



DEPARTMENT OF
Biomedical Engineering
UNIVERSITY OF WISCONSIN-MADISON

Smart Walker - BME 301

Preliminary Report

Date: 07/10/2026

BME 301: Biomedical Engineering Design

Members:

Nicolas Mandalado (Leader)

Shreya Venkatesh (Communicator)

Navya Jain (BPAG&BWIG)

Xicheng Yang (BSAC)

Client:

Daniel Kutschera

Advisor:

Darilis Suarez-Gonzalez, UW-Madison, Department of Biomedical Engineering

Abstract

Patients recovering from Traumatic Brain Injury (TBI) often lose their ability to walk and must undergo Physical therapy to rehabilitate their legs and neural pathways involved in walking. This is a two-week-long process that involves a number of therapies. As they undergo therapy, they have to perform a 10m walk test, in which they walk 10 meters, and the practitioner times them to see how they progress day by day. The biggest challenge when tracking progression is the fact that there is no commercially available method of testing the weight that the patient puts on the walker, as well as human error being involved in manual time trials. This is problematic for the client because Insurance providers need precise metrics in order to cover costs, and patients have no way to track their own progress as they undergo therapy. The system will include load cells to measure the weight put on the walker, and sensors that track movement speed, and distance traveled. This system will connect to a mobile device interface that will allow storage and display of the data. This will allow the client to accurately monitor progress, giving insurance providers and clients concrete data to show progression. Testing will include a series of trials that will measure: the accuracy of the distance and speed sensors across a known distance, and a series of known weights on the walker, to determine the accuracy and sensitivity of the load cells. By designing a system that can track distance, speed and weight accurately, we hope to change the future of stroke and TBI recovery for the better.

Table of Contents:

Smart Walker - BME 301	0
1. Introduction and Background	3
1.1. Overview	3
1.2. Context and Motivation	3
1.3. Problem Statement	4
1.4. Competing Designs	4
2. Preliminary Designs	7
2.1. Electrical Enclosure 3D Print Material	7
2.1.a. 3D Print Material Research	7
2.1.b. 3D Print Material Design Matrix	8
2.2. Software	11
2.2.a. Software Research and Designs	11
2.2.b. Software Design Matrix	12
3. Final Design	14
3.1. Hardware	14
3.2. Electrical Enclosures	14
3.3. Software	16
4. Methods	17
5. Testing and Results	18
6. Discussion	19
7. Conclusion	20
8. Acknowledgements	21
9. References	22
10. Appendix	24
Appendix A: Product Design Specifications	24
Appendix B: Expense Spreadsheet	35

1. Introduction and Background

1.1. Overview

The Smart Walker is a modular rehabilitation monitoring system that attaches to existing clinical walkers to objectively measure patient mobility metrics during neurorehabilitation. This system incorporates force sensors, a distance and speed tracking sensor, and a real-time display interface to quantify weight-bearing, walking speed, and distance traveled. This is particularly important for patients with traumatic brain injury (TBI), who often experience hemiparesis, impaired balance, and asymmetrical weight-bearing due to damage to motor control pathways.

In contrast to traditional walkers that offer only mechanical support, the Smart Walker serves as a clinical assessment tool. It delivers quantitative and repeatable data to document patient progress, inform discharge decisions, and facilitate insurance reimbursement. The system remains compact, removable, and fully compatible with standard aluminum clinical walkers, while preserving structural integrity and patient safety.

1.2. Context and Motivation

Patients recovering from traumatic brain injury (TBI), stroke, and other neurological impairments frequently rely on walkers during rehabilitation. Clinicians commonly use standardized tests, such as the 10-Meter Walk Test, to evaluate progress. However, current assessment methods are predominantly manual and subjective. Therapists are required to estimate weight distribution visually, manually time walking trials, and approximate distance traveled.

The absence of objective data introduces several challenges: limited availability of quantifiable evidence of patient improvement, difficulty in demonstrating medical necessity to insurance providers, and reduced capacity to monitor subtle changes in gait stability and patient motivation due to a lack of measurable feedback. The Smart Walker addresses this gap by transforming a passive mobility aid into an active rehabilitation measurement tool. By collecting real-time force and distance data, the device enables clinicians to make data-driven decisions and increase transparency in patient progress documentation.

Existing smart mobility devices are frequently expensive, complex, or primarily designed for independent living and fall detection rather than clinical rehabilitation tracking. Consequently, there is a significant opportunity for a compact, affordable, clinic-focused monitoring attachment system.

1.3. Problem Statement

Currently, rehabilitation clinicians do all tests involving patient progress by hand, timing how long it takes a patient to walk a certain distance. Clinicians lack a system that objectively

measures and documents weight-bearing, walking speed, and distance during walker-assisted therapy without compromising walker stability, safety, or usability.

Standard progression metrics do not measure applied force or gait metrics, requiring clinicians to rely on manual observation, which lacks precision and repeatability. Additionally, insurance providers increasingly require objective metrics to justify continued rehabilitation services. Lastly, existing smart mobility devices are expensive, bulky, or intended for long-term monitoring rather than short clinical trials.

Accordingly, the Smart Walker must: measure forces ranging from 0 to 100 kg, measure speeds ranging from 0 to 9.65 km/h, track walking distance accurately to within 10% or less, remain detachable, lightweight, and compatible with standard walkers.

The engineering challenge is to integrate sensing technology into a walker without altering its mechanical performance, increasing fall risk, or exceeding cost and size constraints.

1.4. Competing Designs

Most commercially available mobility aids prioritize walking assistance and user safety over quantitative gait measurement or rehabilitation tracking. The Bure Rise & Go Walker (~\$7,746) [1], as seen in figure 1 is designed for powered standing and transfer assistance, incorporating an electrically operated remote control and braking casters to enhance caregiver-managed safety. However, it lacks the capability to measure gait or pressure metrics. Likewise, the U-Step Neuro Walker (~\$124 [2]), as seen in figure 2 focuses on balance and stability through a mechanical hand brake system but does not include integrated electronics or data monitoring features.

The Rollz Motion Rhythm Neuro Rollator (~\$1,999 [3]) most closely aligns with the concept of a smart walker among current products. Intended for individuals with Parkinson's disease and other neurological gait disorders, it integrates three cueing systems: laser, audio, and vibration, to encourage steady walking. These cues can be customized via a Bluetooth-connected mobile app, and the device folds for easy transport. Although it enhances gait through external cueing, it does not offer detailed quantitative gait analysis or rehabilitation progress monitoring. An image of this walker can be seen in figure 3.

Research prototypes incorporating FlexiForce™ sensors illustrate ongoing efforts to integrate force sensing into walker designs. These systems translate applied force through a microcontroller and transmit data via Bluetooth for further processing. Frequently, they use inertial measurement units (IMUs) to estimate gait metrics rather than directly measuring walking speed [4]. The Camino smart walker (~\$2,999 [5]) includes advanced assistive features such as auto-boost, auto-brake, lighting, and application connectivity, but it primarily serves as an intelligent mobility aid rather than a rehabilitation monitoring device. Overall, the current market demonstrates a gap between high-cost assistive automation and low-cost mechanical

walkers, with limited options that integrate sensing, connectivity, and quantitative gait monitoring within a single device. An image of the Camino smart walker can be seen in figure 4.

