearance should be present between the outer diameter of the internal tube and the inner diameter of the external tube. The prototype required that the tubes not be greater than 1.5'' in outer diameter, as this greater diameter would appear bulky and be more challenging to create bends. Additionally, it was preferred that the wall thickness of the tubes be at least 0.125'' because tubes with a smaller wall thickness are more likely to break during bending.

After considering these factors, along with the availability and cost of aluminum, we found two compatible pipe sizes:

1. Larger pipe – 1.050'' outer diameter, 0.113'' wall thickness

2. Smaller tube – 0.75'' outer diameter, 0.120'' wall thickness

Although the wall thickness was smaller than 0.125'', we were unable to purchase aluminum of a larger wall thickness that could still be telescopic and not exceed 1.5'' outer diameter.

It should be noted that the difference between pipes and tubes is that tubes are manufactured to have a precise outer diameter, and pipes are manufactured to have a certain transportation capacity. For the context of our capstone project, these words are used interchangeably.

4.2.1.3 Bending the Frame

Pipes were bent by fitting them into a die that corresponded to their outer diameter. The die had a specific circular radius that are sold according to the diameter of the tube being bent to avoid them fracturing. The tube-bender mechanism bent the pipes incrementally, less than 5 degrees at a time. The small increments are to avoid fractures that occur during high strain rates.

Prior to bending each pipe, a test-pipe was marked in inch-long increments. The technicians were unsure of the bend radius as well as where the bend would begin; these values varies with different diameter pipes and was also set-up specific. The test-pipe was inserted into the tube-bender at a set, repeatable landmark, and bent to 90 degrees. Once removed from the die, it was noted: 1. Where the bend started and 2. How much material was consumed by the bend (how many inch-long marks before the bend ended). This process was repeated for both the smaller and larger pipe designation.

Pipes that required bends are summarized in Table 32 below. Overall, there were 4 components in the larger diameter size that needed to bent and 2 components in the smaller diameter size. A total of 10 bends were required to be executed.

Table 32: Bends required for each part

Part	Size	Quantity	Number of Bends
B	Large	2	1
C	Large	2	2
E	Small	2	2

Challenge 1: Incorrect Outer Diameter

Our first challenge was that the pipe size purchased for the larger diameter designation was slightly too large for the corresponding die. Tubes and pipes are sized differently – tubes have specific **outer** diameters while pipes have specific **inner** diameters. The die was specified for a **tube** with a diameter of 1 inch. Our purchased pipe was a **pipe** with a **nominal diameter** of 1 inch, but an overall outer diameter of 1.05 inches. The additional 0.05 inches of the diameter made it unable to fit into the tube-bender. In order to resolve this issue, we lathed down the larger-diameter parts that would be bent: Part B and Part C.

When setting the lathe for the pipe, we discovered that Part C was too long for the lathe; a significant length of the pipe stuck out of the opposite side of the lathing jaws. During lathing, the workpiece turns, while a linearly-moving tool machines the surface of the part. Since the part is what was rotating, we were concerned with cyclical fatigue causing the pipe to fracture. The weight of the pipe overhanging would create a moment that would result in fully reversible bending stresses when rotating. In order to minimize these stresses, and the moment, we constructed a set-up to support the back end and limit the oscillations of the pipe. As well, during machining, we used a moveable support piece to minimize chatter and excessive oscillations.

Figure 53: Long Pipe in Lathe

Challenge 2: Strain-Hardening and Fracturing During Bending

Our second challenge was that the pipes kept fracturing during bending around the 10-degree point. We initially tried bending the pipes by heating the aluminum with a heat gun and greasing the outside with lubricant. However, our test-bends fractured twice. In order to resolve this issue, we heated the pipes with an oxy-acetylene blow torch and tested the temperature of the pipe with a wax-crayon that melted at 600C, which corresponded to the melting point of aluminum. We fixed the pipes in a jack and ran the torch over the surface continuously to heat it evenly. One point of concern was the length of the pipe; unheated aluminum would act as a heat sink and draw the heat away from the region that we were bending. To account for this, we attempted to heat all of the part that was being bent.

While heating the pipe, we would periodically test the temperature by touching the crayon to the surface of the aluminum. Once the crayon liquified and melted onto the pipe, we stopped torching. The hot pipe was moved into the tube-bender using pliers and thermal gloves. As the pipe was being slid into the bended, it was greased. As well, the die was heated with the heat-gun while the pipe was being torched. This avoided the die acting as a heat sink and consuming the heat inside the pipe. The pipe was aligned as closely as possible with pre-made marks.

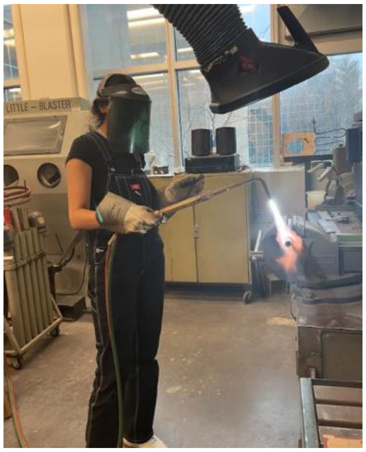


Figure 54: Annealing Material to Increase Ductile Properties

It was difficult to make the bends consistent with each other. Once the pipe was heated, ash and combustion products coated the surface of the pipe which made it difficult to distinguish pre-made marks. As well, the need to move quickly to avoid heat dissipating made it challenging to verify the precision of our alignment. As a result, the left and right sides of Part C have a different internal length.

4.2.1.4 Drilling Adjustment

To make the device height-adjustable, holes were drilled using the milling machine. When using the milling machine to drill holes, a series of steps must be followed for each workpiece:

1. Secure the workpiece into the vice.
2. Use the edge finder to locate the datum of the workpiece (all dimensions will be referenced from this 'zero' point). The edge finder has an RPM of 1000.
3. Determine the material being cut, determine its cutting speed.
4. Determine the diameter of the hole being cut.
5. Calculate the cutting RPM (spindle speed):

$$RPM = 4 * \frac{CS}{OD}$$

*For **drilling**, RPM is **halved***

Sample calculation – for aluminum CS (cutting speed) = 200 surface feet per minute (SFM). For holes 0.272'' in diameter, the RPM is:

$$RPM = 4 * \frac{200}{0.272}$$

$$RPM = 2941$$

For drilling

$$RPM = 1471$$

6. Determine the desired type of fit in order to determine the drill bit needed. This will depend on how many interfacing components are involved and will dictate which drill size to use.
7. Use the center drill to make an indent on the workpiece where the hole will be located.
8. Use the drill to create the hole.

For this project, letter drill sizes were used, as shown in Table 33 below:

Table 33: Letter Drill Sizes for Imperial Holes

Drill Size	Inch
A	0.234
B	0.238
C	0.242
D	0.246
E	0.250
F	0.257
G	0.261
H	0.266
I	0.272
J	0.277
K	0.281
L	0.290
M	0.295
N	0.302
O	0.316
P	0.323

The following holes were made for each part:

Table 34: Hole Specifications

Part Identity	**Image**	**Holes**	**Spindle Speed (RPM)**
A		• 5 holes • 0.75'' apart • Large clearance fit for telescoping poles – drill size 'I' – selected for 0.25'' fastener	1471

B		• 5 holes • 0.75'' apart • Large clearance fit for telescoping poles – drill size 'I' – selected for 0.25'' fastener	1471
C		• 2 holes on each side • 0.75'' apart • Large clearance fit for telescoping poles – drill size 'I' – selected for 0.25'' fastener	1471
D		• 2 holes • 0.25'' apart • Large clearance fit for telescoping poles – drill size 'I' – selected for 0.25'' fastener	1471
E		• 8 holes on each side • 1.20'' apart • Large clearance fit for telescoping poles – drill size 'I' – selected for 0.25'' fastener	1471
F FRONT		• 10 holes • 1.20'' apart • Large clearance fit for telescoping poles – drill size 'I' – selected for 0.25'' fastener	1471
F BACK		• 10 holes • 1.20'' apart • Large clearance fit for telescoping poles – drill size 'I' – selected for 0.25'' fastener • 1 hole • 0.5'' from bottom • Smaller clearance fit required, does not telescope – drill size 'O' – selected for 0.30'' fastener	1471 1266

For parts C and E, it was critical that the holes on both sides were aligned. A more in-depth vice had to be used to achieve this, along with a level. To ensure that the component was symmetrical, the pipes were grinded after milling.

Figure 55: Grinding Apparatus

4.2.1.5 End-Milling

Components being welded needed to be end milled. The spindle speed calculation is the same as previous:

$$RPM = 4 * \frac{CS}{OD}$$

For end-milling, the CS is still metal dependent (200 SFM for aluminum), and the OD is equal to the outer diameter of the pipe.

Table 35: End-Mill Specifications

Part Identity	Image	Interfacing Part	Spindle Speed (RPM)
B	 *	C	760
D		E	1067

Note: Since Part G and Part H (support bars) were 0.75’’ (outer diameter) and being welded to 1.05’’ (outer diameter), they did not need to be end milled. The larger diameter enveloped the entire cross-section.

*Part B was initially end-milled but based on the bend radius (3’’ – unable to be altered based on bending dye available), the device would be too narrow to house the user’s chest breadth. The end-milled region was cut off using the horizontal bandsaw.

Figure 56: Challenge with End-Mill on Part B

Figure 57: Resolution for Part B

Part B was instead double-fillet edge welded to Part C. Part C and D were also cut using the horizontal bandsaw to allow for additional space; internal width adjustment only had two holes, allowing for 0.75’’ of adjustability.

Figure 58: Part C in Horizontal Bandsaw

4.2.1.6 Post-Processing and Safety

As a safety measure, all pieces were chamfered using the grinder. An example of a piece with many burrs that would be dangerous to touch is shown below:

Figure 59: Tube with Burrs

Additionally, all holes were countersunk using the drill press to remove sharp edges.

Figure 60: Countersunk Holes

4.2.1.7 Wheels and Hand-Brakes

Wheels, without additional mounting components, would have cost roughly $25 to purchase each. A walker, with 4 wheels, mounting components for universal wheels, and a fully functional mechanical hand-brake cost roughly $120. Due to budget limitations, we decided to purchase an existing walker and dismantle it for parts. We initially purchased the Medline MDS86860EBS8 steel rollator. However, as shown in Figure 61, the front universal wheels were mounted by being welded onto the walker. While it was possible to detach the wheels with a bandsaw, since our frame was constructed out of aluminum, it would have been possible to re-weld the wheels onto our frame. We decided that it would not possible to dismantle this walker and salvage the parts so we returned it.

Figure 61: Medline MDS86860EBS8 rollotor. Welded universal front wheels shown on right [12].

We purchased the Medline MDS86850EBS8 steel rollator as a replacement. As shown in Figure 62, both the front and back wheels appeared to be bolted rather than welded.

Figure 62: Medline MDS86850EBS8 rollator. Bolted universal front wheels shown on right [13].

The universal front wheels had a spring-steel insert that prevented the removal of the rotating attachment. A through punch was used to hammer out the insert and the wheels were removed. A threaded insert was required to bolt the rotating casing into the bottom of the standing frame. We made the threaded insert out of steel machined to a press-fit size. The friction between the internal walls of the pipe and the insert would prevent the insert from moving.

A cylindrical piece was machined to the internal diameter of the pipe with an additional 0.002 inches to create the press fit. The bolt used to attach the universal wheels to the walker, as shown in Figure 63, was sized to be an M12 bolt. The insert was drilled and reamed in the lathe to create the corresponding threads along the internal surface.

Figure 63: Bolt connecting universal wheels to walker, sized as M12

Once the piece was lathed to size, drilled, and reamed, it was cut into two separate pieces approximately 1.5cm in length. The finished inserts are shown in Figure 64 below.

Figure 64: Finished lathed, drilled, and reamed inserts to connect universal wheels to frame

Part F, as shown in Figure 65 below, interfaced with the wheels. The back wheels were attached on the sides of Part F whereas the front wheels would be attached below Part F through the bolted insert. As a result, the components at the front of the walker for Part F needed to be shorter than the components at the back of the walker. We measured the length of the universal wheel holder to be 14 cm from the edge of the insert to the center of the wheel. In order for the back wheels to be bolted 1 inch up from the end of the pipe, the front wheels were cut 14 cm and 1 inch.

Figure 65: Schematic of overall dimensions of Part F

Once cut, the inserts were hammered into the bottom of the shorter Part F pieces, as shown in Figure 66.

Figure 66: Hammered-in press-fit M12 insert in bottom of Part F (front components)

The universal wheels were then mounted via the insert and the back wheels were mounted with a bolt through the sides of Part F components.

4.2.1.8 Mounting Disc Brakes

The mechanical disc brakes were intended to interact with the linear actuators connected to the electrical system. They were mounted on the back wheels, to avoid the user tipping over the front of the walker due to forwards momentum. In order to mount the brakes, we required a part that interfaced with the wheel such that the rotation of the disc brake was constrained to the rotation of the wheel. The back wheels were 3D scanned to determine the spoke geometry. The scan was then exported as an STL file and a Boolean operation was used to cut out this geometry from a cylindrical component. As well, the brake itself was mounted via a 3D printed part to the walker frame; the brake is static relative to the walker, while the wheel rotates.

Figure 67: Disc brake and mounting on prototype.

4.2.1.9 Welding

Metal Inert Gas (MIG) welding was performed using a thin aluminum insert by Mark Mackenize in the Mechanical Library. Prior to welding, it was observed that Part H was too long. This length would have restricted the device from fitting through doors, so it was cut using the horizontal bandsaw.

The following drawing was used to indicate where welds should be located:

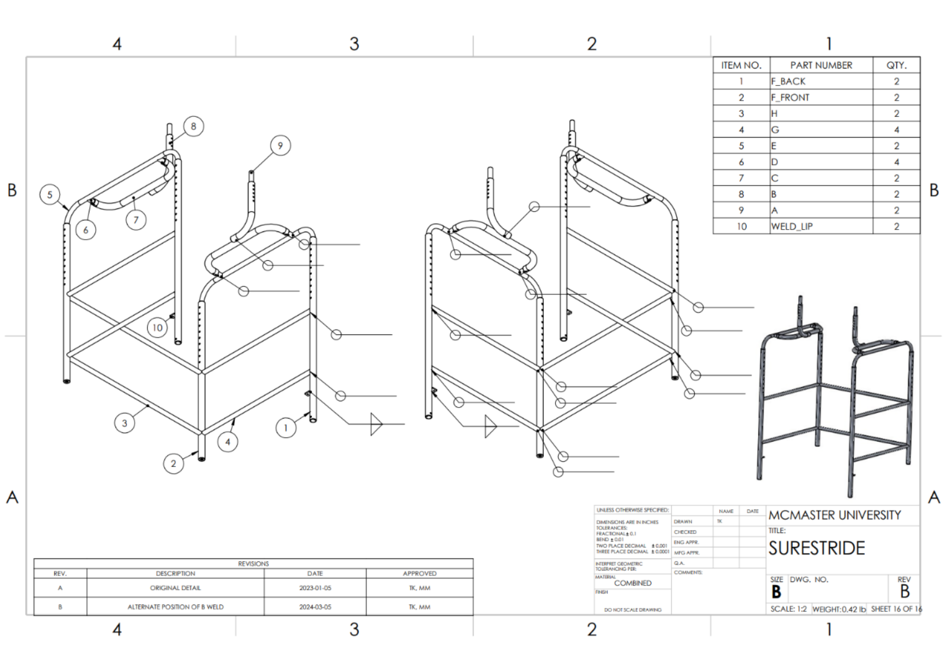


Figure 68: Weld Drawing

Before performing the complete round weld, the joint is tacked in place:

Figure 69: Tacked Weld

Once tacked, the round weld can be performed:

Figure 70: Round-Weld Image

Figure 71: Welding Procedure

4.2.1.10 Mounting Hand Brakes

Hand brakes were mounted using components from the disassembled walker in the same configuration. Holes were drilled to mount the user interface as shown in the figure below. The brakes themselves functioned using a simply lever system, where pulling on one side of the lever would compress the other. A spring was used to expand the level once released so the breaking would not be continuous. A cable connected the user interface to the brake level such that compressing the interface would generate breaking.

Figure 72: User interface with hand brake (Left), spring-lever breaking system (Right)

4.2.1.11 Electrical Housing Components

To mount the electrical components on the SureStride, models were made in Autodesk Inventor. These models were created to be bolted onto tfhe device, which was performed using a hand drill. All cases were made using PLA from the ETB design studio MK2 Prusa printers. Images can be found in Appendix B.

Since the battery had a significant weight, acrylic was purchased to make a stronger case. Unfortunately, despite procuring an adhesive specially made for acrylic, this adhesive was not strong enough to withstand the weight of the battery. To mitigate this design challenge, a 3D printed component was glued directly to the battery.

4.2.1.12 Validation

As mentioned, the primary mechanical validation concepts were the FEA (Results in Appendix B) and the comprehensive stress analysis. Both of these assessment tools confirmed that the designed device is mechanically sound for its intended application, and were previously discussed in this report.

4.2.2 Electrical Design Iteration 1: BNO055 Sensor data to Control Two Linear Actuators

In the initial phase of the SureStride project, the electrical setup underwent its first iteration, focusing on key components to enable the system's basic functionality. The primary objective was to gather data from two BNO055 sensors and utilize this information to control the movement of linear actuators, thereby initiating braking mechanisms.

The ESP32 microcontroller was chosen for processing sensor data and generating control signals. The BNO055 sensors provided crucial input regarding the orientation and movement of the walker.

Through interfacing with the microcontroller, these sensors facilitated real-time monitoring of the walker's motion, allowing for responsive adjustments.

In response to the sensor data, the microcontroller interfaced with a motor driver unit. This interaction activated the linear actuators, which served as the primary means of initiating braking actions. These linear actuators were positioned to pull on an attached cable connected to a disk brake system, directly influencing the braking mechanism of the walker's wheels.

4.2.2.1 Building Design Iteration 1

This section focuses on ensuring reproducibility by detailing crucial aspects of the project.

Wiring Diagram

The following schematic highlights the wiring of the designed circuit consisting of two BNO055 sensors, an ESP32 microcontroller (powered by the computer via a wired connection), a motor driver, and two linear actuators powered by a 12 V DC supply.

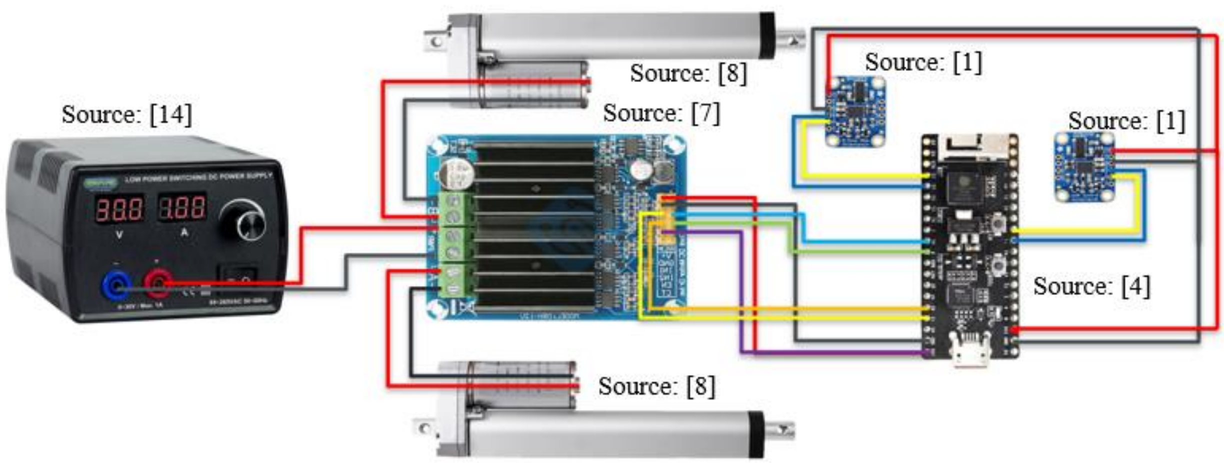


Figure 73: Circuit Wiring for Iteration 1

1. Pin Connections

The table below illustrates the pin connections for all components connected in the circuit.