There is no commercially available walker that measures distance, gait speed, and force applied and provides real-time data about all three metrics. However, there is one research prototype worked on by the Institute of Telecommunications in Lisbon, Portugal that attempts to measure force applied and distance travelled using load cells for weight bearing metrics and LIDAR, but their design included it to be a fixed system, not allowing it to be easily attachable and removable from walkers [6]. Additionally, one thing our design does which this research prototype does not is provide real time data via a developed app.



Figure 1: Bure Rise and Go Walker [1]



Figure 2: U-Step Neuro Walker [2]



Figure 3: Rollz Motion Rhythm Neuro Rollator [3]



Figure 4: Camino Smart Walker [5]

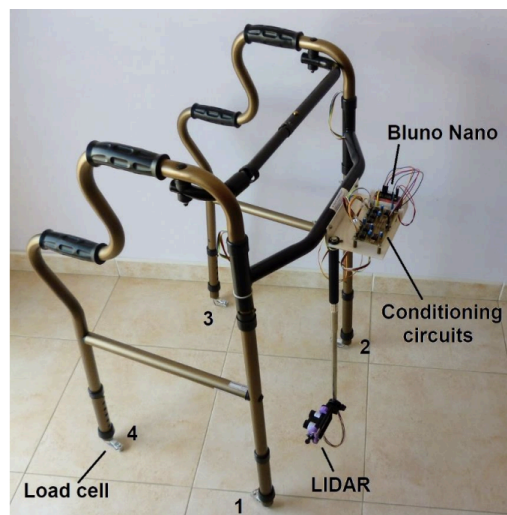


Figure 5: Research Prototype from Instituto de Telecomunicações in Portugal [6]

2. Preliminary Designs

2.1. Electrical Enclosure 3D Print Material

2.1.a. 3D Print Material Research

Concept A: PETG

The first concept is Polyethylene Terephthalate Glycol-Modified (PETG). PETG is a modified version of standard PET plastic; the added glycol during production makes the material less brittle and easier to melt [7]. Visually, the plastic is transparent, allowing fine details, dimensional accuracy, and strong layer adhesion. However, 3D-printed PETG parts will not appear transparent in visible light. PETG offers several benefits, including high strength, toughness, and impact resistance, and it prints easily. The material withstands a variety of outdoor conditions, including UV light, water, and other common chemicals. A disadvantage is that it may flex or creep under sustained clamping force [8].

Concept B: TPU

The second concept is Thermoplastic Polyurethane (TPU). TPU filament is a flexible, rubber-like material commonly used for phone cases, seals, watch straps, and wheels. The Smart Walker team used it in the past for the end cap 3D print; it provided a nice cushion adequate for protecting electrical components, and it was also very straightforward to print. TPU also has several mechanical benefits, including high elasticity, durability, and strong resistance to impact and wear [8]. Additionally, it has high shock absorption and vibration dampening, which could help reduce noise in the electrical signals in our mmWave radar circuitry [9]. A disadvantage is that the material can be too rubbery, which may be unstable for long-term attachment to the walker's posts.

Concept C: ABS

The third concept is Acrylonitrile Butadiene Styrene (ABS). ABS is an incredibly versatile material that can be easily molded; hence, it is used in various applications such as automotive parts, consumer goods, electronics, and toys. Some benefits are excellent impact resistance, as well as high strength and stiffness [8]. ABS also has great electrical insulating properties, which is why it is also commonly used for electronic enclosures, which is what we need [10]. A disadvantage is its poor weather resistance, so it is susceptible to UV degradation, causing discoloration and changes in brittleness and thermal expansion.

2.1.b. 3D Print Material Design Matrix

<i>Criteria (weight)</i>	Concept A: PETG	Concept B: TPU	Concept C: ABS

<i>Strength (35)</i>	9	31.5	7	24.5	6	21
<i>Limit of Elastic Deformation (30)</i>	7	21	10	30	7	21
<i>Longevity (20)</i>	9	18	8	16	7	14
<i>Ease of Fabrication (10)</i>	8	8	7	7	4	4
<i>Cost (5)</i>	10	5	6	3	7	3.5
<i>Total (100)</i>	83.5		80.5		63.5	

Table 1: Design matrix outlining the 6 criteria for 3 materials for the electrical housing prints and their respective scores. The green-highlighted categories indicate the highest scores of the three designs in the specific category. Scores are out of 10 points; displayed as Score | Weighted Score.

Strength - Strength refers to a housing's ability to carry load and resist impact without cracking or failing. For a 3D printed part, this depends on both the material and how well the printed layers bond, since layer boundaries are typically the weakest point. This criterion was weighted the highest at 35/100 because both devices face demanding structural conditions. The inner device sits in the load path between the user and the ground, so it must support a significant portion of the user's body weight and transmit it to the load cell. A failure could cause the walker to give way, creating a serious fall risk. The outer device must protect the electrical components as the walker is bumped against walls and furniture or knocked over, while also withstanding the clamping force that holds it to the walker post. PETG scored the highest with a score of 9/10. It combines high strength and stiffness with good impact resistance, and its strong layer adhesion allows printed parts to carry load without separating along layer lines [7]. This allows the inner device to support the user's weight and the outer device to survive everyday impacts. TPU scored second with a score of 7/10. TPU is extremely tough, resistant to fracture, and prints with excellent layer bonding, making it especially effective at protecting the outer device's electronics from impact [9]. However, its low stiffness means it deflects under load rather than rigidly supporting it, limiting its effectiveness in the inner device and its grip on the walker post in the

outer device. ABS scored the lowest with a score of 6/10. Printed ABS tends to have weaker layer adhesion, and residual stresses from warping can further weaken the part [10]. As a result, it is more brittle and prone to cracking under both repeated loading and impact.

Limit of Elastic Deformation - The limit of elastic deformation describes how much a material can deform under load and still fully return to its original shape. Beyond this limit, the material deforms permanently or cracks. This criterion was weighted the second highest at 30/100 because both devices will be repeatedly deformed over a long period of use. The inner device will be loaded with every step the user takes, and if pushed past its elastic limit, it will accumulate permanent deformation that alters load transfer to the load cell and causes measurements to drift. The outer device must flex each time it is clamped onto or removed from the walker post and return to its original shape to maintain a secure grip, while also absorbing small impacts and vibrations during use. TPU scored the highest with a perfect score of 10/10. As an elastomer, TPU can undergo very large deformations and fully recover, giving it by far the largest elastic range of the three materials [9]. This allows the inner device to withstand peak loads, such as a user suddenly putting their full weight on the walker, without permanent damage. It also allows the outer device to flex repeatedly during attachment without fatiguing, while its vibration dampening can help reduce noise in the mmWave radar signals [9]. PETG and ABS both scored 7/10. Both are rigid thermoplastics that can only deform a small amount before yielding or cracking [10], limiting flexibility in the outer device and peak load margin in the inner device. PETG is more ductile but prone to creep under sustained loads, such as prolonged leaning or constant clamping force [8]. ABS resists creep better but is more brittle and has a smaller margin before cracking [10]. Because each material's advantage is offset by a comparable weakness, the two were scored equally.

Longevity - Because this housing compartment will be constantly attached and removed from a walker, it is important that the housing unit is durable and can withstand this constant wear-and-tear, this is why it was weighted the third highest at 20/100. Amongst the three materials PETG scored the highest with a score of 9/10, then TPU with a score of 8/10, with ABS then ranking the lowest with a score of 7/10. PETG scored the highest due to the material's excellent layer adhesion that would allow for the housing compartment to be strong and durable, and is stronger than TPU in terms of the impact resistance [11]. TPU scored the second highest. In absolute terms TPU is extremely wear resistant and is wear resistance up to eight times that of natural rubber, meaning TPU would essentially never wear through surface abrasion [12]. But the reason it scored lower than PETG is because TPU is too flexible in nature, so the grasp onto the walker of a housing compartment made of TPU would not be nearly as strong as that of a PETG housing compartment. And lastly ABS scored the lowest because it tends to have weaker layer adhesion than PETG and TPU, resulting in printed ABS parts to be more brittle and prone to breakage [13].

Ease of Fabrication - All the housing compartments will be 3D printed using a Bambu Lab 3D printer from the UW-Madison Grainger Engineering Design Lab. This criteria was weighted the

second lowest at 10/100, as, no matter the material, the housing compartments would be produced the same one, which is 3D printed. When comparing the three materials, PETG scored the highest at 8/10 because of its ability to withstand warping during the printing process, whereas ABS is more prone to warping [14]. In addition, PETG does not require any specific enclosure or specialised hardware for the 3D printing process, and is printed at a typical temperature and does not require any special modification [15]. ABS scored the lowest, with a score of 4/10, because it requires more special modifications in comparison to the other two materials. For example, to 3D print something using ABS, it requires an enclosed printer [16]. Additionally, ABS warps significantly more than PETG and TPU, and as ABS cools down, cracking, warping, and poor bed adhesion could occur [16]. The geometry of our housing compartment, one in which there are sharp corners and large surface areas, is one that could be extremely vulnerable to warping. Additionally, ABS can release volatile fumes when printing, meaning the environment in which it is being printed has to be extremely well ventilated otherwise, it poses a significant safety risk [17]. And lastly, TPU was ranked in between PETG and TPU with a score of 7/10 because it doesn't possess any safety issues or require any special modifications, but there are narrower parameters that one must consider and understand when printing with this material [18], so the complexity of the material increases in comparison to printing with PETG.

Cost - Cost is not a major limiting factor when it comes to selecting materials for the housing compartment; however, we would still like to be mindful of cost to ensure that the system is as cost-effective as possible. This is why this criteria was ranked the lowest at 5/100. All materials will be procured from the UW-Madison Grainger Engineering Design Lab, and the housing units will be 3D printed. A housing unit of PETG will be printed using a Bambu Lab printer, at a cost of \$2.00 per 100g of PETG. A TPU housing unit produced on the same printer would cost \$4.00 per 100g, and an ABS housing unit would cost \$3.00. A housing compartment made of PETG would be the most cost-effective amongst the three choices, resulting in a score of 5/5, and a housing compartment made of TPU would be the least effective, which is why we scored it 3/5.

2.2. Software

2.2.a. Software Research and Designs

Concept A: 2 Natives: SwiftUI + Kotlin

The first concept is to maintain two separate native applications: SwiftUI for iOS and Kotlin with Jetpack Compose for Android. SwiftUI is Apple's native framework for Apple platforms including iOS, macOS, etc.[19], while Jetpack Compose is Android's modern Kotlin-based UI framework [20]. This approach provides direct access to each platform's native Bluetooth APIs, making it a reliable option for communication with the Smart Walker's BLE devices. It would also allow the existing SwiftUI application to remain largely unchanged. However, most features

and possible future improvements would need to be implemented and maintained twice and require much more development effort. It does not have desktop support.

Concept B: Skip

The second concept is Skip, a framework that allows applications to be written primarily in Swift and SwiftUI while producing a native Android application using Jetpack Compose [2]. This could allow much of the existing Smart Walker SwiftUI code to be reused with minimum migration effort. Skip can also access Android-specific APIs when necessary, making BLE communication possible. However, Skip is a newer and less established framework, so compatibility problems or limitations may occur, particularly when working with hardware-specific functionality such as BLE. It does not have desktop support.

Concept C: Kotlin Multiplatform

The third concept is Kotlin Multiplatform (KMP), which allows Kotlin code to work on Android, iOS, desktop, web, and other platforms [22]. Smart Walker components can share a common implementation. This provides native-platform integration while reducing duplicated code and offers good potential for desktop support. However, because the existing application is written in Swift, adopting KMP would require significant rewriting.

Concept D: Flutter

The fourth concept is Flutter, Google's cross-platform application framework using the Dart programming language. Flutter officially supports Android, iOS, Windows, macOS, Linux, and web applications from a shared codebase [19]. Similar to KMP, Smart Walker components can share a common implementation. This will greatly simplify maintaining the application across multiple platforms. The main disadvantage is that the existing SwiftUI application would need to be largely rewritten in Dart.

2.2.b. Software Design Matrix

<i>Criteria (weight)</i>	Concept A: 2 Natives		Concept B: Skip		Concept C: Kotlin multiplatform		Concept D: Flutter	
<i>Swift reuse (20)</i>	5	10	10	20	0	0	3	6
<i>Multiplatform compatibility</i>	10	40	8	32	8	32	10	40

(40)								
Maintenance (40)	0	0	5	20	8	32	8	32
Total (100)	50		72		64		78	

Table 2: Design matrix outlining the 3 criteria for 4 software options to port current SwiftUI app to multiplatform. The green-highlighted categories indicate the highest scores of the three designs in the specific category. Scores are out of 10 points; displayed as Score | Weighted Score.

Swift reuse - Swift reuse describes how much of the existing Smart Walker SwiftUI app can be preserved. It was weighted 20/100 because reusing tested code can reduce development time, but the rewrite will be much more manageable with AI-assisted development and long-term compatibility is more important. Skip scored highest at 10/10 because it is designed to reuse Swift and SwiftUI code across iOS and Android. Two natives scored 5/10 because the iOS app can remain, but Android must be rebuilt in Kotlin. Flutter scored 3/10 because the Swift code must be rewritten in Dart but the general Swift structure of the app can be preserved. Kotlin Multiplatform scored 0/10 because most of the current Swift implementation would need to be fully replaced.

Multiplatform compatibility - Multiplatform compatibility describes how well each approach can support multiple operating systems. This criterion was weighted at 40/100 because one of the main goals of this redesign is to expand the Smart Walker application beyond iOS. Flutter and the two-native approach both scored the highest with scores of 10/10. Flutter officially supports iOS, Android, macOS, Windows, and Linux. The two-native approach also provides excellent platform compatibility because separate native applications can be developed for any required platform. Skip scored 8/10 because it provides strong support for iOS and Android, which are the project's primary targets, but it has limited desktop support and less tested reliability compared to other options. Kotlin Multiplatform also scored 8/10 for similar reasons: multiplatform support, but less tested reliability on iOS.

Maintenance - Maintenance describes the amount of effort required to update, debug, and extend the software after the multiplatform application has been developed. This criterion was weighted at 40/100 because the Smart Walker project will likely continue to be developed by us or future team members. Thus a software architecture with less duplicated code is preferred. Flutter and Kotlin Multiplatform scored the highest with scores of 8/10, since they both contain the whole multiplatform app in a single codebase, meaning a feature or bug fix can generally be applied once and used across multiple platforms. Skip scored 5/10 because it can also reduce duplicated development between iOS and Android, but its smaller and newer ecosystem may create additional maintenance challenges. The two-native approach scored 0/10 because the iOS and

Android applications would be maintained as separate codebases. Any modifications will need to be implemented and tested separately, producing the greatest long-term maintenance burden.