Table 36: Iteration 1 Pin connections

ESP32 Pin	Connection
5	Red LED
9	Motor Driver IN2A
10	Motor Driver IN1A
18	Yellow LED
21	SDA BNO055 1
22	SCL BNO055 1
25	Motor Driver IN1B
26	Motor Driver IN2B

27	Green LED
32	SCL BNO055 2
33	SDA BNO055 2
BNO055 Pin	**Connection**
Vin	ESP32 3V3
GND	GND
SDA	ESP32 Pin 21 and 33
SCL	ESP32 Pin 22 and 32
Motor Driver Pin	**Connection**
VINA	ESP32 3V3
VINB	ESP32 3V3
GND	GND
IN1A	ESP32 Pin 10
IN1B	ESP32 Pin 25
IN2A	ESP32 Pin 9
IN2B	ESP32 Pin 26
ENA	ESP32 3V3
ENB	ESP32 3V3
A+	Linear Actuator 1 (+)
A -	Linear Actuator 1 (-)
B +	Linear Actuator 2 (+)
B -	Linear Actuator 2 (-)
PWR +	12 V DC Supply (+)
PWR -	DC Supply (-)

2. Device Logic Flowchart

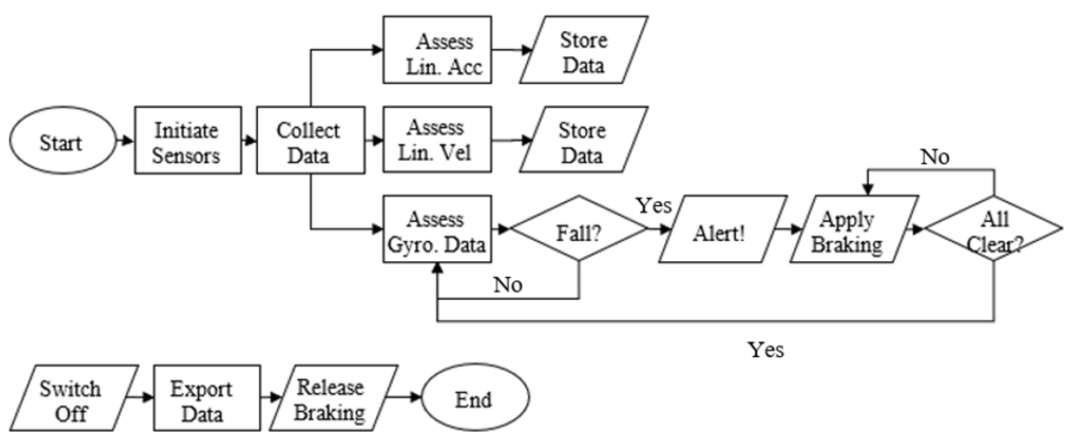


Figure 74: Flowchart for Device Iteration 1

3. <u>High Level Block Diagram</u>

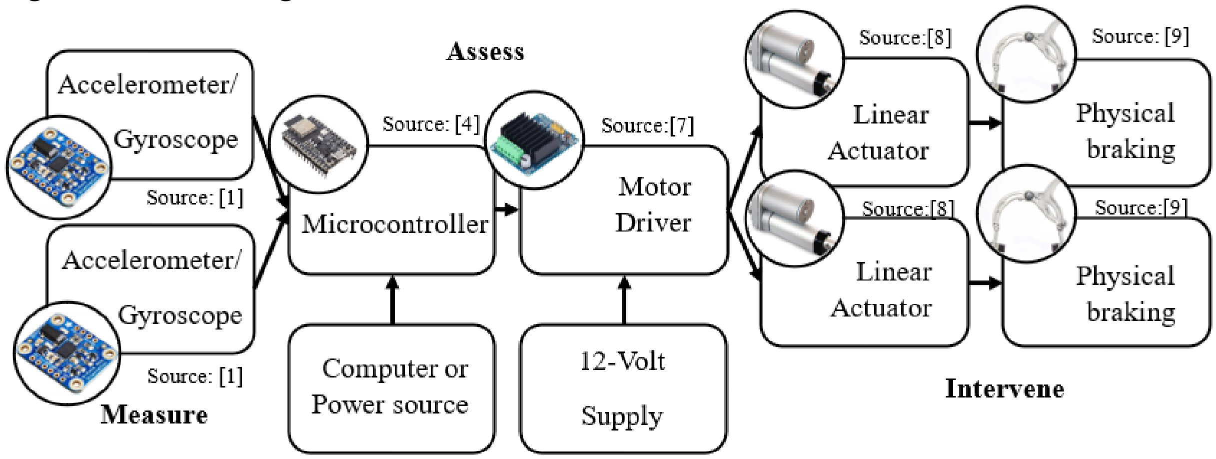


Figure 75: High Level Block Diagram for Iteration 1

4. <u>Pseudocode</u>

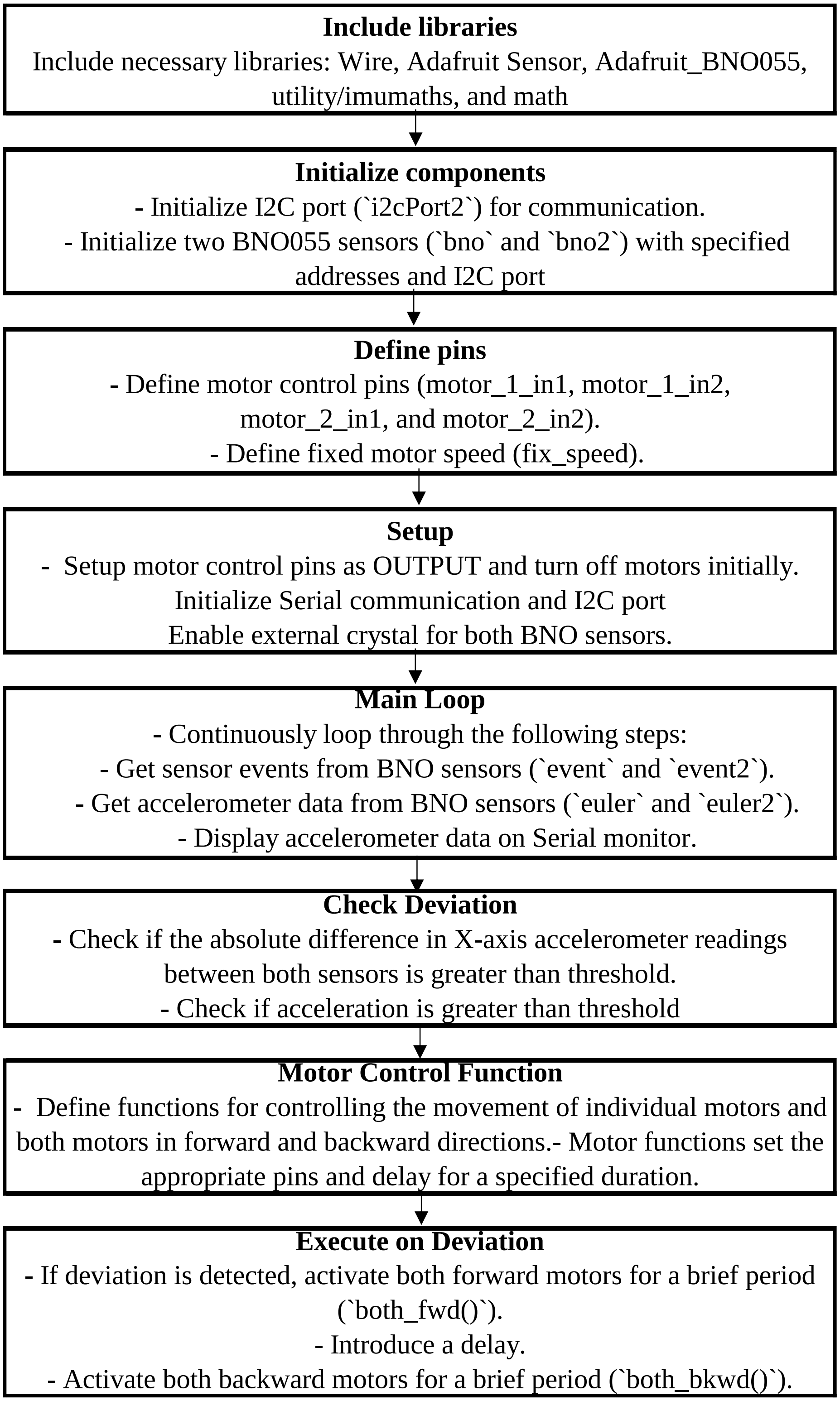


Figure 76: Pseudocode for Iteration 1

4.2.2.2 Testing and Validating Design Iteration 1

This section will include a comprehensive test plan detailing specific tests for circuit wiring accuracy, pin connection integrity, flowchart functionality, high-level block diagram coherence, and pseudocode logic validity.

1. Test Plan and Experimental Setup

   To ensure all components of the design are tested for functionality and interaction with other components, a comprehensive test plan was developed. The following table outlines the objectives for the tests.

Table 37: Test Plan for Design Iteration 1

Test case	Objective
Integration of sensors and microcontroller	
1	Verify the connectivity and the accurate functioning of BNO055 sensors.
2	Verify the connectivity and the accurate functioning of the ESP32.
3	Verify accurate data transmission from the sensors to ESP32.
Integration of linear actuators, motor driver and microcontroller	
4	Verify the working of the linear actuators
5	Verify the connection between the motor driver and ESP32
6	Verify the logic to control the linear actuators incrementally

2. Test Cases and Results

The following table outlines the achieved results for each of the test cases executed.

Table 38: Test Cases for Design Iteration 1

Test case	Procedure	Expected Result	Obtained Result
Integration of sensors and microcontroller			
1	• Connect the BNO055 sensors to ESP32 according to the pin connections in Table 36. • Run code given in Appendix BIV. Defensive code is included to display "Oops, no BNO055 detected…. Please check your connection" in case the SDA and SCL are not connected.	• The green LED on both BNO055 sensors should turn ON indicating that the sensors are powered. • This statement should not be displayed on the serial monitor in case of a successful connection.	• The green LED on both BNO055 turned ON indicating that the sensors are powered. • BNO055 readings displayed without the defensive statement.
2	• Use example code given in Appendix BV to determine the status of the ESP32 microcontroller.	• The code should upload without any errors, indicating that the computer can successfully connect to the COM port and the device. • The serial monitor should display all available Wi-Fi networks.	• Code uploads and runs without errors. • Serial monitor displays available Wi-Fi networks.
3	• Connect the BNO055 sensors to ESP32 and run code given in Appendix BIV. • Note the initial readings of the sensor and turn both sensors by approximately the same amount and in the same direction.	• Both sensors should display readings for X, Y and Z data. • A similar change should be observed in the readings when the sensors are turned.	• Both sensors display X, Y and Z data. • Similar changes in data readings are obtained as sensors start from absolute orientation of ~ 0, 0, 0.
Integration of linear actuators, motor driver and microcontroller			
4	• Connect the 12V linear actuators directly to a 12V DC supply • Switch the leads and connect to DC supply	• The linear actuators should shorten in length • Upon switching, the actuators should extend in length.	• Linear actuators contract in length • Linear actuators extend in length when leads are switched.

5, 6	• Connect the motor driver according to the pin connections given in Table 36. • Fully extend the linear actuator in length and then run code given in Appendix BVI to determine how the ESP controls the linear actuators through the motor driver.	• The blue LED on the motor driver should light signalling that it is powered. • The linear actuator should shorten in length in increments depending on the time defined in the code.	• The blue LED on the motor driver turns ON signalling successful powering of the device. • The linear actuator incrementally shortens in length in increments according to the defined time.

Given the results in the table above, iteration 1 of the prototype passes all designed tests, demonstrating seamless integration and functionality of sensors, microcontroller, linear actuators, and the motor driver. The resistive braking system functions effectively at different intensity levels.

The experimental setup used to test the cases is shown below:

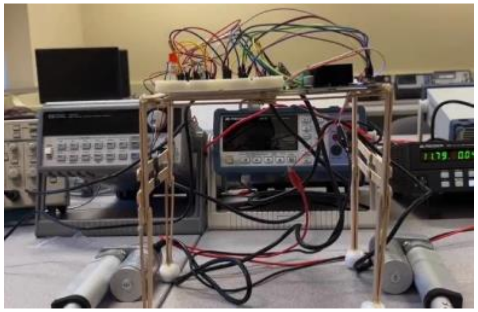


Figure 77: Experimental Setup for Design Iteration 1

3. <u>Discussion</u>

   Iteration 1 demonstrates effective integration and functionality of sensors, microcontroller, linear actuators, motor driver, and power components. However, several limitations and constraints were identified during the iteration, which need to be addressed in Iteration 2 to enhance the system's performance and usability:

a. User interface: The lack of a dedicated user interface, such as an LCD screen, limits the device's usability and user interaction capabilities. Without visual feedback, users may find it challenging to understand the device's status and make informed decisions.
b. Power Management: Iteration 1 did not incorporate a dedicated DC/DC converter to regulate the voltage from the 12V battery to the required 3.3V for powering the microcontroller and other components. This needs to be addressed to make the device portable and have a compatible and stable power supply.
c. Battery Integration: The absence of a battery in Iteration 1 restricts the device's portability and independence from external power sources. Integrating a battery is crucial for enabling mobile use cases and ensuring continuous operation even in the absence of a direct power supply.

For the second iteration of the electrical design, the focus will be on addressing the identified limitations and constraints from Iteration 1 to enhance the system's functionality and user experience.

4.2.3 Electrical Design Iteration 2: Sensor-Controlled Actuators with LCD Display

Design Iteration 2 marks the next phase of development in the evolution of the fall-preventative braking system. Building upon the foundation laid in Iteration 1, this iteration introduces significant enhancements aimed at addressing identified limitations and constraints to further refine the system's functionality and usability. Iteration 2 focuses on integrating an LCD for enhanced user interface, incorporating a dedicated DC/DC converter to optimize power management, and integrating a battery to enhance portability and autonomy.

4.2.3.1 Building Design Iteration 2

1. Updated Wiring Diagram

The updated wiring diagram, including the LCD, the portable battery and the DC/DC converter is presented in the figure below.

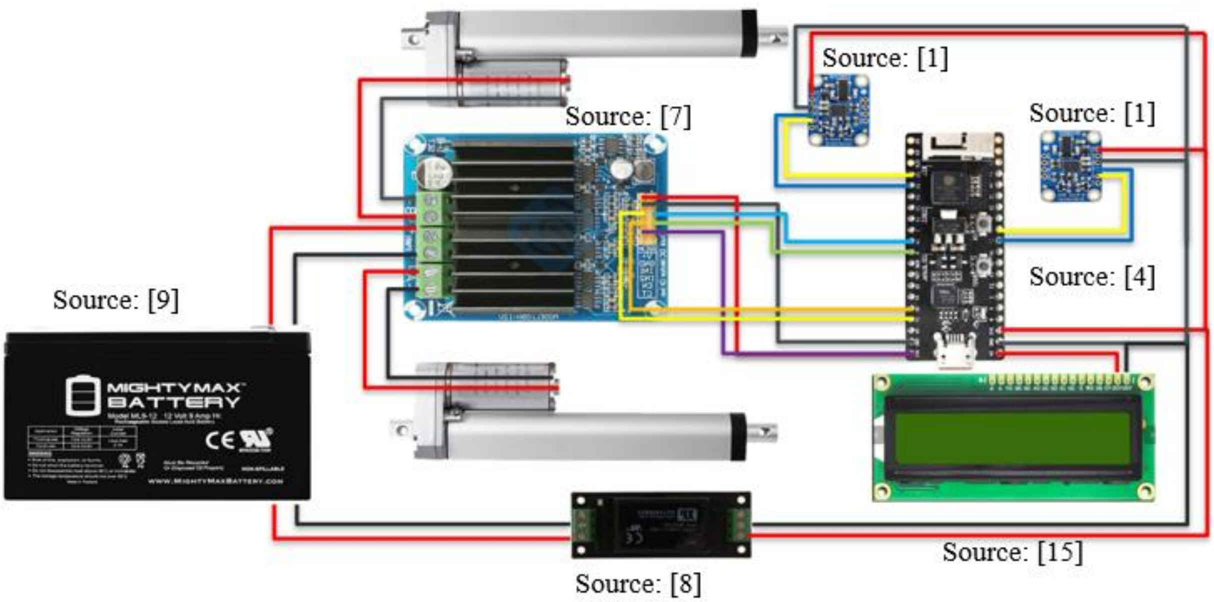


Figure 78: Updated Circuit Wiring for Iteration 2

2. Updated Pin Connections

The updated pin connections needed for the incorporation of the LCD, buck converter and the 12 V battery are presented in the table below.