3. Final Design

3.1. Hardware

The final Smart Walker design involves using integrated end caps which will house the load cells, which will measure how much force is being applied to the walker, serving as a metric on how much support the patient needs to walk. Additionally, in order to track the distance the patient has travelled, mmWave Radar sensors will be utilised, and the sensors will be placed in the electrical housing component that is attached to the walker. The mmWave radars require a receiving sensor, which will be anchored onto the wall the patient will walk to, in order to get accurate data measurements. Figure 6 below demonstrates the electrical circuit that will be created and housed in the electrical housing unit, in order to make the sensors and load cells functional.

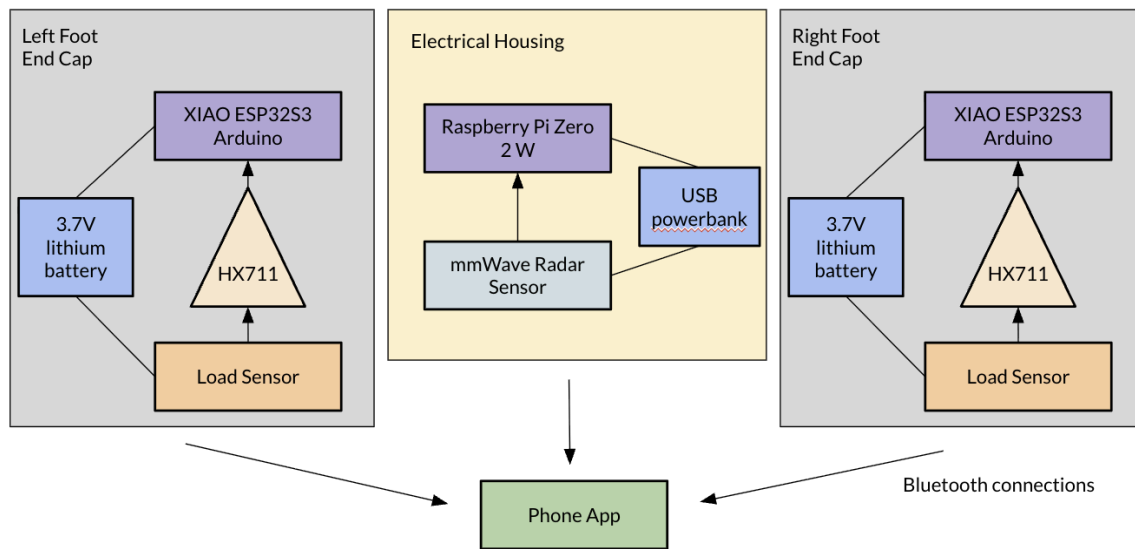


Figure 6: Circuit Diagram Flow for Electrical Attachments

3.2. Electrical Enclosures

The Smart Walker uses three 3D-printed enclosures. Two load cell end caps sit on the walker's rear legs, and one radar enclosure clamps onto the front of the walker frame. Based on the material design matrix (Table 1), all enclosures will be printed in PETG on a Bambu Lab printer at the UW-Madison Grainger Engineering Design Lab. The redesign addresses problems found with the previous prototype: loose internal wiring, a clamp that was hard to attach and remove, a material that wasn't durable enough, and end caps that didn't sit flush with the floor.

3.2.a. Load cell

Each end cap replaces the standard rubber foot on a rear walker leg. The top of the end cap is a cylindrical insert that slides into the walker leg, which has a 1 in (25.4 mm) inner diameter. Friction alone holds it in place. The insert is sized for a snug fit so the end cap stays secure while the walker is in use, yet can still be pulled out by hand without tools. It also works at every walker height setting. Below the insert, the 50 kg load cell sits directly in the load path between the walker leg and the floor. All vertical force the user puts through that leg therefore passes through the load cell. Walker legs usually splay outward slightly, meeting the floor at an estimated 5° to 10° from vertical. The end cap base will be angled to match this so it sits flat on the floor and the load cell is loaded along its axis, which reduces errors from side loading. The exact angle will be measured and refined in later testing. A side compartment holds the HX711 amplifier, the XIAO ESP32S3 microcontroller and the 3.7 V lithium battery (Figure 6). Internal channels route the wires from the load cell to the HX711 so they stay away from moving or load-bearing surfaces. A USB-C port lets the battery be charged without taking the end cap apart. The end cap is designed to withstand the 136 kg load in the product design specifications without permanent deformation. Figure 7 shows the CAD model.

3.2.b. mmWave Radar Electrical Enclosure

The radar enclosure holds the mmWave radar sensor, the Raspberry Pi Zero 2 W and a USB power bank. It mounts on a [front] walker leg with the radar facing forward, toward the direction of travel. mmWave signals pass through thin plastic, so the front wall in front of the antenna is kept as thin as practical, and there is no metal hardware in the signal path. The enclosure will attach to the leg with a latching clamp that goes on and comes off in 5 to 10 seconds without tools, as the product design specifications require. The clamp design is still in development. PETG flexes enough for repeated latching and is rigid enough to keep a firm grip on the leg. A heat sink on the Raspberry Pi pulls heat away from the processor, and ventilation holes in the housing next to the Pi let that heat escape so it doesn't build up inside the enclosure. The housing opens easily, so the power bank can be reached and recharged without removing any electronics. The enclosure sticks out less than 10 cm from the walker frame so the walker still fits through doorways. Figure 7 shows the CAD model.

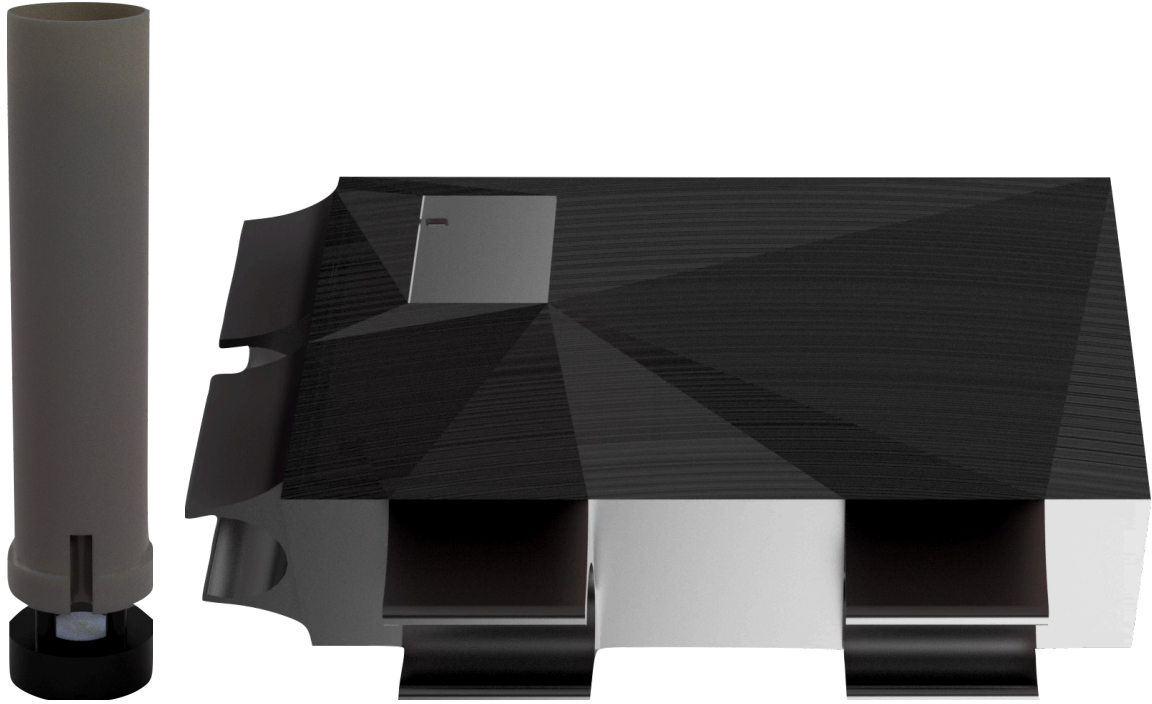


Figure 7: Hardware CAD models

3.3. Software

The smart walker mobile application was developed using SwiftUI for iOS and serves as the primary user interface for real-time monitoring, data recording, and post-trial analysis. The application connects wirelessly to three independent sensor modules via BLE, integrates their data streams, and presents clinically relevant mobility metrics to the user. The application is structured into three main functional layers: bluetooth communication, data processing and storage, and user interface.

This semester, software development focuses on transitioning the existing iOS application to a cross-platform architecture to support both iOS and Android devices. As stated in the design matrix, after evaluating several development frameworks, Flutter was selected as the primary framework due to its ability to support multiple platforms from a shared Dart codebase. The migration process involves reconstructing the existing SwiftUI views as Flutter widgets while preserving the functionality and overall organization of the original application. Major interface components, including device connection controls, real-time sensor displays, trial management screens, and recorded data visualization, can be translated into reusable Flutter widgets (marked in red in Figure 8) [20].

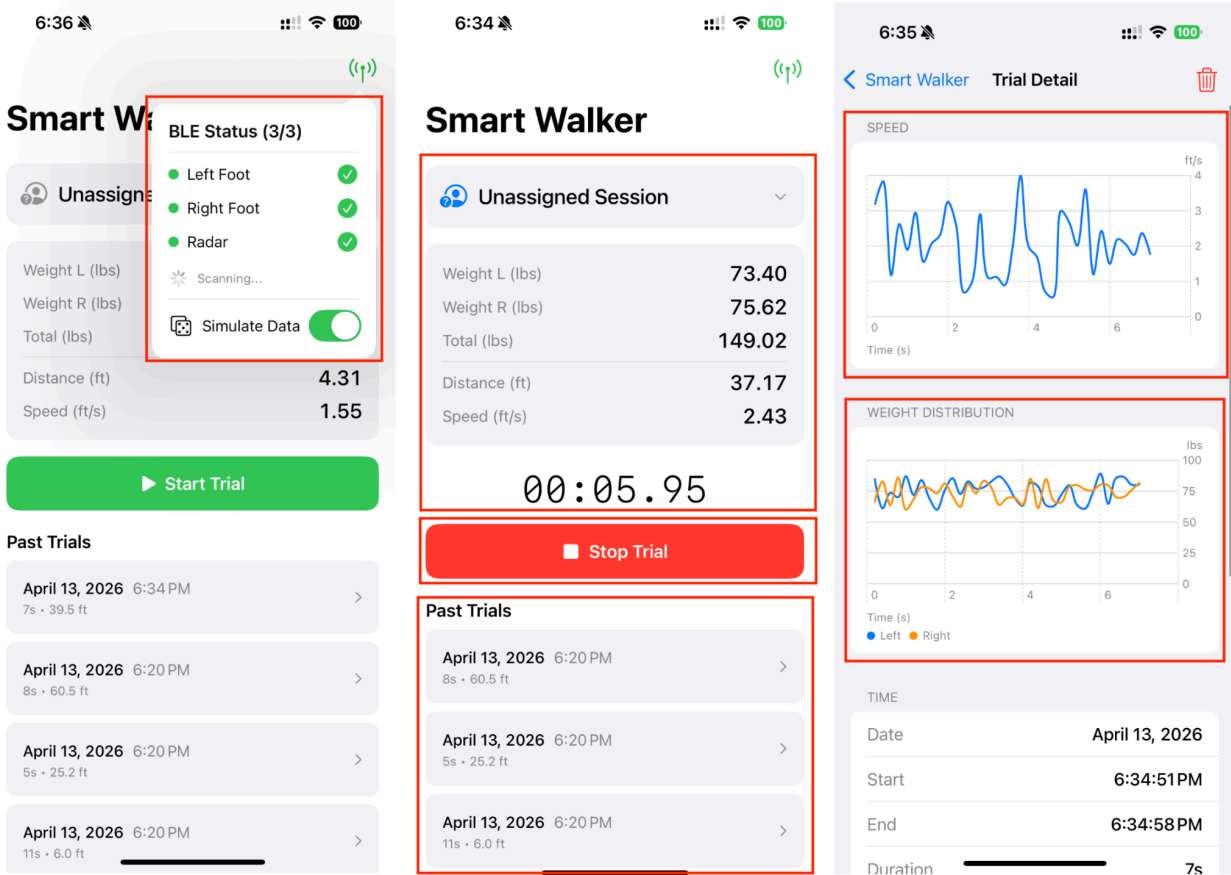


Figure 8: Current UI with UIView markings

Beyond the user interface, the transition also requires adapting the application's underlying communication and data processing architecture. The original application utilizes Apple's Core Bluetooth framework to communicate with the sensor modules. In the Flutter implementation, this functionality must be replaced with a cross-platform BLE solution capable of supporting device discovery, connection management, and real-time sensor data transmission on both iOS and Android.

4. Methods

The Smart Walker system was constructed by integrating two 50 kg load cells into custom 3D-printed end caps attached to the walker's rear legs. The end caps will be modeled in CAD to securely house the load cells while maintaining structural alignment with the walker frame. They will be fabricated using 3D printing and mechanically fastened to ensure stability. Each load cell was connected to an HX711 load cell amplifier, which interfaced with an Arduino Uno WiFi Rev2 microcontroller located within a central electrical enclosure secured between the walker crossbars. The enclosure is designed to protect internal circuitry while maintaining

accessibility for maintenance and future sensor upgrades. The system was powered by a 9V battery connected through an inline power switch.

The load cells were calibrated with known static weights to establish a force-to-voltage conversion factor. Multiple trials were conducted to verify the linearity and repeatability of the measurements. The LiDAR module was installed at the front of the electrical housing and aligned toward a fixed wall target. The team plans to replace this with mmWave Radar, but the concept remains the same. Distance measurements were validated against tape-measured values to assess baseline accuracy. All sensor data was transmitted from the Arduino to a computer via serial communication for real-time monitoring and logging. Custom software was developed to simultaneously sample force and distance data, enabling synchronized analysis of walker loading and displacement during testing trials.

5. Testing and Results

The following tests will check whether the Smart Walker meets the product design specifications (Appendix A). Unless stated otherwise, a test passes if measurements are within 10% of the reference value, the PDS accuracy requirement. Results will be added as testing is completed.

5.1. *mmWave radar occlusion sensing testing*

This test will check that the mmWave radar measures distance and walking speed accurately, including when the signal is blocked in ways common during rehabilitation walking. The radar enclosure will be mounted on the walker leg facing forward, and the walker will be pushed along a tape-measured course in an open hallway. Course lengths will be 10 m, matching the standard 10-Meter Walk Test, and 45.7 m (150 ft), the team's target range. Reference speed will be calculated from the course length divided by the time measured with a stopwatch (or timing gates, if available). Trials will be run at three paces, slow, moderate and fast (approximately 0.3, 0.6 and 1.0 m/s), to cover realistic walker speeds within the 0 to 9.65 km/h PDS range.