Table 39: Updated Pin Connections for Iteration 2

ESP32 Pin	Connection
3V3	DC-DC V_{out}
GND	DC-DC GND (out), LCD V_{ss}
5V	LCD V_{dd}

5	Red LED
9	Motor Driver IN2A
10	Motor Driver IN1A
18	Yellow LED
21	SDA BNO055 1
22	SCL BNO055 1
25	Motor Driver IN1B
26	Motor Driver IN2B
27	Green LED
32	SCL BNO055 2
33	SDA BNO055 2
BNO055 Pin	**Connection**
V_{IN}	ESP32 3V3
GND	GND
SDA	ESP32 Pin 21 and 33
SCL	ESP32 Pin 22 and 32
Motor Driver Pin	**Connection**
$V_{IN}A$	ESP32 3V3
$V_{IN}B$	ESP32 3V3
GND	GND
IN1A	ESP32 Pin 10
IN1B	ESP32 Pin 25
IN2A	ESP32 Pin 9
IN2B	ESP32 Pin 26
ENA	ESP32 3V3
ENB	ESP32 3V3
A+	Linear Actuator 1 (+)
A -	Linear Actuator 1 (-)
B +	Linear Actuator 2 (+)
B -	Linear Actuator 2 (-)
PWR +	12 V Battery (+)
PWR -	12 V Battery (-)
DC-DC Converter Pin	**Connection**
V_{in}	12 V Battery (+)
GND (in)	12 V Battery (-)
V_{out}	ESP32 3V3
GND (out)	ESP32 GND
LCD Pin	**Connection**
V_{ss}	ESP32 GND
V_{dd}	ESP32 5V
SDA	ESP32 Pin 19
SCL	ESP32 Pin 23

12V Battery Pin	Connection
12 V Battery (+)	DC-DC V_{in}, Motor Driver PWR +
12 V Battery (-)	DC-DC GND, Motor Driver PWR -

3. Updated High-level Block Diagram

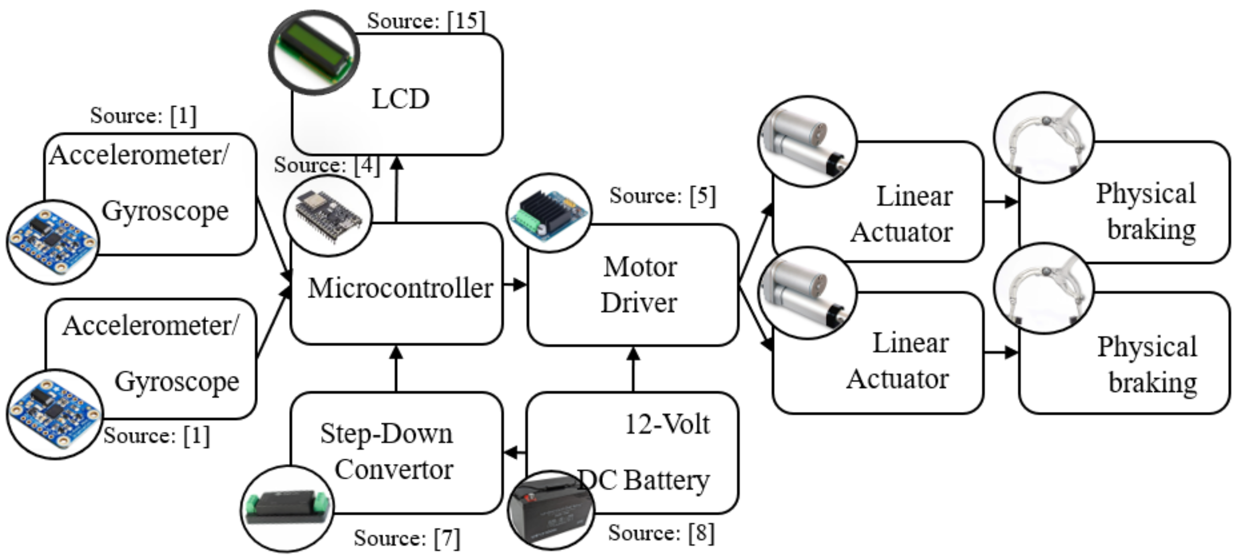


Figure 79: High-level Block Diagram for Iteration 2

4.2.3.2 Testing and Validating Design Iteration 2

In testing Design Iteration 2, we build upon the foundation established in Iteration 1, where successful integration and functionality of key components such as sensors, microcontrollers, linear actuators, and motor drivers were confirmed.

1. Test Plan and Experimental Setup

To ensure all components of the design are tested for functionality and interaction with other components, a comprehensive test plan was developed *in addition* to the test plan defined in Table 37 for iteration 1. The following table outlines the objectives for the tests.

Table 40: Test Plan for Design Iteration 1

Test case	Objective
Integration of the power management components (DC-DC converter and 12 V Battery)	
1	Verify the connectivity and the voltage of the 12 V battery.
2	Verify the connectivity and the input/output voltage of the DC-DC converter.
Integration of the LCD as User Interface	
3	Verify the working of the LCD
4	Verify the connection between the LCD and ESP32

1. Test Cases and Expected Results

The following table outlines the achieved results for each of the test cases above.

Table 41: Test Cases for Design Iteration 2

Test case	Procedure	Expected Result	Obtained Result
Integration of the power components (DC-DC converter and 12 V Battery)			
1	• Use a voltmeter to confirm the output voltage by connecting the leads to the positive and negative terminals of the battery	• The voltmeter should read 12 V.	• The voltmeter reads 12 V
2	• Connect the DC-DC step down converter to the ESP32 and the 12 V battery according to the pin connections in Table 36. • Use a voltmeter to confirm the output voltage of the buck converter by connecting the leads to the input side. Repeat by doing the same at the output side.	• The voltmeter reading for the input side should be ~12 V. • The voltmeter reading for the output side should be ~3.3 V	• The voltmeter reading for the input side is 12.09 V. • The voltmeter reading for the output side is 3.301 V
Integration of the LCD as User Interface			
3,4	• Connect the LCD to ESP32 according to the pin connections in Table 39. • Run the script in Appendix BVII to ensure the proper working of the LCD with the microcontroller.	• The LCD should light up signalling successful powering up. • The LCD should display "Hello World!"	• The LCD lights up signalling the successful powering up. • The LCD displays anomalies or erratic behavior.

Given the results in the table above, iteration 2 of the prototype passes 3 out of the 4 designed tests. The failure of LCD to correctly transfer data and have proper communication with the microcontroller can be attributed to the mismatch in the voltage levels between the ESP32 (3.3V input) and the LCD (5V input). Upon further research, we discovered that connecting the ESP32 directly to a 5V LCD without voltage level-shifting may expose the microcontroller to excessive voltage levels, potentially damaging its pins or internal components. Some potential solutions to this problem include using appropriate level-shifting or voltage regulation techniques to ensure compatibility between the 5V LCD and the 3.3V ESP32 to protect both components from potential damage.

3. Discussion

Upon analyzing the limitations of the current design, several areas for improvement and additional features have been identified. Firstly, the LCD, although eventually functional, is not an effective user interface due to its small size and potential usability issues, especially for seniors. Therefore, it has been decided to include a switch panel with intuitive LEDs resembling traffic lights—green when the device is ON, yellow to signal for minor braking, and red for major braking. This will provide a more user-friendly interface and enhance the overall user experience.

Furthermore, during the assembly of the device, it became apparent that the battery and component housing obstructed the user's line of sight, making it challenging to see the area ahead. To address this issue, the inclusion of an object detection or obstacle detection system, such as a distance sensor, is being considered. This addition will enable the device to detect obstacles in the user's path and provide timely alerts, enhancing safety and usability.

Additionally, during the testing, it has been recognized that personalized calibration is essential to optimize the device's performance according to the user's individual measurements, such as acceleration and wobble. Therefore, the next steps will include developing a calibration routine to tailor the device to the user's specific requirements, ensuring optimal functionality and effectiveness.

4.3 Future Work

4.3.1 Future Mechanical Work

There are many alterations that could be made to this design. To enhance user safety, a feature could be implemented that notifies emergency services if a fall is experienced and the user cannot get up. To make the design more equitable, the height/width adjustments could be made continuous rather than incremental. This would allow a better fit for users, and this could be applied to the currently un-adjustable forearm distance as well. Additionally, the internal chest breadth dimension could be optimized to allow for more internal width adjustment.

Originally, the project was intended to be a collapsible mechanism. If more time or resources were permitted, it would have been interesting to make a collapsible/portable device that is also adjustable. It could also be an interesting approach to implement a portable ramp mechanism that could be used outdoors for curbs or busses. Likewise, a seat could be added so that the user could easily rest when needed, and a fall prevention mechanism could be implemented that mitigates the impact of a fall after it has already been initiated.

Additionally, at the iBioMed showcase, one community stakeholder shared with us that he thinks this device could have alternative applications outside of nursing homes. He shared that after he underwent brain surgery he had to start walking very soon afterwards and required help from others. It would be interesting to investigate alternative applications for the verified design.

4.3.2 Future Electrical Work

In terms of next steps for electrical integration in the walker, there are several areas in which the system's performance can be further developed. For sensors, the addition of a velocity sensor would be beneficial to assess the user's speed and detect potential falls through this modality. Although the acceleration data can be used to estimate this, having the raw data would be more accurate. Additionally, the current design only uses the time-of-flight sensor to detect object approaching the walker from directly in front of it. A new iteration of the design could incorporate views at an angle to detect objects approaching from oblique angles. Further, optimizing the device's power source to a higher efficiency battery with an easier charging mechanism would make the prototype more user friendly and decrease the weight of the walker. Additionally, stakeholders have identified another area of concern in navigation. Another iteration of the design could incorporate navigation aids for walker users. Finally, the development of a simple yet effective user interface for patients and clinicians to review the recorded data is a nice addition to the design.

4.4 Reflections and Recommendations

Overall, some successes include our team's ability to navigate setbacks and adapt to problems with creative solutions. Our major setback occurred in January, when we realized that our device was not structurally sound and needed to remove our collapsible mechanism to actually manufacture it. From a mechanical perspective, the sub team frequently experienced issues during the manufacturing process including pipes breaking during bending, pipes not fitting in the bend die, our overall internal dimensions being too small, and our overall width not fitting through standard doorways. Although these were failures in the moment, we found ways to overcome them by asking for assistance from the more experienced technicians and not allowing ourselves to become unmotivated: we heated the pipes to avoid breaking, we lathed them down to the correct size, and we cut our internal pieces to accommodate the necessary widths.

Compared to the initial Gantt chart scheduling, the hurdles experienced by both electrical and mechanical sub teams forced the team to make some modifications. Primarily, the added steps in the mechanical manufacturing added time to that step which in turn delayed mechanical and electrical implementation. However, the team was able to recover from this by delaying the commencement of some of the documentation. Although not according to the initial schedule, the project was completed on time and reflected the final design.

4.4.1 Team Reflections

Elizabeth: Create a snack schedule for each meeting – it keeps things lighthearted and fun.

Namya: Open every package as you receive it – make sure you receive everything you ordered.

Taylor: If you’re a fellow mech-eng, talk to the machine shop technicians about how to build your design (/if your design is possible) *before* December!

Meera: Try to keep a good sense of humor throughout the project.

4.5 References

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[15] “Arduino - Hooking up LCD without pot.” Stackexchange.com, sa=i&url=https%3A%2F%2Felectronics.stackexchange.com%2Fquestions%2F2574%2Farduino-hooking-up-lcd-without-pot&psig=AOvVaw2N25dZ6OSlgW4urlLZI5ML&ust=1713048659109000&source=images&cd=vfe&opi=89978449&ved=0CBQQjhxqFwoTCPiK7tfhvYUDFQAAAAAdAAAAABAK (Accessed: Apr. 12, 2024).

CHAPTER 5: CONCLUSION

In conversations with stakeholders from a senior home, *Amica Dundas,* the team is interested in developing a design solution for seniors in retirement homes who require the use of assistive mobility devices (AMDs) to mitigate risks associated with falling. The most used AMDs are walkers and wheelchairs. However, both devices have significant limitations; walkers are limited in stability and possess increased fall risk, while wheelchairs limit the autonomy of the user and decrease use of the lower limbs, leading to comorbidities that lower quality of life. Due to the prioritization of user safety, those who do not have the stability for walkers are directed to use wheelchairs despite having enough strength to not need one. The team is specifically interested in addressing this gap in nursing homes to **developing an intermediate mobility device** to mitigate fall risk while providing sufficient mobility. The **social impacts** of the design are to increase the autonomy of users, and consequently, their quality of life. 35% of seniors have an abnormal gait, and the annual prevalence of falls is estimated to be 28%. Postural instability also increases with a reduced level of physical activity. The **safety and health impacts** of the design are therefore to decrease fall risk for users and allow for physical activity. The proposed solution is the *SureStride*, an intermediate mobility device between a walker and a wheelchair that stabilizes the upper body and maintains the center of mass within the base of support, reducing postural instability and providing more support than a traditional walker.

For the mechanical team, our implementation consisted of manufacturing the device out of aluminum piping and machining parts to correct specifications. Our analysis consisted of a cyclical fatigue and yield stress analysis, which our device successfully passed with a minimum safety factor of 4. Our validation also consisted of an FEA under 3 loading conditions at the most critical point. Our device also successfully passed this process. For the electrical team, the implementation consisted of the execution of automatic braking under 3 scenarios: an increased walker acceleration as detected by the BNO055 sensors, a side-to-side wobble as detected by the BNO055 sensors and the detection of an obstacle by the Time-of-Flight sensor.

Future work for the mechanical team includes making dimensional adjustments continuous rather than incremental, optimizing the internal dimensions, developing a collapsible mechanism, adding a ramp or seat for outdoor excursions, and considering alternative applications for post-operative patients. Future enhancements for the walker's electrical system include adding a velocity sensor for more accurate fall detection, expanding the time-of-flight sensor's detection angle for better obstacle awareness, and upgrading to a high-efficiency battery for user convenience and reduced weight. Improvements also aim to integrate navigation aids and a straightforward interface for data analysis by users and healthcare providers.

Appendix A: Project Management

Table 42 Stakeholder meeting dates

Date	Stakeholder
October 5, 2023	Dr. Quenneville
October 23, 2023	Jessica and Parinda (Amica Dundas)
October 16, 2023	Dr. Quenneville
November 6, 2023	Jessica and Parinda (Amica Dundas)
November 30, 2023	Dr. Quenneville
January 24, 2024	Dr. Quenneville
February 14, 2024	Dr. Quenneville

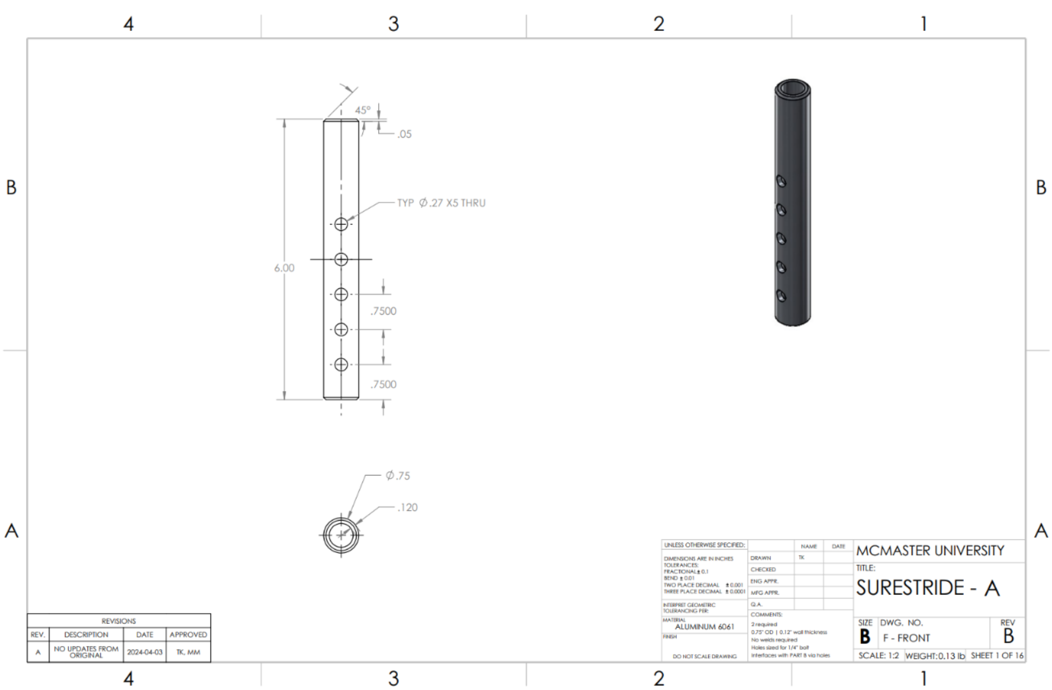
Table 43: Discipline Co-instructor meeting dates.

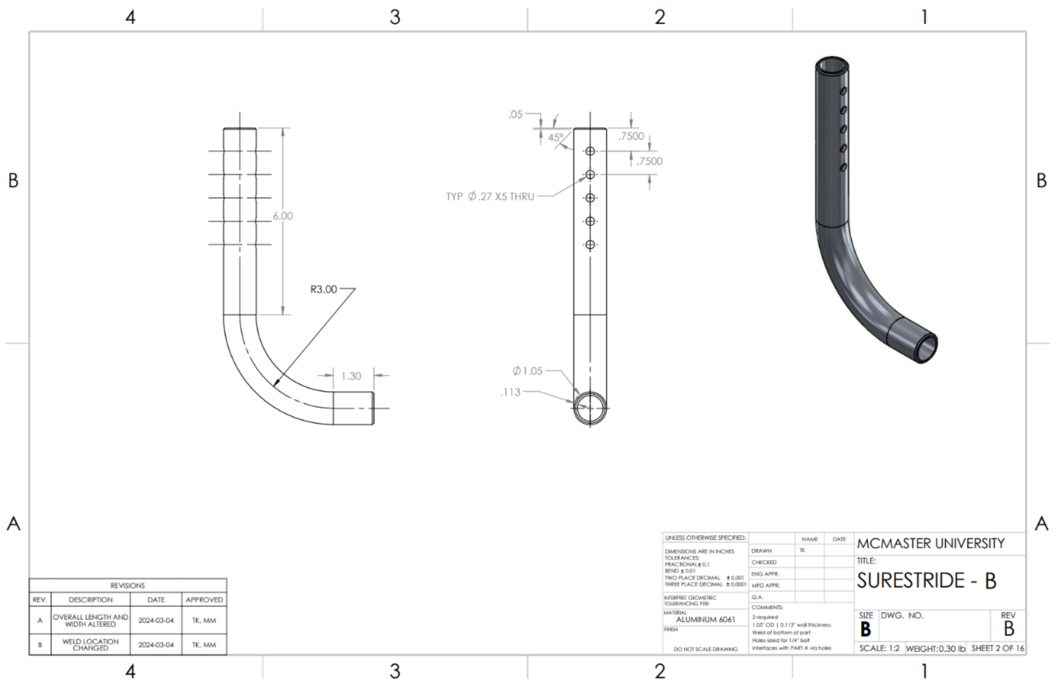
Electrical – Dr. Shirani	Mechanical – Dr. McDonald
October 5, 2023	October 4, 2023
October 19, 2023	October 25, 2024
November 2, 2023	November 1, 2024
November 16, 2023	November 15, 2024
November 30, 2023	January 19, 2024
January 17, 2024	February 16, 2024
January 31, 2024	March 1, 2024
February 14, 2024	
February 28, 2024	
March 13, 2024	
March 27, 2024	

Appendix B

Mechanical Documentation

- Appendix BI: Parts Breakdown and Manufacturing Plan

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.7500
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∅1.05
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B WELD LOCATION CHANGED 2024-03-04 TK, MM
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DIMENSIONS ARE IN INCHES
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FRACTIONAL ± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN TK
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 required
1.05" OD | 0.113" wall thickness
Weld at bottom of part
Holes sized for 1/4" bolt
Interfaces with PART A via holes
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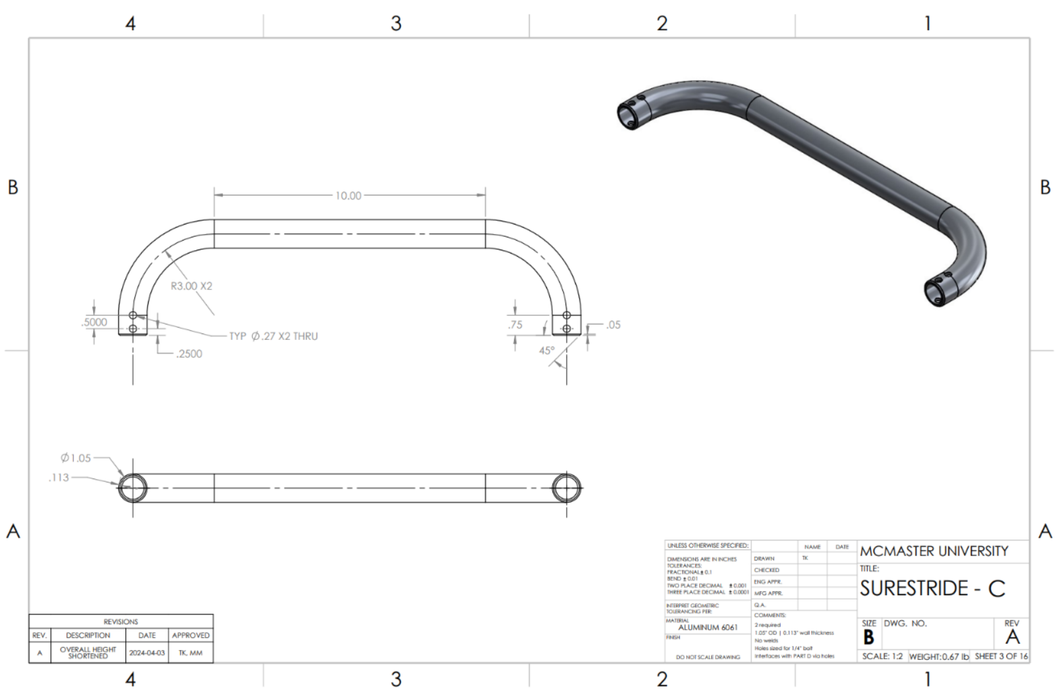
SHEET 2 OF 16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.2500
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∅1.05
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BEND ± 0.01
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THREE PLACE DECIMAL ± 0.0001
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NAME DATE
DRAWN TK
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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No welds
Holes sized for 1/4" bolt
Interfaces with PART D via holes
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REV A
SCALE: 1:2
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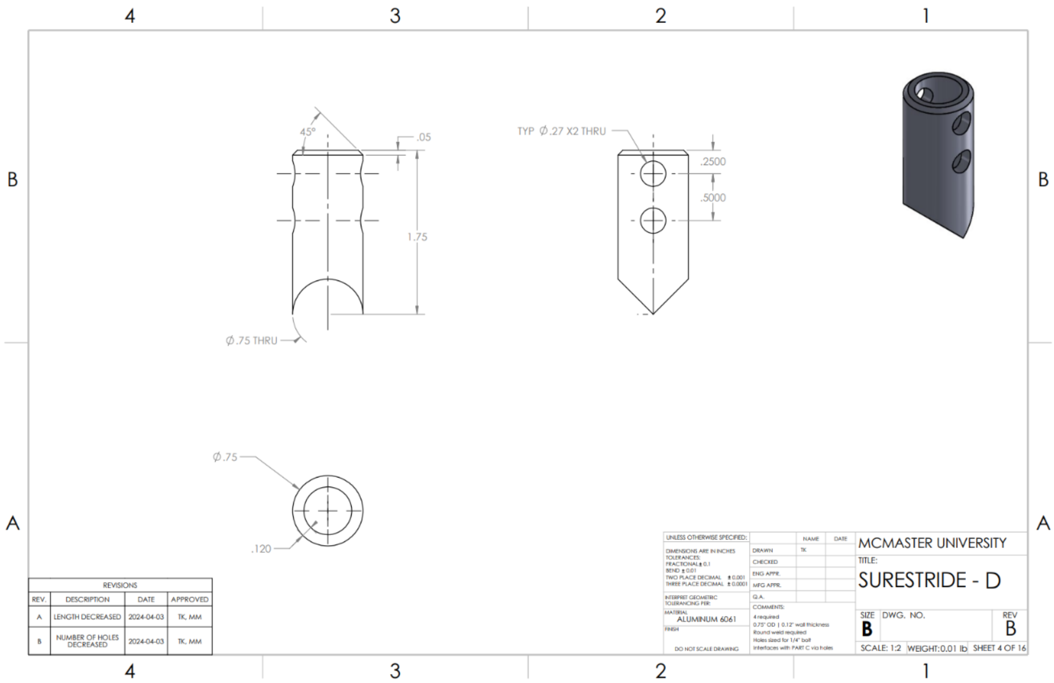
SHEET 3 OF 16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TOLERANCES:
FRACTIONAL± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN TK
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
4 required
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Round weld required
Holes sized for 1/4" bolt
Interfaces with PART C via holes
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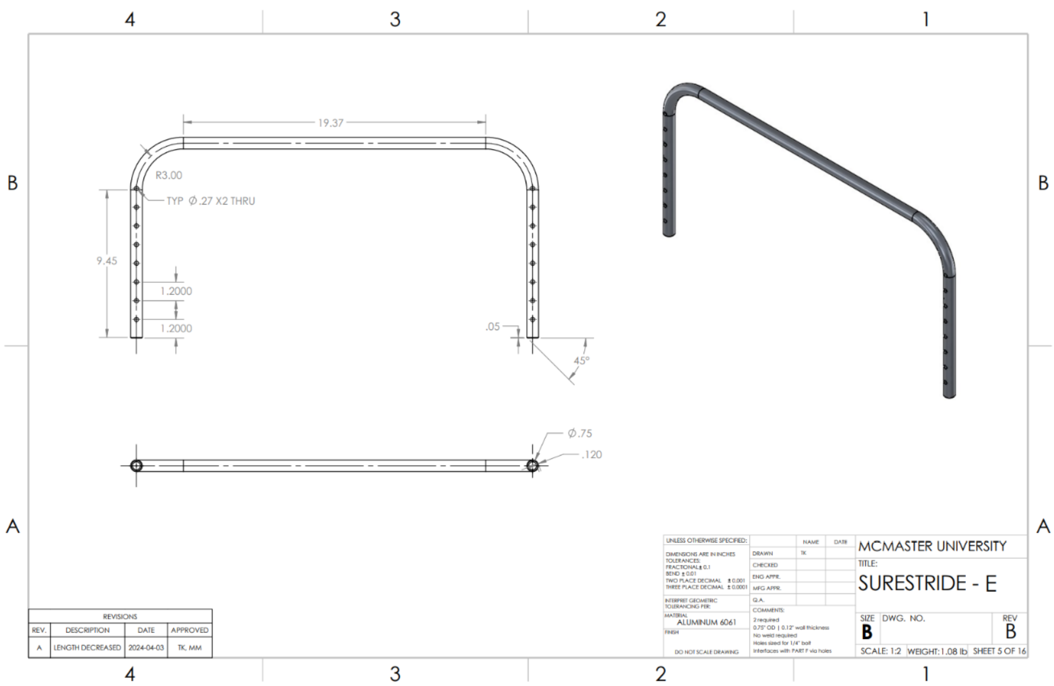
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DIMENSIONS ARE IN INCHES
TOLERANCES:
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BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
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DO NOT SCALE DRAWING
NAME DATE
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 required
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No weld required
Holes sized for 1/4" bolt
Interfaces with PART F via holes
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REV B
SCALE: 1:2
WEIGHT: 1.08 lb
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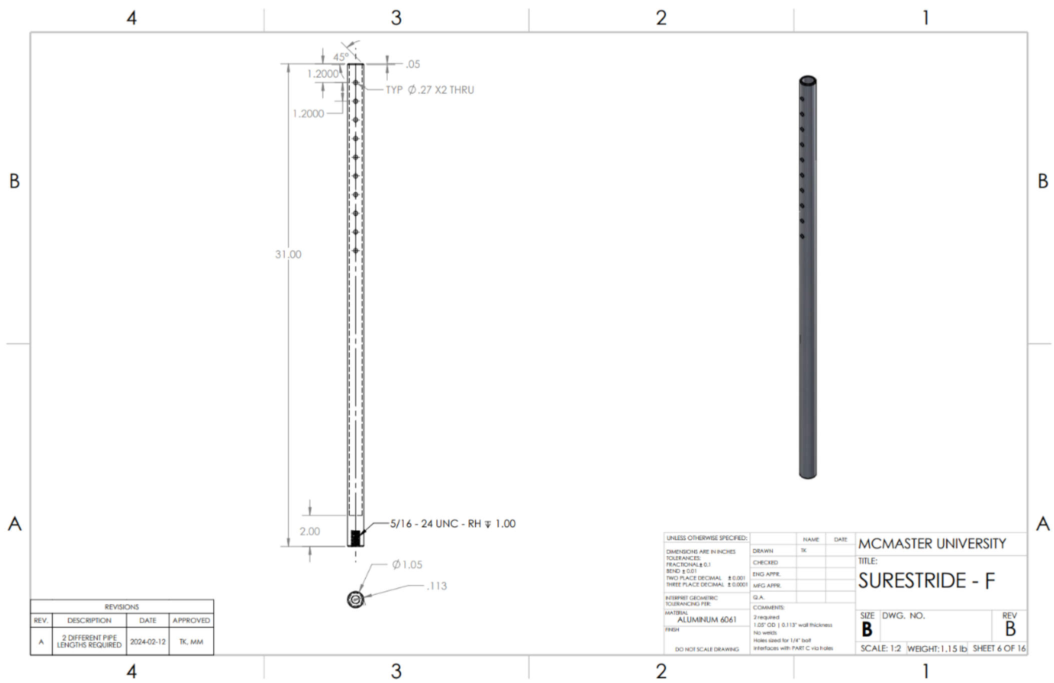
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.113
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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No welds
Holes sized for 1/4" bolt
Interfaces with PART C via holes
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B B
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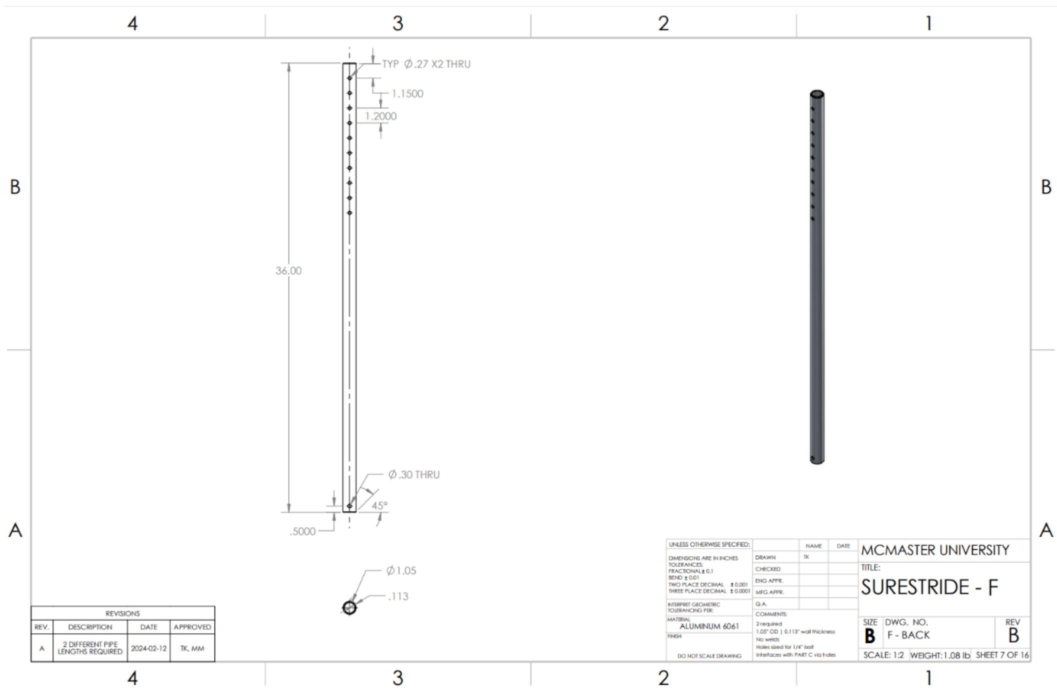
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ALUMINUM 6061
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NAME DATE
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 required
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No welds
Holes sized for 1/4" bolt
Interfaces with PART C via holes
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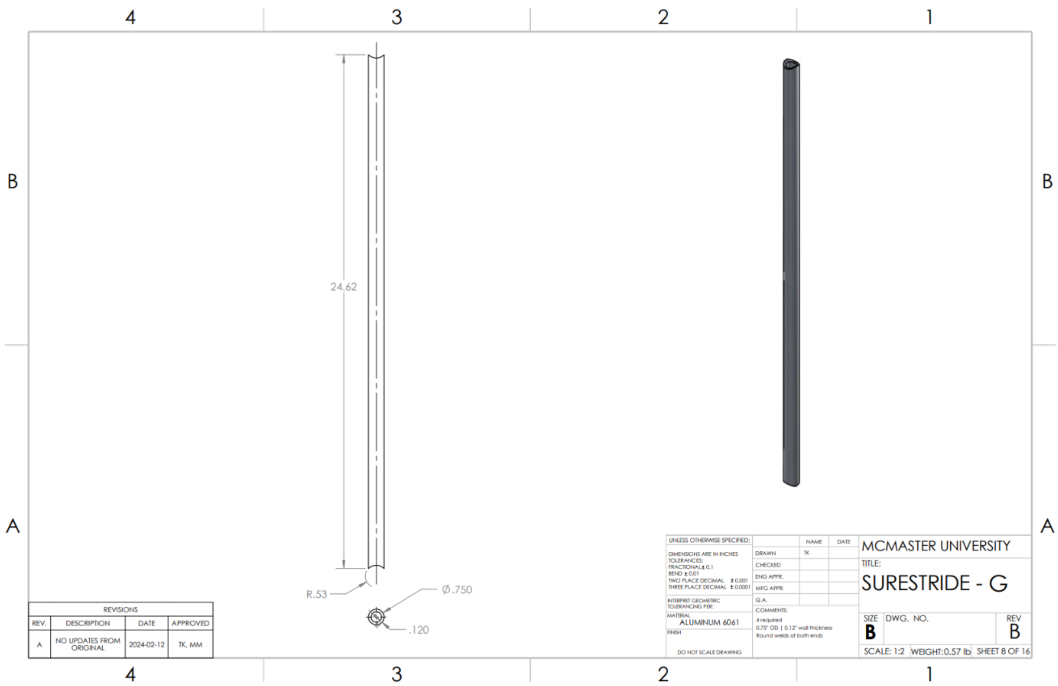
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TOLERANCES:
FRACTIONAL ± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
TK
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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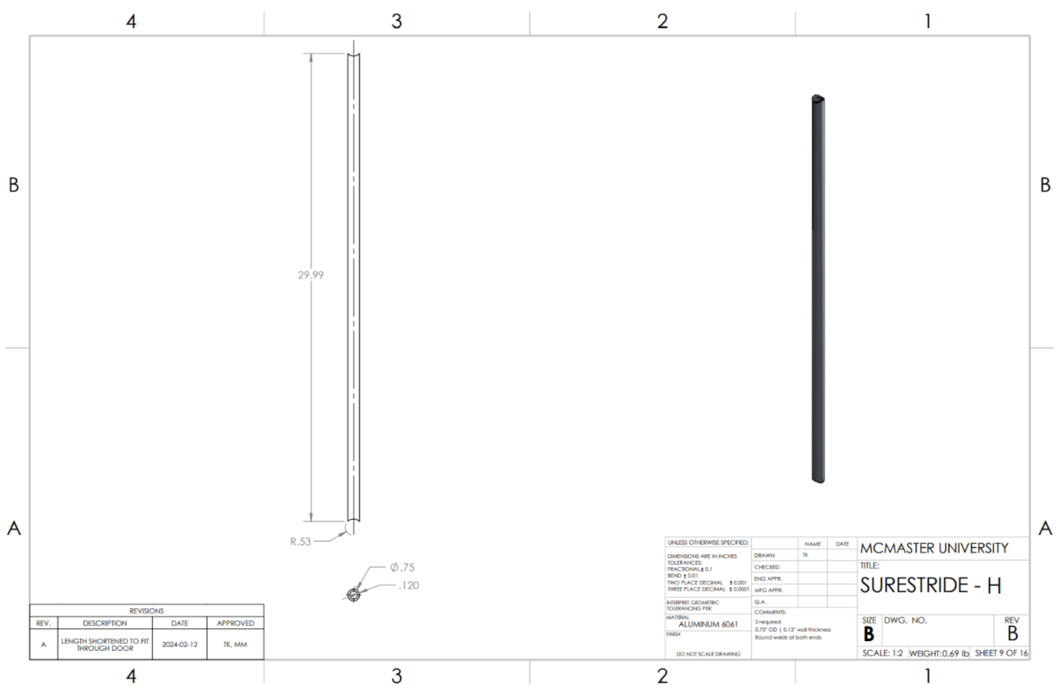
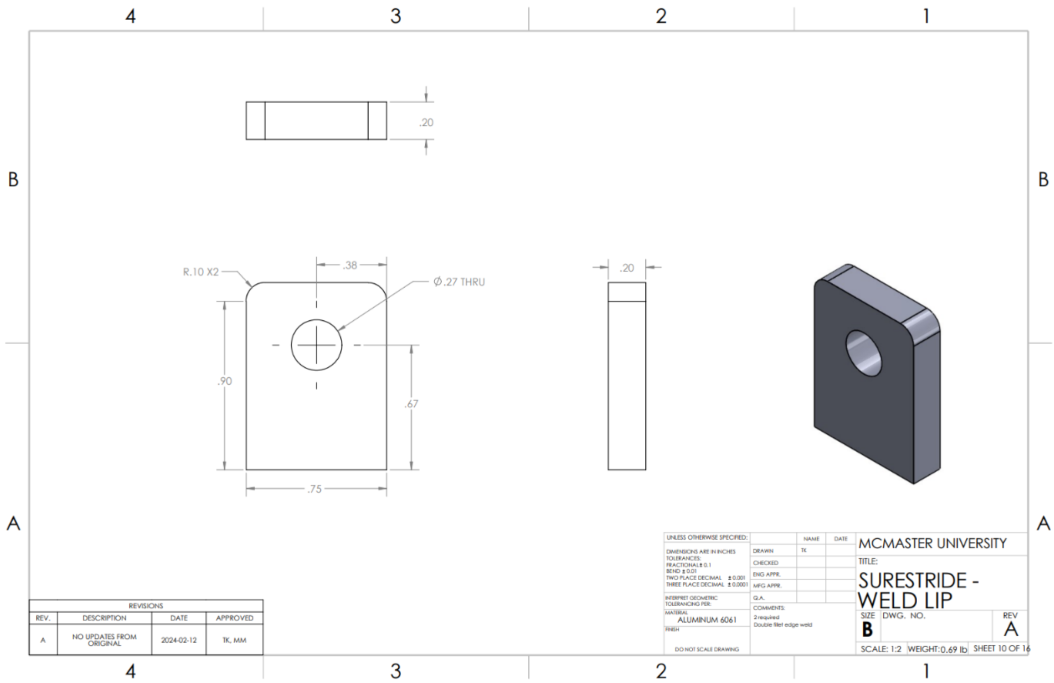
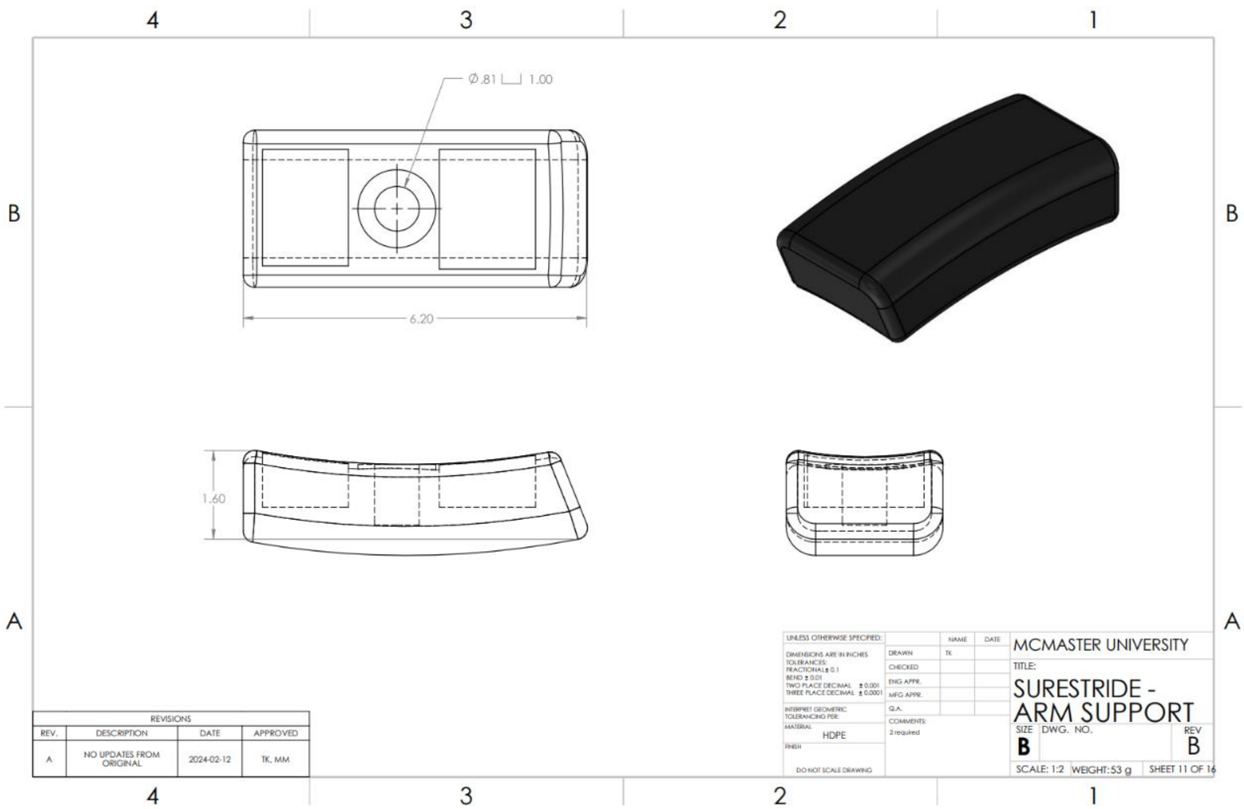
0.75" OD | 0.12" wall thickness
Round welds at both ends
MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - G
SIZE
B
DWG. NO.
REV
B
SCALE: 1:2
WEIGHT:0.57 lb
SHEET 8 OF 16