Each condition will be tested over 5 trials. The conditions are a no-occlusion baseline, partial occlusion with a hand passed in front of the radar (about 1 s every 5 s), and full occlusion with a person stepping between the radar and the wall-mounted receiver. To meet the PDS requirement for non-linear distances, additional trials will be run on an L-shaped course. Metrics will include distance error and speed error compared with the reference values, track continuity, recovery time after occlusion, false positive rate, and dropout rate [23]. The test passes if distance and speed are within 10% of the reference in all baseline trials and the system recovers from occlusion within 2 s.

5.2. *Load cell measurement testing*

This test will check that each load cell end cap measures applied force accurately and repeatably. Each end cap will be tested on its own with known calibrated weights from 0 to 50 kg, the rated capacity of each load cell, in 5 kg increments. Weights will be added in increasing steps and then removed in decreasing steps to check for hysteresis. Each load will be repeated 5 times. To check for error from the angle of the walker leg, trials will also be run with the end cap installed on the walker leg at its normal angle. Then, with both end caps installed, a user will lean on the walker while the walker's rear legs stand on a calibrated reference scale. The scale readings will be compared with the combined end cap readings.

Statistical analysis will include percent error and root mean square error (RMSE) at each load, standard deviation across repeated trials, and hysteresis between loading and unloading. To measure drift, a constant 25 kg load will be held for 10 minutes while readings are recorded every 10 s. The test passes if all readings are within 10% of the reference load and drift is less than 1% over 10 minutes.

5.3. *Wireless connectivity testing*

This test will check that the phone app can receive data from all three sensor modules (two end caps and the radar enclosure) over Bluetooth Low Energy at the same time, reliably and without data loss. In a baseline test, all three modules will stream to the phone for 10 minutes while the walker sits still. In a walking test, the walker will be pushed along the 150 ft course while the phone stays at the starting point, to check range and connection stability as distance grows. In a reconnection test, each module will be powered off and back on during a session to measure how long it takes to reconnect and whether the app records the gap correctly. Metrics will include packet delivery ratio, dropout count and duration, latency, and reconnection time. The test passes if the packet delivery ratio is at least 99%, no dropout lasts longer than 1 s, and every module reconnects within 5 s.

6. Discussion

It is important that load measurement, speed, and distance testing are accurate, as these are the key quantitative identifiers in the client requirements, and their accuracy will be used to confirm the reliability of our device. If any of these tests initially fall below the desired standard, modifications will be made to improve the system and ensure data consistency. Based on past testing results, we determined that we require more feasibility and effectiveness in testing before using the smart walker device in clinical settings. For the load cell testing, the average load error was 23.5% lb/lb, and 13.1% lb/lb up to 120lbs (54kg). However, the weight capacity of the load cell is 100kg, so we are going to do a recalibration of the load cell systems with calibrated weights between 0 and 100kg. For the mmWave radar, we compared the actual and measured distances from 2-10m are accurate, with a distance error of 5.7% m/m, which is within the range

of our product design specifications. However, for distance measurements above 10m, the results had errors exceeding 50% m/m due to configuration issues in the mmWave radar code and were therefore not tested. Additionally, when the smart walker is in use, any recorded data needs to be in accordance with HIPAA, to protect patient identity and confidentiality [24].

Potential sources of error in the testing process, related to inaccurate measurement of distance and speed, can be due to calibration, testing procedures, or mechanical design of electrical enclosures. In addition, mmWave radars are highly sensitive, which can lead to false positives. Potential sources of error in load measurement could include mechanical damage from overloading or uneven weight distribution. 3D-printed tolerances can also affect force transfer and electrical noise in the strain gauge amplifier.

7. Conclusion

This project aims to provide neurorehabilitation physical therapists and patients with an accurate and convenient way to track real-time measurements of patient performance, specifically of speed, pressure, and distance, without altering the safety or function of a standard walker. Through research and testing, it was determined that a modified version of Smart Walker 2.0 will include a sensor combination of load cells to measure pressure, an mmWave radar sensor to measure speed and distance. The mmWave radar sensor will improve occlusion sensing and reduce the impact of environmental factors compared to the previously used LiDAR sensor, making it an effective replacement. These components will provide accurate, reliable data while minimizing the walker's structural integrity, ensuring safety. An Arduino Uno WiFi Rev2 will be used to connect WiFi and Bluetooth data transmission and ensure that the system is compatible with a variety of platforms.

The team will successfully produce a proof-of-concept prototype that will meet all the client's requirements, with minimal error of $\pm 2\%$ compared to the manual and actual measurements, as shown in the load measurement testing and mmWave radar testing. Fabrication is straightforward and requires minimal unique parts apart from the sensor housing in the integrated end cap design, to ensure bulk production and ease of manufacturing. The cost for the entire system is also kept under the client's budget of \$500.

Future work would involve completing soldering components permanently to a PCD board in order to avoid loose wires or mechanical contacts that can cause unstable readings or safety hazards. In addition, incorporating clinical trials and human subject testing with on-site patients can provide realistic feedback and help determine adjustments we can make, especially for ergonomics.

8. Acknowledgements

The team extends special thanks to advisor Dr. Suarez for her advice throughout the design process, as well as the client Dan Kutschera for his ongoing support and the inspiration behind the design.

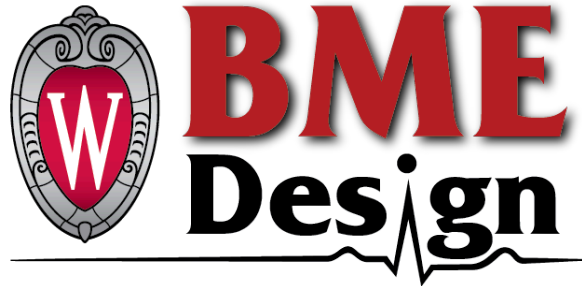
9. References

- [1] Rehabmart.com, “Sit to Stand Patient Lift, Bure Rise & Go Walker by TR Equipment | 330 lb. Weight Capacity, Power Base Widening,” Rehabmart.com, 2026.
<https://www.rehabmart.com/product/bure-rise-go-walker-47525.html>
- [2] “U-Step Neuro Walker,” Performancehealth.com, 2018.
https://www.performancehealth.com/u-step-neuro-walker?srsId=AfmBOOpEg6EsUnvG_JDjrRDqb-GvIkD-xmPufm0GeStIoNgRvemTxAeq
- [3] “Parkinson rollator walker | Rollz Motion Rhythm,” Rollz International.
<https://www.rollz.com/rollator-walkers/parkinson-rollator-walker/>
- [4] “Smart Walker using FlexiForce Sensors | Tekscan,” Tekscan.com, 2015.
<https://www.tekscan.com/applications/smart-walker-using-flexiforce-sensors>
- [5] “Camino : The World’s First Smart Walker,” Camino Mobility. <https://caminomobility.com/>
- [6] V. Viegas, J. M. Dias Pereira, O. Postolache, and P. S. Girão, “Monitoring Walker Assistive Devices: A Novel Approach Based on Load Cells and Optical Distance Measurements,” *Sensors* (Basel, Switzerland), vol. 18, no. 2. Switzerland, p. 540, Feb. 10, 2018. doi: 10.3390/s18020540.
- [7] “What is PETG Plastic? Information on PETG | Acme Plastics,” Acmeplastics.com, 2026.
<https://www.acmeplastics.com/what-is-petg>.
- [8] “3D Printing Filament | FDM Durable Plastic Parts & Prototypes | Curbell Plastics,” Curbell Plastics, Dec. 16, 2022.
<https://www.curbellplastics.com/materials/specialty-products/prototyping-tooling/3d-printing-filament/>
- [9] MarkForged, “Your TPU 3D Printing Questions Answered,” *markforged.com*.
<https://markforged.com/resources/blog/your-tpu-3d-printing-questions-answered>
- [10] Protolabs, “ABS Plastic: Advantages, Disadvantages, and Applications,” *www.protolabs.com*, 2024. <https://www.protolabs.com/materials/abs/>
- [11] David, “PETG vs TPU vs ABS: Choosing the Right 3D Printing Filament for Drone Parts,” UAVMODEL Insights, June 14, 2026.
<https://blog.uavmodel.com/petg-vs-tpu-vs-abs-choosing-the-right-3d-printing-filament-for-drone-parts/>
- [12] “TPU Elastomer Benefits and Applications,” Protolabs.com, 2019.
<https://www.protolabs.com/materials/tpu/>