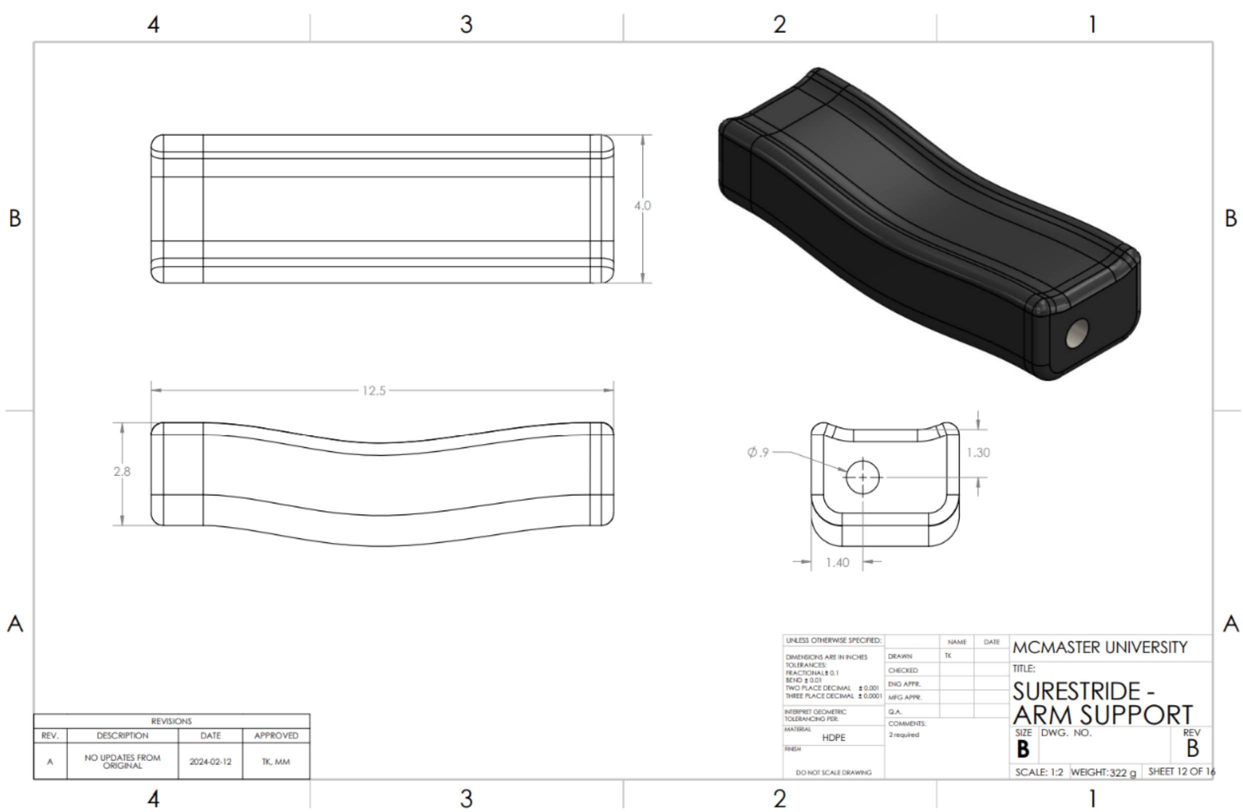

29.99
R.53
Ø.75
.120
REVISIONS
REV. | DESCRIPTION | DATE | APPROVED
A | LENGTH SHORTENED TO FIT THROUGH DOOR | 2024-02-12 | TK, MM
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
TK
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 required
0.75" OD | 0.12" wall thickness
Round welds at both ends
MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - H
SIZE
B
DWG. NO.
REV
B
SCALE: 1:2
WEIGHT:0.69 lb
SHEET 9 OF 16



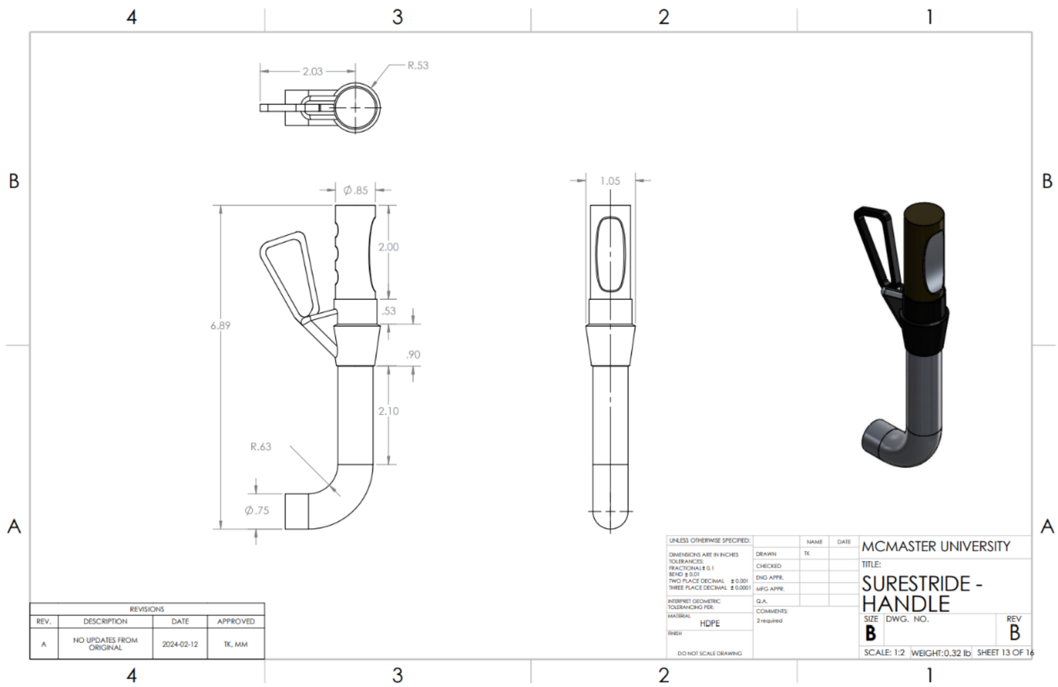
.20
R.10 X2
.38
⌀.27 THRU
.90
.67
.75
.20
REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
A
NO UPDATES FROM ORIGINAL
2024-02-12
TK, MM
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
TK
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 required
Double fillet edge weld
MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - WELD LIP
SIZE
B
DWG. NO.
REV
A
SCALE: 1:2
WEIGHT: 0.69 lb
SHEET 10 OF 16

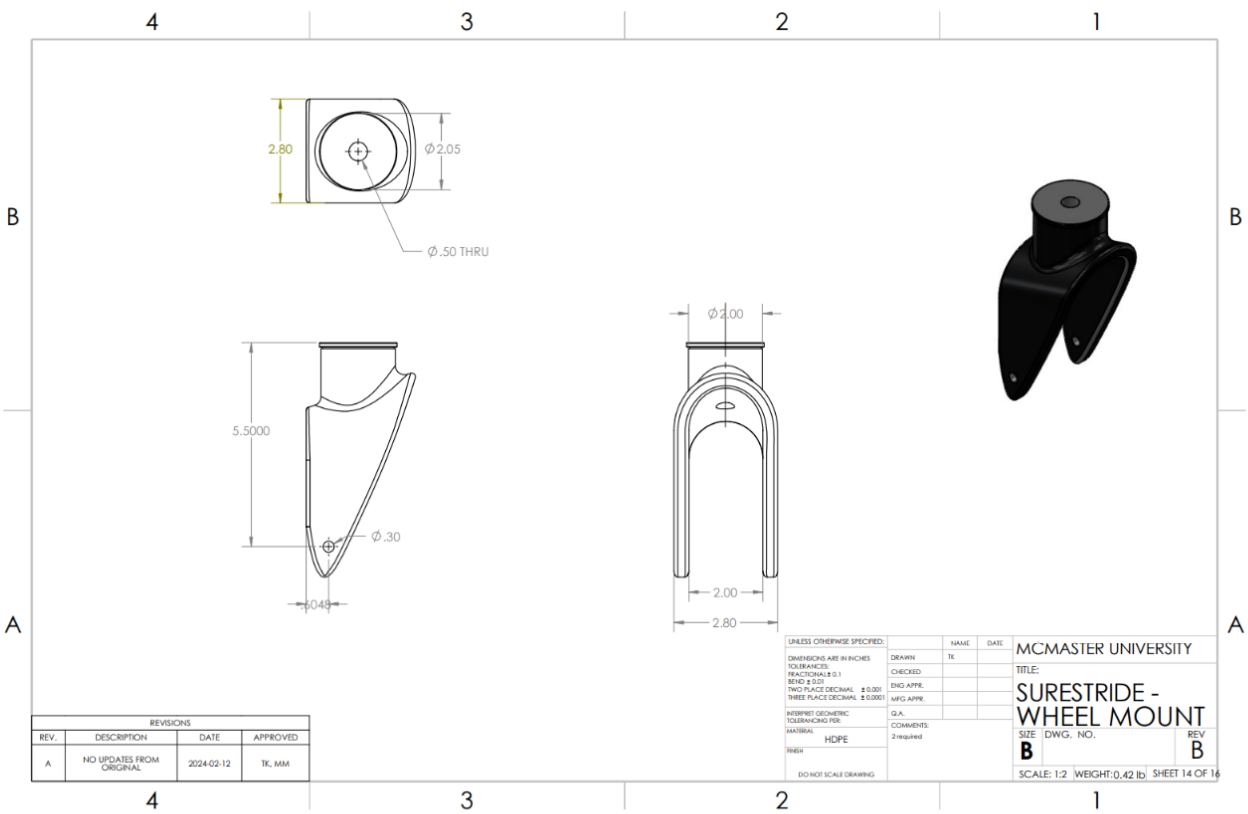


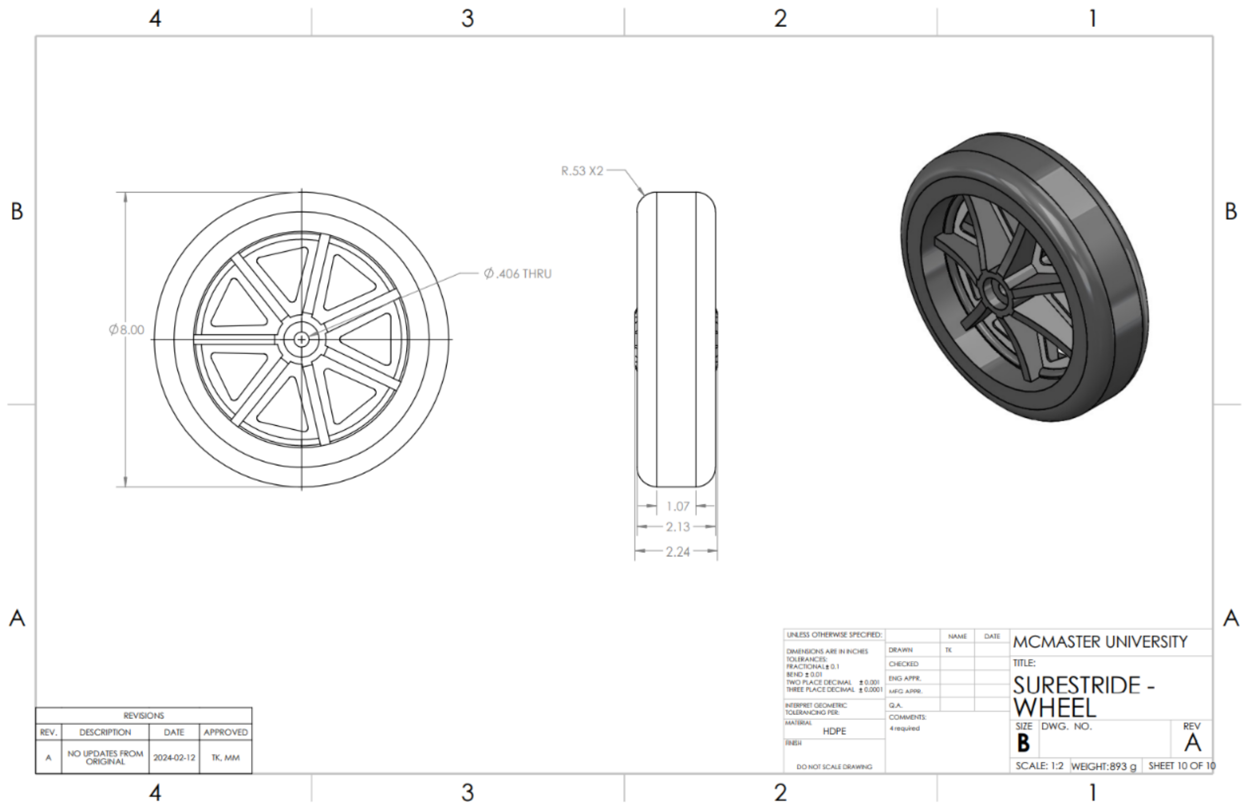
Ø.81 ⌴ 1.00
6.20
1.60
REVISIONS
REV. | DESCRIPTION | DATE | APPROVED
A | NO UPDATES FROM ORIGINAL | 2024-02-12 | TK, MM
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
HDPE
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
TK
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 required
MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - ARM SUPPORT
SIZE
DWG. NO.
REV
B
B
SCALE: 1:2
WEIGHT: 53 g
SHEET 11 OF 16

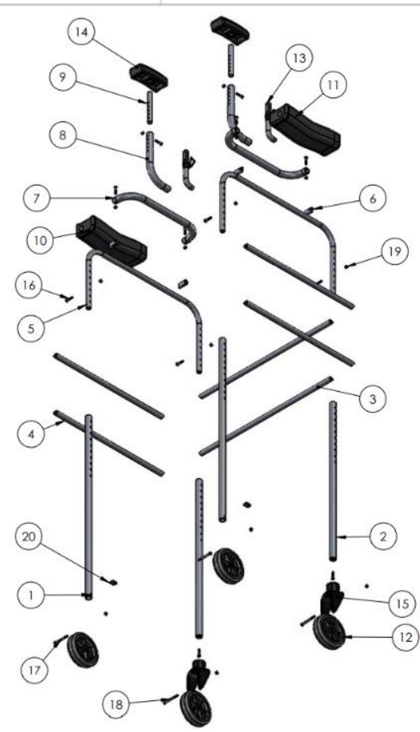


4.0
12.5
2.8
Ø.9
1.30
1.40
REVISIONS
REV. | DESCRIPTION | DATE | APPROVED
A | NO UPDATES FROM ORIGINAL | 2024-02-12 | TK, MM
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
HDPE
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
TK
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 required
MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - ARM SUPPORT
SIZE
DWG. NO.
REV
B
B
SCALE: 1:2
WEIGHT: 322 g
SHEET 12 OF 16


2.03
R.53
Ø.85
2.00
.53
.90
2.10
6.89
R.63
Ø.75
1.05
MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - HANDLE
HDPE
2 required
SCALE: 1:2 WEIGHT:0.32 lb SHEET 13 OF 16
REVISIONS
A NO UPDATES FROM ORIGINAL 2024-02-12 TK, MM


2.80
Ø2.05
Ø.50 THRU
5.5000
Ø.30
Ø2.00
2.00
2.80
MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - WHEEL MOUNT
HDPE
2 required
SCALE: 1:2 WEIGHT:0.42 lb SHEET 14 OF 16
REVISIONS
A NO UPDATES FROM ORIGINAL 2024-02-12 TK, MM