- [13] schafe, “Poorly adhered layers with ABS,” UltiMaker Community of 3D Printing Experts, Jan. 30, 2014. <https://community.ultimaker.com/topic/3932-poorly-adhered-layers-with-abs/>
- [14] BigRep Industrial 3D Printers, “ABS vs PETG: Material Comparison for Durable Industrial Prints,” BigRep Industrial 3D Printers, Apr. 22, 2026. <https://bigrep.com/posts/abs-vs-petg-material-comparison/>
- [15] C. Schwaar, “PETG Filament Quick Guide: When to Use It & When Not To,” All3DP, July 17, 2026. <https://all3dp.com/1/petg-filament-quick-guide-when-to-use-it-when-not-to/>
- [16] “ABS Print Warping: How to Stop It,” All3DP, Sept. 15, 2021. <https://all3dp.com/2/how-to-prevent-abs-from-warping-on-a-heated-bed/>
- [17] B. Lab, “Toxicity of filaments,” Bambu Lab Community Forum, Apr. 18, 2023. <https://forum.bambulab.com/t/toxicity-of-filaments/10287>
- [18] J. Jain, “TPU Filament Printing Guide: Settings, Tips & Tricks - Zbotic,” Zbotic, Mar. 11, 2026. <https://zbotic.in/tpu-filament-printing-guide-settings-tips-tricks/>
- [19] Flutter, “Flutter - Beautiful native apps in record time,” *Flutter.dev*. <https://flutter.dev/>
- [20] “Kotlin for Jetpack Compose,” *Android Developers*, 2024. <https://developer.android.com/develop/ui/compose/kotlin>
- [21] *SKIP*. <https://skip.dev/>
- [22] A. Murtada, B. S. M. R. Rao, M. Ahmadi, and U. Schroeder, “Occlusion-Informed Radar Detection for Millimeter-Wave Indoor Sensing,” *IEEE Open Journal of Signal Processing*, vol. 5, pp. 976–990, 2024, doi: <https://doi.org/10.1109/ojsp.2024.3444709>.
- [23] <https://www.hipaajournal.com/why-is-hipaa-important/>
- [24] <https://nami.ai/blog/mmwave-radar-sensing/#:~:text=It%20is%20far%20less%20accurate,in%20much%20smaller%2C%20discreet%20packaging>

10. Appendix

Appendix A: Product Design Specifications



Smart Walker - BME 400

Product Design Specifications

September 17, 2026

Updated: September 17, 2026

Section 302

Client:	Dan Kutschera	dankutschera@gmail.com
Advisor:	Darilis Suarez-Gonzalez	dsuarez@wisc.edu
Team:	Nicolas Maldonado (Team Leader)	namaldonado@wisc.edu
	Navya Jain (BWIG & BPAG)	njain52@wisc.edu
	Shreya Venkatesh (Communicator)	svenkatesh9@wisc.edu
	Xicheng Yang (BSAC)	xyang622@wisc.edu

Function:

Patients with traumatic brain injury (TBI) frequently experience significant trauma followed by intensive rehabilitation aimed at restoring mobility and facilitating a return to daily activities [1]. During rehabilitation, clinicians often face challenges in objectively measuring patient progress, limiting their ability to provide quantifiable feedback and to show insurance providers evidence of improvement, which complicates reimbursement for clinical services [1]. The proposed smart walker accessories will objectively measure applied pressure, walking speed, and distance covered during patients' daily evaluations. These data will be reported and displayed in real time to support clinicians in monitoring patient progress and enhancing patient motivation. Ultimately, the device is expected to streamline Medicare documentation requirements and provide objective indicators of patient readiness for discharge.

Client requirements:

- The device must measure pressure from 0-100 kg, speed from 0-9.65 km/h, and track appropriate distances (limited constraint).
- The device must be suitable for both physical training sessions and clinical everyday usage.
- The device attachments must remain compatible with existing walkers without compromising their structural integrity.
- Each device attachment should be separable and usable both in tandem and individually.
- The device should send real-time data to a mobile device and website for collection and display.
- The device needs to be compact, user-friendly, accurate, and reliable within the project budget of approximately \$500.
- The device must be easy to sanitize for daily use, including domestic personal purposes.

Design requirements:

1. Physical and Operational Characteristics

a. Performance requirements:

- i. The smart walker components should be easily detachable so that they can be connected to any standard walker.
- ii. The housing compartments should withstand repeated removal and attachment without significant wear and tear.
- iii. The components, specifically the load sensor, should withstand a load of 136kg, the standard load expected to be supported by a walker for patients undergoing rehabilitation with one-sided weakness, often resulting from a stroke [2].
- iv. The electronic display should relay real-time information about the patient's walking pattern.
- v. The electronic components and sensors should be able to measure weight-bearing, distance traveled, and speed traveled.

1. The radar should be able to measure non-linear distances

- vi. All attachments to the walker should not impede its function or stability.
- vii. The app should be compatible with both iOS and Android devices.
- viii. The device should have a secure, adjustable section for attaching the smartphone to the walker.

b. Safety:

- i. The structural integrity and stability of the walker should not be compromised
- ii. The device must withstand the patient's weight.
- iii. All electrical components should contain ESD (electrostatic discharge) prevention.
- iv. All electrical components must comply with applicable ISO, IEC, and FDA requirements.

c. Accuracy and Reliability:

- i. The walker must measure distances, speeds of 0-9.65km/h, and pressures of 0-100 kg within 10% of the absolute values.