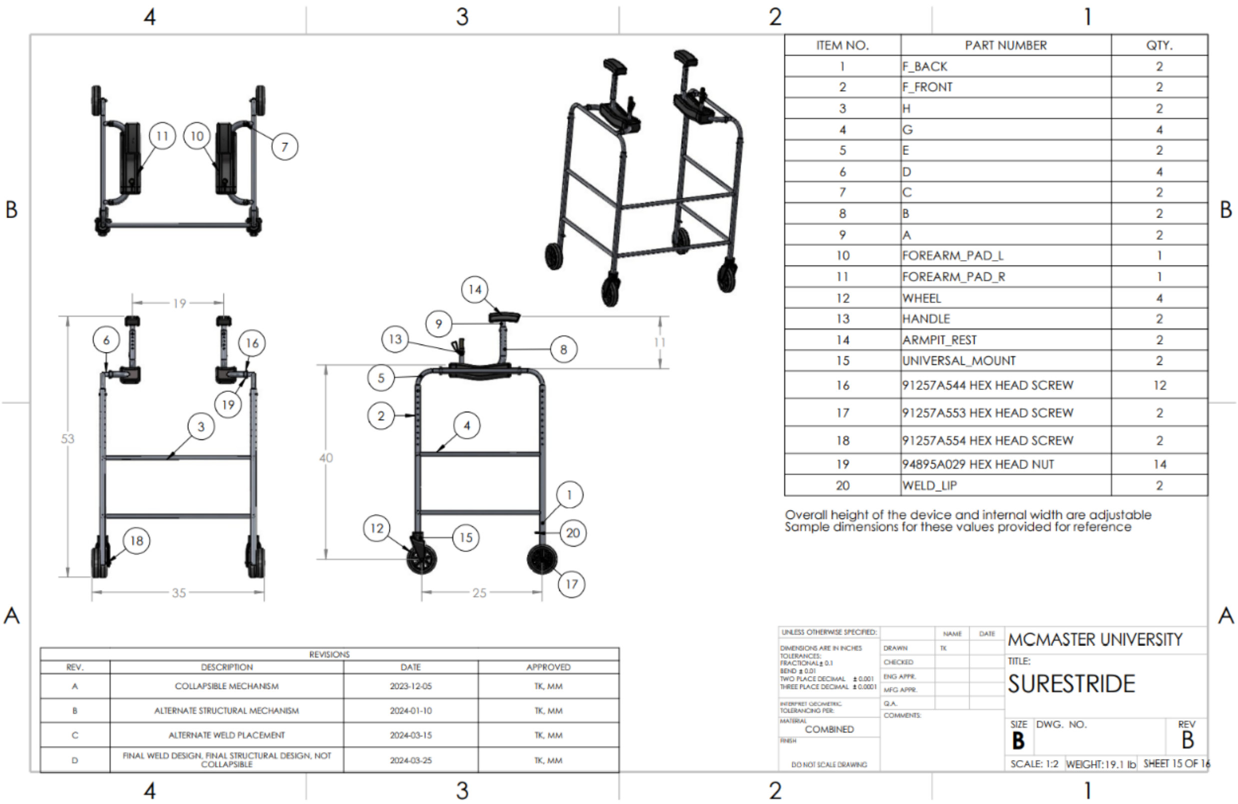
ITEM NO.	PART NUMBER	DESCRIPTION/MATERIAL	QTY.
1	F_BACK	ALUMINUM 6061	2
2	F_FRONT	ALUMINUM 6061	2
3	H	ALUMINUM 6061	2
4	G	ALUMINUM 6061	4
5	E	ALUMINUM 6061	2
6	D	ALUMINUM 6061	4
7	C	ALUMINUM 6061	2
8	B	ALUMINUM 6061	2
9	A	ALUMINUM 6061	2
10	FOREARM_PAD_L	HDPE + FOAM	1
11	FOREARM_PAD_R	HDPE + FOAM	1
12	WHEEL	HDPE	4
13	HANDLE	HDPE	2
14	ARMPIT_REST	HDPE + FOAM	2
15	UNIVERSAL_MOUNT	HDPE	2
16	91257A544	Zinc Yellow-Chromate Plated Hex Head Screw	12
17	91257A553	Zinc Yellow-Chromate Plated Hex Head Screw	2
18	91257A554	Zinc Yellow-Chromate Plated Hex Head Screw	2
19	94895A029	High-Strength Steel Hex Nut	14
20	WELD_LIP	ALUMINUM 6061	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Combined
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TK	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

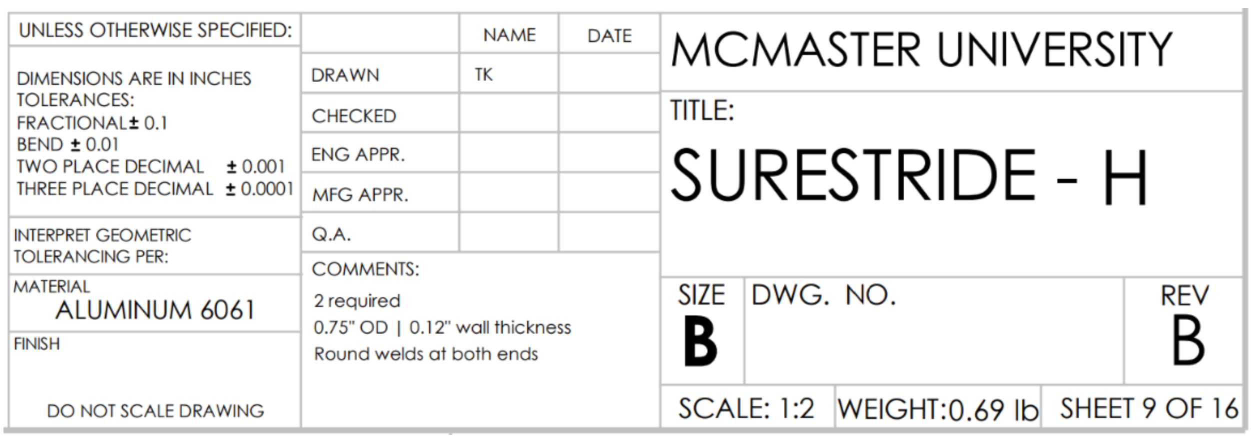
COMMENTS:

MCMASTER UNIVERSITY
TITLE: EXPLODED ASSM
SIZE B DWG. NO. REV
SCALE: 1:12 WEIGHT: 19.07 lb SHEET 1 OF 1



ITEM NO.	PART NUMBER	QTY.
1	F_BACK	2
2	F_FRONT	2
3	H	2
4	G	4
5	E	2
6	D	4
7	C	2
8	B	2
9	A	2
10	FOREARM_PAD_L	1
11	FOREARM_PAD_R	1
12	WHEEL	4
13	HANDLE	2
14	ARMPIT_REST	2
15	UNIVERSAL_MOUNT	2
16	91257A544 HEX HEAD SCREW	12
17	91257A553 HEX HEAD SCREW	2
18	91257A554 HEX HEAD SCREW	2
19	94895A029 HEX HEAD NUT	14
20	WELD_LIP	2

REV.	DESCRIPTION	DATE	APPROVED
A	COLLAPSIBLE MECHANISM	2023-12-05	TK, MM
B	ALTERNATE STRUCTURAL MECHANISM	2024-01-10	TK, MM
C	ALTERNATE WELD PLACEMENT	2024-03-15	TK, MM
D	FINAL WELD DESIGN, FINAL STRUCTURAL DESIGN, NOT COLLAPSIBLE	2024-03-25	TK, MM



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 0.1
BEND ± 0.01
TWO PLACE DECIMAL ± 0.001
THREE PLACE DECIMAL ± 0.0001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM 6061
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TK	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
2 required
0.75" OD | 0.12" wall thickness
Round welds at both ends

MCMASTER UNIVERSITY
TITLE:
SURESTRIDE - H
SIZE B
DWG. NO.
REV B
SCALE: 1:2
WEIGHT:0.69 lb
SHEET 9 OF 16

Sample higher resolution title block highlighting tolerancing specifications, mass, material type, and additional comments

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	LENGTH SHORTENED TO FIT THROUGH DOOR	2024-02-12	TK, MM

Sample higher resolution revision table

- ## Appendix BII: CAD Drawings of Mounting Components

1. Wheel-disc interface
2. Brake-pipe interface
3. Linear actuator
4. Battery
5. Sensors

Electrical Housings

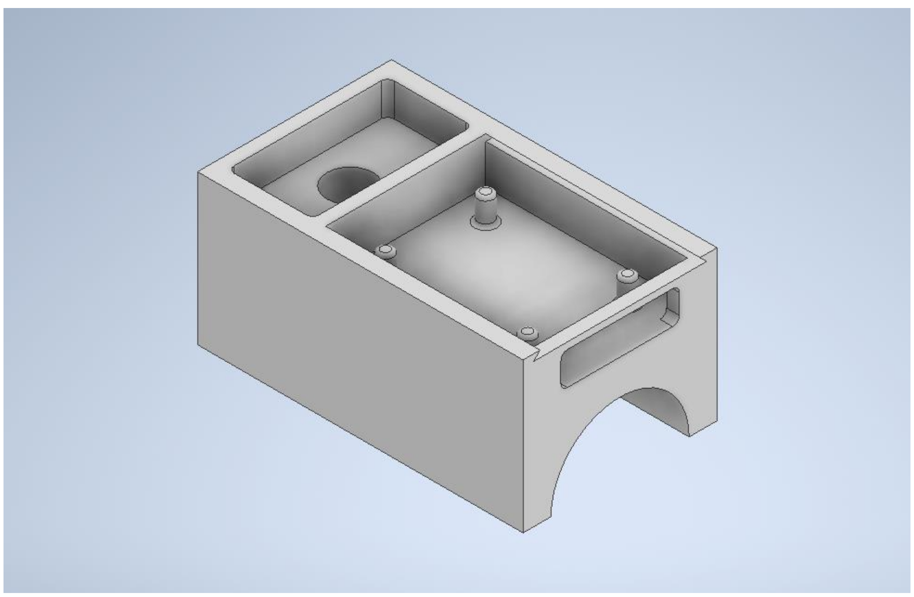


Figure 80: BNO 055 Case

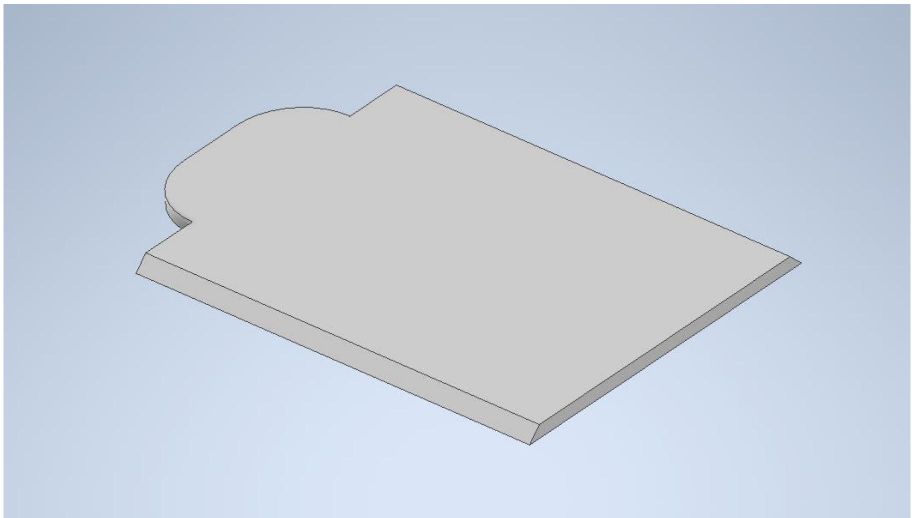


Figure 81: BNO 055 Lid

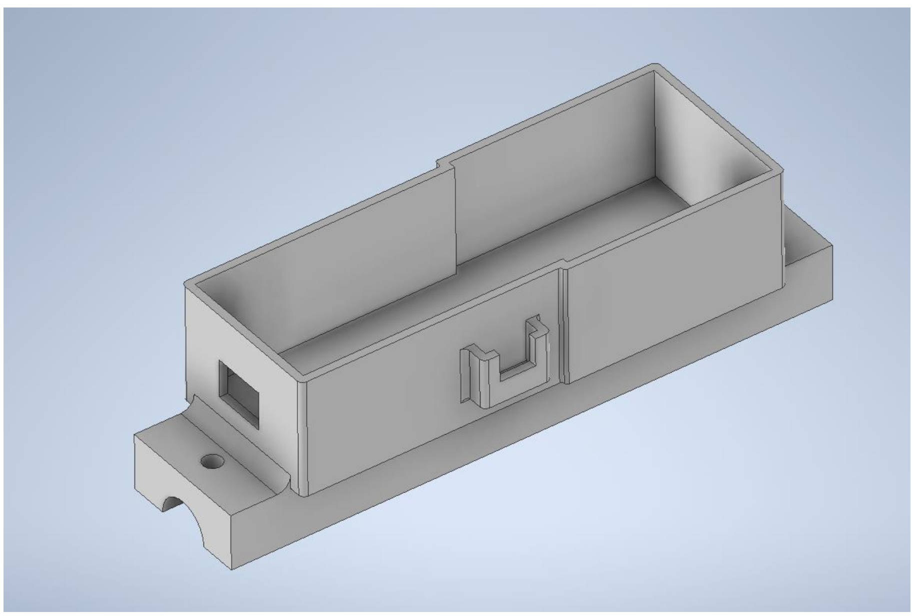


Figure 82: Driver Board, Breadboard, TOF (Time of Flight) Base Case

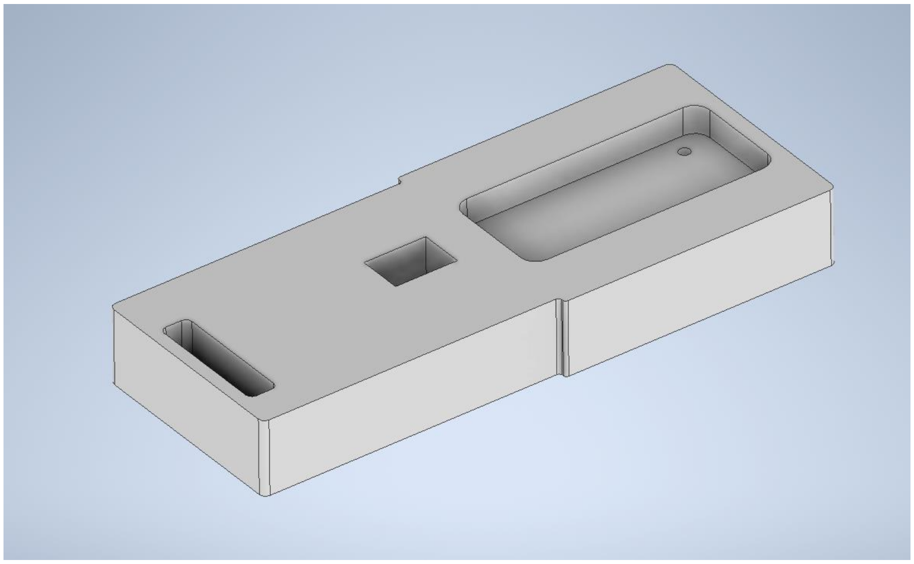


Figure 83: Driver Board, Breadboard, TOF (Time of Flight) Lid Case

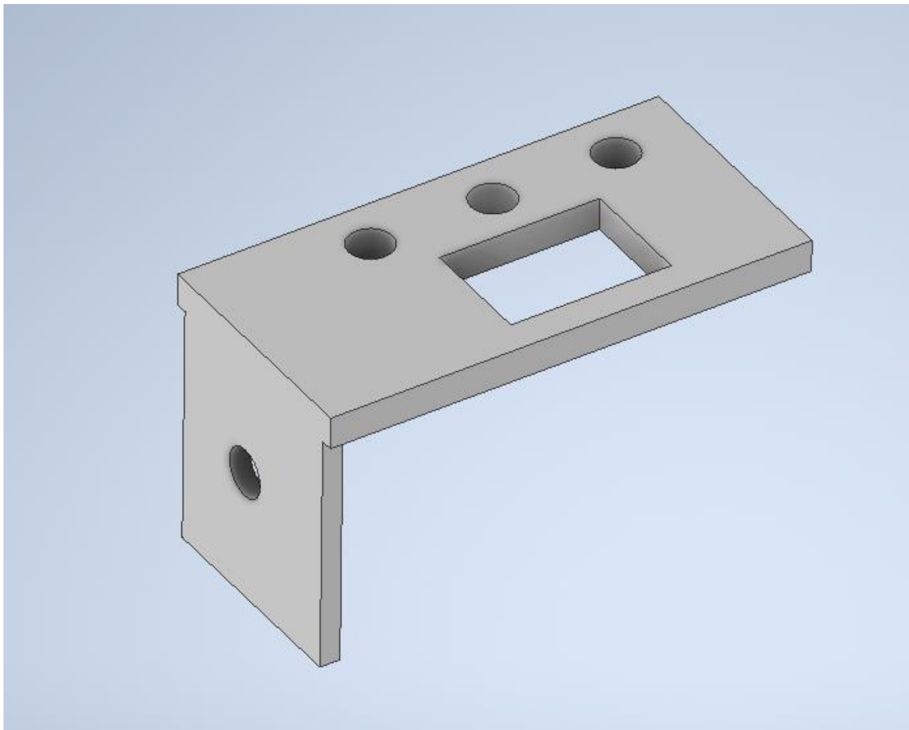


Figure 84: LED Switch Board Lid

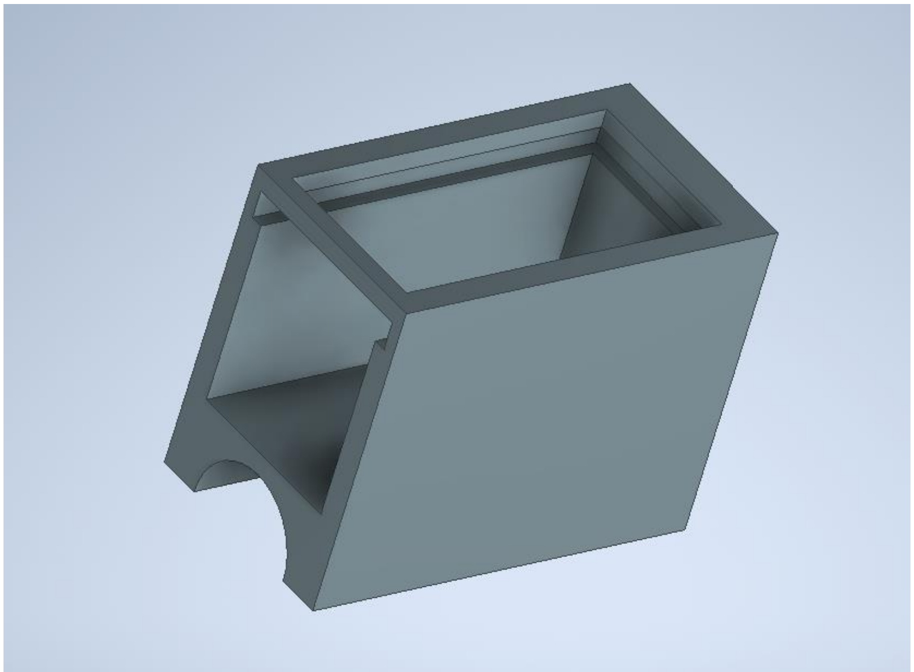


Figure 85: LED Switch Board Case

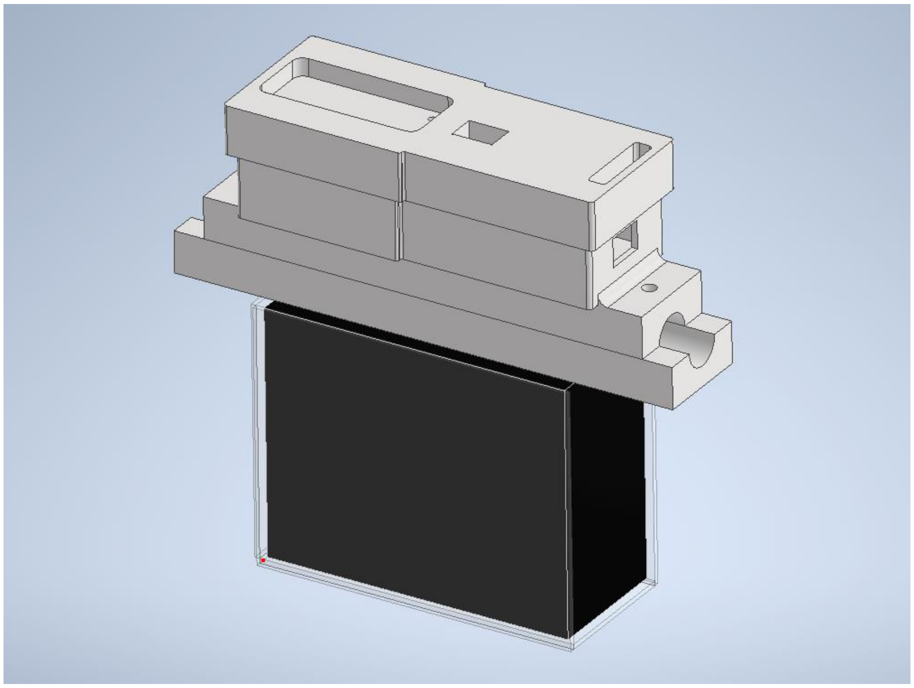


Figure 86: Initial Battery Acrylic Case

- ## Appendix BIII: FEA Results

Test Case #1 – 50 kg (245 N per support)

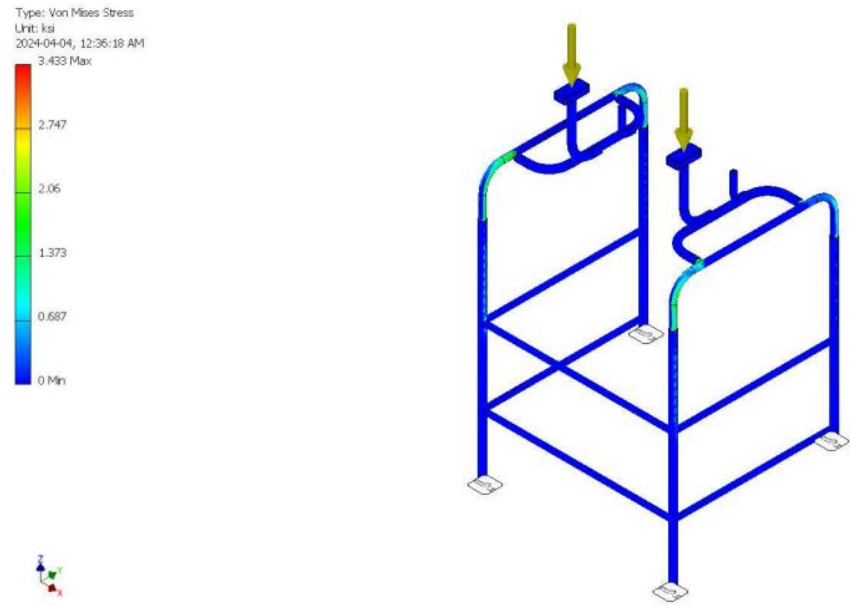


Figure 87: Von-Mises Stress

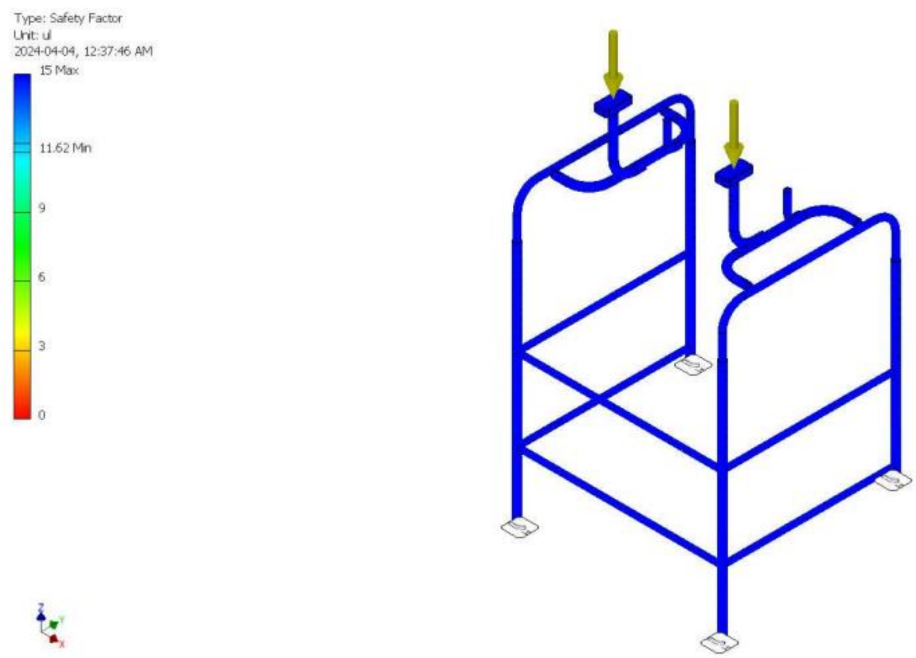


Figure 88: Factor of Safety

Test Case #2 – 75 kg (368 N per support)

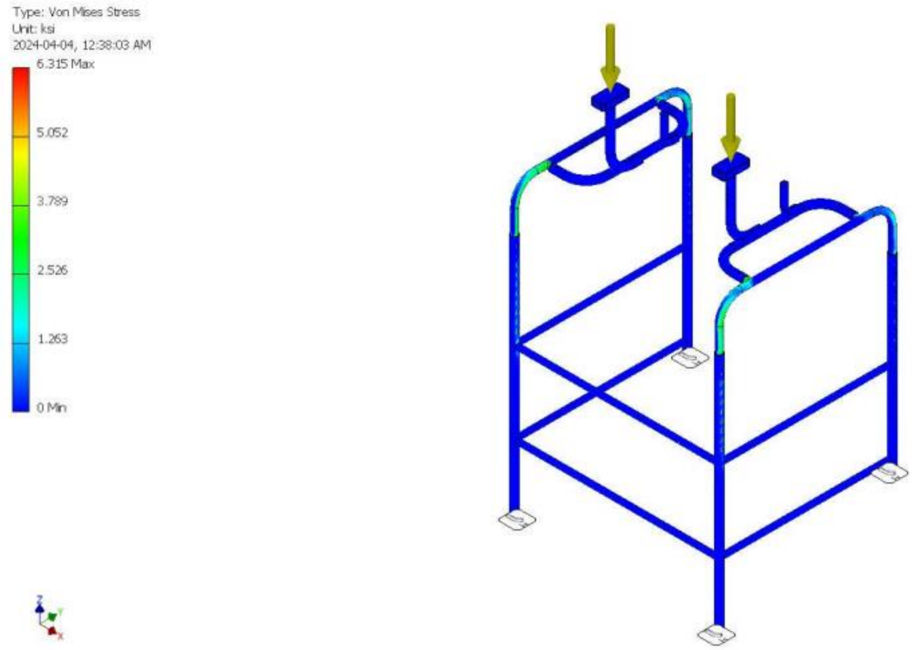


Figure 89: Von-Mises Stress

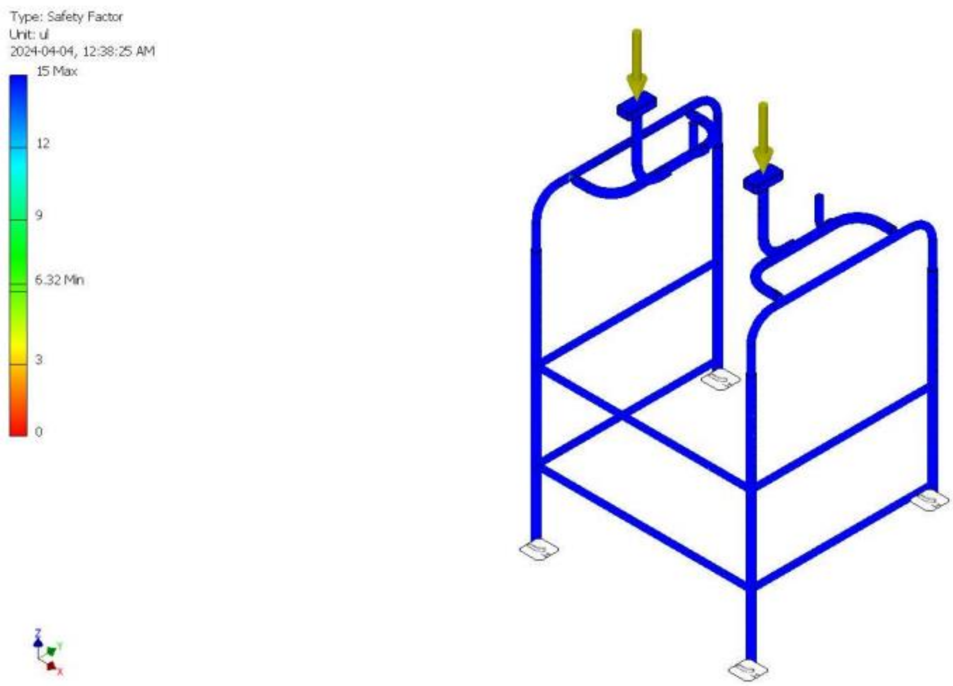


Figure 90: Safety Factor

Test Case #3 – 100 kg (491 N per support)

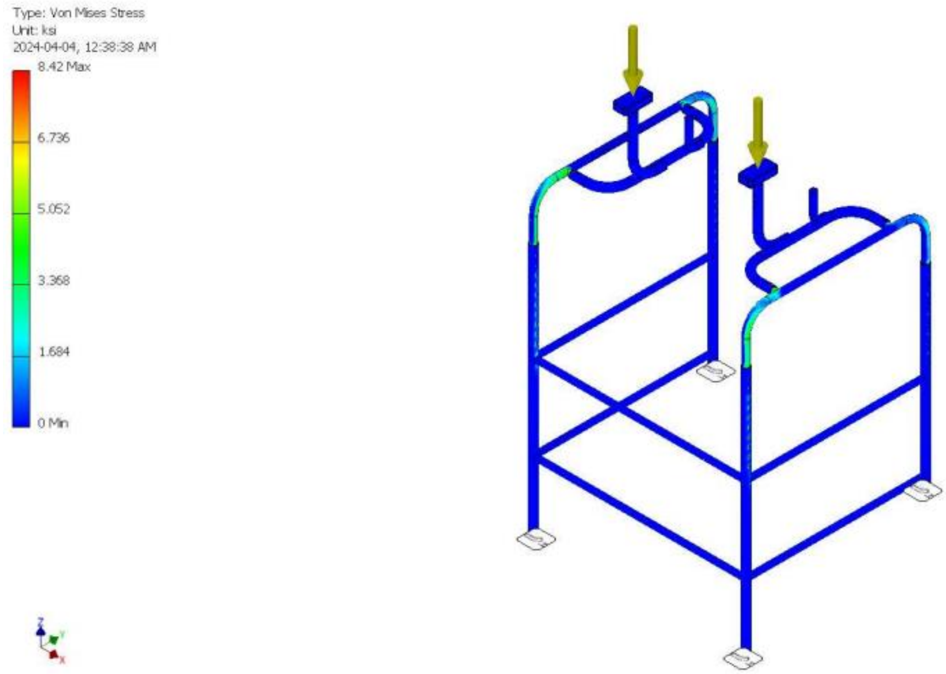


Figure 91: Von-Mises Stress

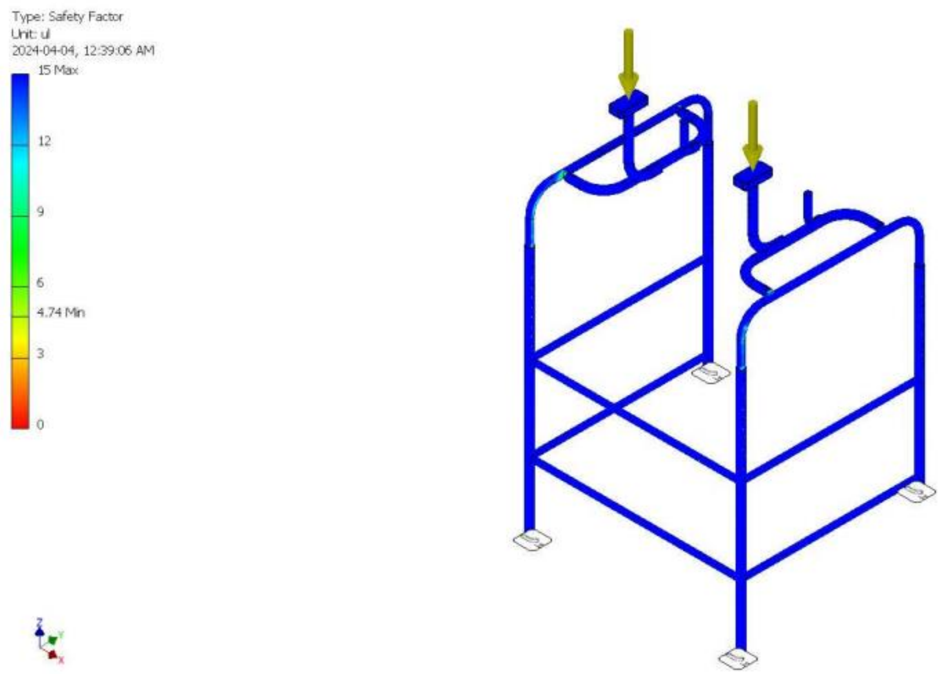


Figure 92: Factor of Safety

Electrical Documentation

- ## Appendix BIV: Validation Code for BNO055 Sensors

```
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BNO055.h>
#include <utility/imumaths.h>
#include <math.h>

TwoWire i2cPort1 = TwoWire(2);
TwoWire i2cPort2 = TwoWire(1);

Adafruit_BNO055 bno = Adafruit_BNO055(55, 0x29, &i2cPort1);
Adafruit_BNO055 bno2 = Adafruit_BNO055(55,0x28,&i2cPort1);

const int ledPin = 5;
const int led2 = 18;


void setup(void)
{
  Serial.begin(9600);
  //i2cPort2.begin(21, 22, 100000);
  i2cPort1.begin(19, 23, 100000);
  pinMode(ledPin, OUTPUT);
  pinMode(led2, OUTPUT);

  Serial.println("Orientation Sensor Test"); Serial.println("");

  /* Initialise the sensor */
  if(!bno.begin() || !bno2.begin())
  {
    /* There was a problem detecting the BNO055 ... check your connections
*/
    Serial.print("Ooops, no BNO055 detected ... Check your wiring or I2C
ADDR!");
    while(1);
  }

  delay(1000);

  bno.setExtCrystalUse(true);
  bno2.setExtCrystalUse(true);
}

void loop(void)
{
  /* Get a new sensor event */
  sensors_event_t event;
  bno.getEvent(&event);
  sensors_event_t event2;
  bno2.getEvent(&event2);
```

```
    if (abs(event.orientation.x - event2.orientation.x)>45){
    /* Blink the LED */
    digitalWrite (ledPin, HIGH);
    delay(500);
    digitalWrite (ledPin, LOW);
  }

//  /* Display the floating point data */
//  Serial.print("X: ");
//  Serial.print(event.orientation.x, 4);
//  Serial.print("\tY: ");
//  Serial.print(event.orientation.y, 4);
//  Serial.print("\tZ: ");
//  Serial.print(event.orientation.z, 4);
//  Serial.println("");
//
//  Serial.print("X2: ");
//  Serial.print(event2.orientation.x, 4);
//  Serial.print("\tY2: ");
//  Serial.print(event2.orientation.y, 4);
//  Serial.print("\tZ2: ");
//  Serial.print(event2.orientation.z, 4);
//  Serial.println("");


imu::Vector<3> euler =
bno.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);

  /* Display the floating point data */
  Serial.print("X1: ");
  Serial.print(euler.x());
  Serial.print(" Y1: ");
  Serial.print(euler.y());
  Serial.print(" Z1: ");
  Serial.print(euler.z());
  Serial.print("\t\t");

  imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);

  /* Display the floating point data */
  Serial.print("X2: ");
  Serial.print(euler2.x());
  Serial.print(" Y2: ");
  Serial.print(euler2.y());
  Serial.print(" Z2: ");
  Serial.print(euler2.z());
  Serial.print("\t\n");

     if (abs(euler.x() - euler2.x())>1){
    /* Blink the LED */
//    will want to change this to just one acceleration because both
sensors should have the same - using the difference for demo purposes
```

```
    digitalWrite (led2, HIGH);
    delay(500);
    digitalWrite (led2, LOW);
  }

}
```

- ## Appendix BV: Validation Code for ESP32 Micro

```
/*
 *  This sketch demonstrates how to scan WiFi networks.
 *  The API is almost the same as with the WiFi Shield library,
 *  the most obvious difference being the different file you need to
include:
 */
#include "WiFi.h"

void setup()
{
    Serial.begin(115200);

    // Set WiFi to station mode and disconnect from an AP if it was
previously connected
    WiFi.mode(WIFI_STA);
    WiFi.disconnect();
    delay(100);

    Serial.println("Setup done");
}

void loop()
{
    Serial.println("scan start");

    // WiFi.scanNetworks will return the number of networks found
    int n = WiFi.scanNetworks();
    Serial.println("scan done");
    if (n == 0) {
        Serial.println("no networks found");
    } else {
        Serial.print(n);
        Serial.println(" networks found");
        for (int i = 0; i < n; ++i) {
            // Print SSID and RSSI for each network found
            Serial.print(i + 1);
            Serial.print(": ");
            Serial.print(WiFi.SSID(i));
            Serial.print(" (");
            Serial.print(WiFi.RSSI(i));
            Serial.print(")");
            Serial.println((WiFi.encryptionType(i) == WIFI_AUTH_OPEN)?"
":"*");
            delay(10);
        }
```

```
    }
    Serial.println("");

    // Wait a bit before scanning again
    delay(5000);
}
```

- ## Appendix BVI: Code for Controlling Motors

```
// Include libraries
#include <ezButton.h>
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BNO055.h>
#include <utility/imumaths.h>
#include <math.h>
#include <LiquidCrystal_I2C.h>
#include "Adafruit_VL53L1X.h"
#include "BluetoothSerial.h"

//#define bluetooth USE_PIN // Uncomment this to use PIN during pairing.
The pin is specified on the line below
const char *pin = "1234"; // Change this to more secure PIN.
String device_name = "SureStrideBT";

#if !defined(CONFIG_BT_ENABLED) || !defined(CONFIG_BLUEDROID_ENABLED)
#error Bluetooth is not enabled! Please run `make menuconfig` to and
enable it
#endif

BluetoothSerial SerialBT;

TwoWire i2cPort1 = TwoWire(1);
Adafruit_BNO055 bno = Adafruit_BNO055(55,0x29,&i2cPort1);
Adafruit_BNO055 bno2 = Adafruit_BNO055(55,0x28,&i2cPort1);
#define IRQ_PIN 2
#define XSHUT_PIN 3
Adafruit_VL53L1X vl53 = Adafruit_VL53L1X();
ezButton mySwitch(27);
ezButton mySwitch2(33);

// setup led pins
const int led_R = 5;
const int led_Y = 18;
const int led_G = 32;

// setup motor pins
const int motor_1_in1 = 10;
const int motor_1_in2 = 9;
const int motor_2_in1 = 25;
const int motor_2_in2 = 26;
const int fix_speed = 1;

// make additional I2C port on these pins
```

```
#define I2C_SDA 19
#define I2C_SCL 23

int16_t tof_range;

// Save maximum linear accelerations (from callibration)
double max_accel1 = 0.6;
double max_accel2 = 0.6;
//save average angular acceleration maximums
double av_x1 = 5;
double av_y1 = 0;
double av_z1 = 0; //calibrated threshold vals for wobble

// Save the number of times the person braked for each of the reasons
int major_wobble = 0;
int minor_wobble = 0;
int major_tof = 0;
int minor_tof = 0;
int major_accel = 0;
int minor_accel = 0;

// Braking status 0=none, 1=minor, 2=major
int brake_status = 0;
int emerg_stop = 0;

int switch_status_1 = 0;
int switch_status_2 = 0;
// Prior switch status for power (S1)
int old_status = 0;

void setup() {

  // LED setup
  pinMode(led_R, OUTPUT);
  pinMode(led_Y, OUTPUT);
  pinMode(led_G, OUTPUT);

  // switch setup
  Serial.begin(9600);
  mySwitch.setDebounceTime(50); // set debounce time to 50 milliseconds

  //Bluetooth setup
  SerialBT.begin(device_name); //Bluetooth device name
  Serial.printf("The device with name \"%s\" is started.\nNow you can pair
it with Bluetooth!\n", device_name.c_str());
  //Serial.printf("The device with name \"%s\" and MAC address %s is
started.\nNow you can pair it with Bluetooth!\n", device_name.c_str(),
SerialBT.getMacString()); // Use this after the MAC method is implemented
  #ifdef USE_PIN
    SerialBT.setPin(pin);
    Serial.println("Using PIN");
  #endif

  //BNO055 setup
```

```
  Wire.begin();
  /* Initialise the sensor */
  i2cPort1.begin(19, 23, 100000);
  if(!bno.begin() || !bno2.begin())
  {
    /* There was a problem detecting the BNO055 ... check your connections
*/
    Serial.print("Ooops, no BNO055 detected ... Check your wiring or I2C
ADDR!");
    while(1);
  }
  delay(1000);
  bno.setExtCrystalUse(true);
  bno2.setExtCrystalUse(true);

  // ToF setup
  if (! vl53.begin(0x29, &Wire)) {
    Serial.print(F("Error on init of VL sensor: "));
    Serial.println(vl53.vl_status);
    while (1)       delay(10);
  }
  Serial.println(F("VL53L1X sensor OK!"));

  Serial.print(F("Sensor ID: 0x"));
  Serial.println(vl53.sensorID(), HEX);

  if (! vl53.startRanging()) {
    Serial.print(F("Couldn't start ranging: "));
    Serial.println(vl53.vl_status);
    while (1)       delay(10);
  }
  Serial.println(F("Ranging started"));

  // Valid timing budgets: 15, 20, 33, 50, 100, 200 and 500ms!
  vl53.setTimingBudget(50);
  Serial.print(F("Timing budget (ms): "));
  Serial.println(vl53.getTimingBudget());

  //Motor setup
  pinMode (motor_1_in1, OUTPUT);
  pinMode (motor_1_in2, OUTPUT);
  pinMode (motor_2_in1, OUTPUT);
  pinMode (motor_2_in2, OUTPUT);
  digitalWrite(motor_1_in1, 0);
  digitalWrite(motor_1_in2, 0);
  digitalWrite(motor_2_in1, 0);
  digitalWrite(motor_2_in2, 0);

  //replacing this part of calibration
  sensors_event_t event2;
  bno2.getEvent(&event2);
  imu::Vector<3> euler =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
  Serial.println("Calibrating now");
```

```
  av_x1 = euler.x();
  Serial.println(euler.x());
  av_y1 = euler.y();
  Serial.println(euler.y());
  av_z1 = euler.z();
  Serial.println(euler.z());

}

void loop() {
  check_switch_1();
  if (switch_status_1 == 1){ // power switch is ON
    digitalWrite (led_G, HIGH);
    old_status = switch_status_1;
    check_switch_2();
    Serial.println(switch_status_2);
    if (switch_status_2 == 1){     //calibration switch is ON
      calibrate();
    }

    sensor_lin_accel();
    check_ToF();
    check_wobble();
  }
  else if (switch_status_1 == 0 && old_status == 1){
    // switch just got turned off, do stop procedure
    old_status = 0;
    stop();
  }

}



void sensor_lin_accel(){
  sensors_event_t linearAccelData;
  imu::Vector<3> accel =
bno.getVector(Adafruit_BNO055::VECTOR_LINEARACCEL);
  imu::Vector<3> accel2 =
bno2.getVector(Adafruit_BNO055::VECTOR_LINEARACCEL);

//  Serial.print("\nlinear acceleration in x:");
//  Serial.print(accel2.x());

  Serial.print("\nlinear acceleration in y:");
  Serial.print(accel2.y());

  double max_threshold = 2;

  if (abs(accel2.y()) > (max_accel2 + max_threshold) && (emerg_stop ==0)){
// will need to determine the threshold
      //brake lots
      Serial.print("Major lin accel braking\n");
      major_braking();
```

```
      major_accel = major_accel+1;
      while(abs(accel2.y()) > (max_accel2 + max_threshold)){
        imu::Vector<3> accel2 =
bno2.getVector(Adafruit_BNO055::VECTOR_LINEARACCEL); // get new event
        delay(200);
        emergency_stop();
        if (abs(accel2.y()) < (max_accel2 + 3)){
          break;
        }
      }
      major_unbraking();
      Serial.print("Major lin accel unbraking\n");
    }

  double minor_threshold = 0.7;
  if(abs(accel2.y()) > (max_accel2 + minor_threshold) && (emerg_stop
==0)){  // will need to determine the threshold
    //brake a little
    Serial.print("minor lin accel braking\n");
    minor_braking();
    Serial.println("done minor braking");
    minor_accel = minor_accel+1;
    while(abs(accel2.y()) > (max_accel2 + minor_threshold)){
      imu::Vector<3> accel2 =
bno2.getVector(Adafruit_BNO055::VECTOR_LINEARACCEL); // get new event
      Serial.println(accel2.y());
      delay(200);
      emergency_stop();
      if(abs(accel2.y()) < (max_accel2 + 0.5)){
        break;
      }
    }
    minor_unbraking();
    Serial.print("Minor lin accel unbraking\n");
  }
}

void check_wobble(){
  Serial.println("check wobble");
  double tolerance = 2;   // will need to determine this tolerance
  sensors_event_t event2;
  bno2.getEvent(&event2);
  imu::Vector<3> euler =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
  Serial.println(euler.x());

// Wobble for x
  if (abs(euler.x()) > av_x1 + tolerance ){
    delay(100);
    Serial.println(euler.x());
    Serial.println("Braking now for x!");
    minor_braking();
    delay(200);
    minor_wobble = minor_wobble+1;
```

```
    imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
    while (abs(euler2.x()) > av_x1 + tolerance && (emerg_stop ==0)){
      imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
      Serial.println(euler2.x());
      Serial.println("Still braking for x");
      delay(200);
      emergency_stop();
      if (abs(euler2.x()) < av_x1 + tolerance){
        break;
      }
    }
  //Serial.println("Stop please for x");
  minor_unbraking();
  }
//// Wobble for y
  if (abs(euler.y()) > av_y1 + tolerance+1.2){
    delay(100);
    Serial.println(euler.y());
    Serial.println("Braking now for y!");
    minor_braking();
    delay(200);
    minor_wobble = minor_wobble+1;
    imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
    while (abs(euler2.y()) > av_y1 + tolerance+1.2 && (emerg_stop ==0)){
      imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
      Serial.println(euler2.y());
      Serial.println("Still braking for y");
      delay(200);
      emergency_stop();
      if (abs(euler2.y()) < av_y1 + tolerance+1.2){
        break;
      }
    }
  Serial.println("Stop please for y");
  minor_unbraking();
  }
//  //Wobble for z
//  if (abs(euler.z()) > av_z1 + tolerance){
//    delay(100);
//    Serial.println(euler.z());
//    Serial.println("Braking now for z!");
//    minor_braking();
//    minor_wobble = minor_wobble+1;
//    delay(200);
//    imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
//    while (abs(euler2.z()) > av_z1 + tolerance && (emerg_stop ==0)){
//      imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
//      Serial.println(euler2.z());
```

```
//       Serial.println("Still braking for z");
//       delay(200);
//       emergency_stop();
//       if (abs(euler2.z()) < av_z1 + tolerance){
//         break;
//       }
//     }
//   //Serial.println("Stop please for z");
//   minor_unbraking();
//   }
}


//void sensor_data(){
//   /* Get a new sensor event */
//   sensors_event_t event;
//   sensors_event_t event2;
//   bno.getEvent(&event);
//   bno2.getEvent(&event2);
//   imu::Vector<3> euler =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
//   /* Display the floating point data */
//   Serial.print("X1: ");
//   Serial.print(euler.x());
//   Serial.print(" Y1: ");
//   Serial.print(euler.y());
//   Serial.print(" Z1: ");
//   Serial.print(euler.z());
//   Serial.print("\t\t");
//   imu::Vector<3> euler2 =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
//   /* Display the floating point data */
//   Serial.print("X2: ");
//   Serial.print(euler2.x());
//   Serial.print(" Y2: ");
//   Serial.print(euler2.y());
//   Serial.print(" Z2: ");
//   Serial.print(euler2.z());
//   Serial.print("\t\n");
//}
void minor_braking(){
  digitalWrite (led_Y, HIGH);
  both_bkwd(1000);
  brake_status = 1;
}
void minor_unbraking(){
  digitalWrite (led_Y, LOW);
  both_fwd(1000);
  brake_status = 0;
}

void major_braking(){
  digitalWrite (led_Y, HIGH);
  digitalWrite (led_R, HIGH);
```

```
  both_bkwd(2000);
  brake_status = 2;
}
void major_unbraking(){
  digitalWrite (led_Y, LOW);
  digitalWrite (led_R, LOW);
  both_fwd(2000);
  brake_status = 0;
}

void stop(){
  // if switch status is 0, stop
  // stop collecting sensor data

  // leave actuators in open position
  if (brake_status ==1){
    minor_unbraking();
  }
  if (brake_status ==2){
    major_unbraking();
  }

  // turn LED off
  digitalWrite (led_R, LOW);
  digitalWrite (led_Y, LOW);
  digitalWrite (led_G, LOW);

  // offload data
  //SerialBT.print("
  Serial.print("stop procedure");
  delay(2000);

  //reset the number of braking
  major_wobble = 0;
  minor_wobble = 0;
  major_tof = 0;
  minor_tof = 0;
  major_accel = 0;
  minor_accel = 0;
}

void check_switch_1(){
  mySwitch.loop(); // MUST call the loop() function first
  int state = mySwitch.getState();
  if (state == HIGH){
    Serial.println("\nSwitch1 : OFF");
    delay(200);
    if (switch_status_1 ==1){
      // switch is going from on to off so call stop procedure
      stop();
    }
    switch_status_1 = 0;
  }
    else{
```

```
    Serial.println("\nSwitch 1: ON");
    delay(200);
    switch_status_1 = 1;
    }
}
void check_switch_2(){
  mySwitch2.loop(); // MUST call the loop() function first
  int state = mySwitch2.getState();
  if (state == HIGH){
    Serial.println("Switch 2: OFF");
    switch_status_2 = 0;
  }
    else{
    Serial.println("Switch 2: ON");
    switch_status_2 = 1;
    }
}

void both_fwd(int len){
  digitalWrite(motor_1_in1, LOW);
  digitalWrite(motor_1_in2, fix_speed);
  digitalWrite(motor_2_in1, LOW);
  digitalWrite(motor_2_in2, fix_speed);
  delay(len);
  // stop both motors
  digitalWrite(motor_1_in1, 0);
  digitalWrite(motor_1_in2, 0);
  digitalWrite(motor_2_in1, 0);
  digitalWrite(motor_2_in2, 0);
}

void both_bkwd(int len){
  digitalWrite(motor_1_in2, LOW);
  digitalWrite(motor_1_in1, fix_speed);
  digitalWrite(motor_2_in2, LOW);
  digitalWrite(motor_2_in1, fix_speed);
  delay(len);
  // stop both motors
  digitalWrite(motor_1_in1, 0);
  digitalWrite(motor_1_in2, 0);
  digitalWrite(motor_2_in1, 0);
  digitalWrite(motor_2_in2, 0);
}

void calibrate (){
  // User will start from standing then walk forward for 10 seconds then
stop.
  Serial.print("\n Start calibration");
  Serial.print("\n");
  digitalWrite (led_R, HIGH);
  int ledY = HIGH;
  digitalWrite (led_Y, ledY);
```

```
  // Walk will happen for 10 seconds - sensors will capture every 0.1 sec
(100 measurements)
  int i; //counter
  int j = 0;  //counter
  double accel_1 [100];
  double accel_2 [100];
  double ang_vel_x[3] = {0,0,0};
  double ang_vel_y[3] = {0,0,0};
  double ang_vel_z[3] = {0,0,0};
  double old_max = 0;
  double old_max2 = 0;

  sensors_event_t event2;
  bno2.getEvent(&event2);
  imu::Vector<3> euler =
bno2.getVector(Adafruit_BNO055::VECTOR_ACCELEROMETER);
//  av_x1 = euler.x();
//  av_y1 = euler.y();
//  av_z1 = euler.z();

  for (i=0; i<100; i++){
    sensors_event_t event, orientationData , angVelocityData ,
linearAccelData;
    // Get the acceleration - will keep 3 largest accelerations to get avg
maximum
    imu::Vector<3> accel = bno.getEvent(&linearAccelData,
Adafruit_BNO055::VECTOR_LINEARACCEL);
    imu::Vector<3> accel2 = bno2.getEvent(&linearAccelData,
Adafruit_BNO055::VECTOR_LINEARACCEL);
    accel_1[i] = accel.x();   //The direction of forward acceleration will
need to be determined
    accel_2[i] = accel2.x();

    //save the maximum
    if (accel.x()>old_max){
      old_max = accel.x(); }
    if (accel2.x()>old_max2){
      old_max2 = accel2.x(); }

    if (i%10 == 0){ //prints to lcd screen how much time left
      ledY = !ledY;
      digitalWrite (led_Y, ledY);
    }
    delay(100);
  }

  // Use the acceleration data to get the speed (assumes starting from
still)
  double time_step = 0.1;  // measurements taken every 0.1 sec
  double velocity[100] = {0};  // Initial velocity is 0

    for (int i = 1; i < 100; ++i) {
      // Average the accelerations between the two sensors
      double acceleration = (accel_1[i] + accel_2[i])/2;
```

```
        // Discrete integration to get velocity
        double velocity_i = velocity[i-1] + acceleration * time_step;
        velocity[i] = velocity_i;
      }

      max_accel1 = old_max;
      max_accel2 = old_max2;

    Serial.print("Calibration complete\n");
    digitalWrite (led_R, LOW);
    digitalWrite (led_Y, LOW);
  }
  void check_ToF (){
    if (vl53.dataReady()) {
      // new measurement for the taking!
      tof_range = vl53.distance();
      if (tof_range == -1) {
        // something went wrong!
        Serial.print(F("Couldn't get distance: "));
        Serial.println(vl53.vl_status);
        return;
      }
      Serial.print(F("Distance: "));
      Serial.print(tof_range);
      Serial.println(" mm");
      // data is read out, time for another reading!
      vl53.clearInterrupt();
    }
    if (tof_range<250){ // if the tof detects something too close, brake
      minor_braking();
      minor_tof = minor_tof+1;
      while(tof_range<250 && tof_range> 0 && (emerg_stop ==0)){
        // check to see if obstacle is still close
        tof_range = vl53.distance();
        if (tof_range == -1) {
          // something went wrong!
          Serial.print(F("Couldn't get distance: "));
          Serial.println(vl53.vl_status);
          //return;
        }
        emergency_stop();
        delay(200);
      }
      //all clear - release brakes
      minor_unbraking();
    }
  }
  void emergency_stop(){
    check_switch_1();
    if(switch_status_1 == 0){

      stop();
      // turn LED off
```

```
    digitalWrite (led_R, HIGH);
    digitalWrite (led_Y, LOW);
    digitalWrite (led_G, LOW);

    // offload data
    //SerialBT.print("
    Serial.print("emergency stop");
    delay(2000);
  }
}
```

- ## Appendix BVII: LCD Validation Code

```
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BNO055.h>
#include <utility/imumaths.h>
#include <math.h>
#include <ezButton.h>
#include <LiquidCrystal_I2C.h>

// Set the LCD address to 0x3F for a 16 chars and 2 line display
LiquidCrystal_I2C lcd(0x3F, 16, 2);
// 0x28 was found using the i2c scanner
#define I2C_SDA 21
#define I2C_SCL 22
TwoWire I2CBME = TwoWire(0);

int count = 0;

void setup() {
  // Start the serial monitor
  Serial.begin(9600);

  // Setup for the LCD screen
  Wire.begin();
  I2CBME.begin(I2C_SDA, I2C_SCL, 100000);
  lcd.begin();
  lcd.backlight();
  lcd.print("Robojax ESP32");

  delay(2000);


}

void loop() {
  // Checking LCD monitor
  lcd.clear();// clear previous values from screen
  lcd.print("Current speed:");
  lcd.setCursor(0,1);
  lcd.print("Counting:");
  lcd.setCursor(11,1);
  lcd.print(count);
```

```
  delay(200);
  count = count+1;
```

- ## Appendix BVIII: Python Code for Post Processing

```
import matplotlib.pyplot as plt

# Read the data from the text file
data = []
with open("BNO.txt", "r", encoding="utf-8") as file:
    for line in file:
        parts = line.strip().split(": ")
        if len(parts) == 2:  # Ensure the line has both event and value
            event, value = parts
            try:
                data.append((event, int(value)))
            except ValueError:
                print(f"Skipping line: {line.strip()}")  # Skip lines with
invalid value format

# Filter data for major, minor, and emergency braking
major_braking = [(event, value) for event, value in data if "Major
braking" in event]
minor_braking = [(event, value) for event, value in data if "Minor
braking" in event]
emergency_braking = [(event, value) for event, value in data if "Emergency
braking" in event]

# Plotting
plt.figure(figsize=(10, 6))

# Plot major braking
plt.subplot(3, 1, 1)
plt.plot(range(len(major_braking)), [val for _, val in major_braking],
color='blue')
plt.title('Major Braking')
plt.xlabel('Data Points')
plt.ylabel('Value')

# Plot minor braking
plt.subplot(3, 1, 2)
plt.plot(range(len(minor_braking)), [val for _, val in minor_braking],
color='pink')
plt.title('Minor Braking')
plt.xlabel('Data Points')
plt.ylabel('Value')

# Plot emergency braking
plt.subplot(3, 1, 3)
plt.plot(range(len(emergency_braking)), [val for _, val in
emergency_braking], color='red')
plt.title('Emergency Braking')
plt.xlabel('Data Points')
plt.ylabel('Value')
```

```
plt.tight_layout()
plt.show()
```

- ## Appendix BIX: Gantt Chart

  Attached on the following page.