- ii. Metrics should be accurate over distances of at least 10m (standard 10-Meter Walk test)

d. *Life in Service:*

- i. The walker accessories should withstand up to 50 trials per day over 10 years before requiring serious maintenance (electrical component replacement).

e. *Shelf Life:*

- i. The walker is expected to last a standard shelf life of 3-5 years, as over time the rubber soles would wear out [3].
- ii. The mmWave radar should last up to 10 years [4].
- iii. Load cells have a lifespan of 10 years. However, their lifespan is dependent on their fatigue life, specifically the number of cycles, so a load cell's lifespan is highly subject to its fatigue life [5].
- iv. The HX711 amplifier board has a lifespan of between 5-10 years, although it is highly susceptible to damage due to environmental conditions, so it often doesn't reach its entire lifespan [6].

f. *Operating Environment:*

- i. Due to the number of electrical components associated with the attachments to the walker, the operating environment must be dry and indoors.
- ii. The walker will be used at the client's neurorehabilitation center, which will be at a temperature of 16-26 °C.
- iii. Multiple people will use the walker, so it must be sanitized between each use. The walker should withstand repeated use of alcohol-based disinfectants.

g. *Ergonomics:*

- i. The height of the walker should be adjustable to heights of 80-100 centimeters [7].
- ii. The width of the walker should be 60 centimeters. This will not be adjustable; however, the attachments designed can be switched between walkers if needed [7].

h. *Size:*

- i. The attachments should be small enough to avoid interference with the patient's movement and easy to transition between walkers.
- ii. The components should not protrude from the existing walker by > 10 cm to ensure the walker still fits easily through doorways and can be stored effectively.

i. *Weight:*

- i. The attachments to the walker must be relatively light so they do not add significant weight to the preexisting walker.
- ii. Clinical walkers weigh between 4.5 and 9 kg; therefore, the combined weight of the smart walker attachments and the walker should not exceed this range [8].
- iii. Studies have found that the allowable attachment weight should be $\leq 5\%$ of the user's body weight to ensure stability and prevent slower gait patterns [9].

j. *Materials:*

- i. Walker structures are most commonly made from aluminum tubing and can include rubber or composite materials for mechanisms/grips, all of which provide a stable base for the attachments [10].
- ii. The end caps for load cells are 3D-printed from polylactic acid (PLA).
- iii. The attachments will include electronic hardware such as wires, load cells, an mmWave radar, an HX711 amplifier board, and batteries.

k. *Appearance:*

- i. Device attachments should be compact and integrated within the walker to maintain an unobtrusive appearance.
- ii. Real-time data should be displayed through an intuitive UI on a phone app, website, attachment display or other display methods to make it easier for clinicians and users to read.
- iii. All electronic hardware should be concealed to extend the device's longevity and ensure patient safety.

2. Production Characteristics

a. *Quantity:*

- i. There will be 1 final smart walker device with 3 separate attachments: 2 pressure sensors with end caps to measure force, an mmWave radar to measure speed and distance, and a live reader display.
- ii. All attachments should be removable within 5-10 secs and be compatible with other walkers.

b. *Target Product Cost:*

- i. The budget for the design is approximately \$500. Load cells cost around \$100 each, and UWB sensors cost range from \$50 to \$100 [11]. All other costs will be kept to a minimum.

3. Miscellaneous

a. *Standards and Specifications:*

- i. The Smart Walker accessory device is for clinical rehabilitation environments and must comply with standards relevant to medical devices, assistive mobility, electrical safety, and patient data privacy.
- ii. Medical device standards: FDA 21 CFR Part 820 Quality System Regulation[12], with the newest amendment effective on February 2, 2026, incorporates ISO 13485:2016 Medical Device Quality Management Systems, serves as comprehensive guidelines and requirements for consistent medical design, development, production and servicing. ISO 14971:2019 Risk Management for Medical Devices [13] requires systematic identification, evaluation, and mitigation of risks of Smart Walker including device instability, inaccurate measurements, electrical hazards, and user misuse.
- iii. Assistive mobility standards: ISO 11199-1:2021 Walking Frames [14] and ISO 11199-2:2021 Rollators (with 2024 amendment) [15], together specify strength, stability, fatigue resistance, and safety testing requirements of Smart Walker to ensure the attachments added to the walking frame do not compromise walker safety or performance.
- iv. Electrical safety standards: IEC 60601-1-12:2014 Medical Electrical Equipment Safety [16] applies to electrical components, including pressure and distance sensors in the Smart Walker, used in clinical environments, covering protection against shock, overheating, and electrical hazards.

- v. Patient data privacy requirements: The Smart Walker system might store, export, or transmit patient data including walking speed, distance, and applied pressure to the floor. It may become part of a system handling Protected Health Information (PHI) and therefore must align with the Health Insurance Portability and Accountability Act (HIPAA) Privacy and Security Rules [17].

b. *Customer:*

- i. Primary customers are rehabilitation clinicians and therapy facilities treating TBI and mobility-impaired patients, while secondary customers include hospital administrators and insurance providers.
- ii. Customer needs including:
 - 1. Objective and repeatable metrics for patient rehabilitation progress documentation
 - 2. Real-time display of walking performance, in the format of either a display on the handles or a remote monitor at a distance.
 - 3. Durable and low-maintenance hardware for daily clinical use
 - 4. Intuitive interface usable by therapists and patients
 - 5. Enclosed electronics to ensure safety
 - 6. Potential capability with electronic medical recording systems

c. *Patient-related concerns:*

- i. Patients using the device often have neurological impairments and mobility limitations caused by TBI; therefore, the design should not impair the basic functions of a 2-wheeled walker by not increasing the walker's instability or the user's risk of falling. The device's weight and size must not significantly increase the walker's effort. Displays must be readable without forcing unsafe posture changes by the patients. Components must avoid sharp edges.
- ii. In practical applications, Smart Walker must maintain fundamental durability and ease of use for patients. Materials used can tolerate routine cleaning and sanitization between patients. The system must operate reliably without requiring technical knowledge from patients.

d. *Competition:*

- i. Existing products mainly focus on assisting patient movement instead of a clinical rehabilitation monitoring tool as Smart Walker. Therefore, those solutions fall into the following categories:
 - 1. Standard walkers and rollators: Conventional walkers only provide mobility assistance but do not record rehabilitation progress. Therapists need to rely on either subjective observation or manual timing and distance measurements during therapy sessions
 - 2. Smart mobility aids [18]: Some advanced walkers measure gait parameters or walking speed, like a competitive product by Camino Mobility [19]. But these systems are often designed for long-term monitoring and are extremely expensive (\$2999 RSVP for Camino), complex, and impractical for routine clinical sessions.
 - 3. Fall prevention mobility devices: Certain smart walkers incorporate terrain sensing to support independent living of people with walking disabilities, but those designs are often in the format of home safety installations, wearable alert and monitoring systems, footwear, and mobility support furniture [20], which do not meet the Smart Walker customer needs.
- ii. Thus, the purpose of Smart Walker differentiates itself from those competitive designs by serving as a clinical monitoring and documentation tool rather than a mobility aid. It provides objective metrics such as pressure support, walking speed, and distance to quantify rehabilitation progress.

References

- [1] C. Matney, K. Bowman, and D. Berwick, *Rehabilitation and Long-Term Care Needs After Traumatic Brain Injury*. National Academies Press (US), 2022. Accessed: Sept. 14, 2026. [Online]. Available: <https://www.ncbi.nlm.nih.gov/books/NBK580075/>
- [2] “Days Folding Hemi Walker,” Performancehealth.com, 2018. <https://www.performancehealth.com/days-folding-hemi-walker> (accessed Feb. 04, 2026).
- [3] “What is the lifespan of a rollator walker? (Rollator Accessories),” Avacaremedical.com, Nov. 02, 2025. <https://answers.avacaremedical.com/6423287/What-is-the-lifespan-of-a-rollator-walker> (accessed Feb. 04, 2026).
- [4] “The Pi Hut,” *The Pi Hut*, 2026. <https://thepihut.com/products/24ghz-mmwave-sensor-human-stationary-presence-module> (accessed Sept. 14, 2026).
- [5] Sensortronic Weighing & Inspection Australasia (SWIA), “How to Know When You Should Replace a Load Cell,” Sensortronic Weighing & Inspection, Jul. 30, 2025. <https://swia.com.au/load-cell-replacement/> (accessed Feb. 04, 2026).

- [6] “HX711 Amplifier with 4x 50kg Load Cells - 24-Bit Precision ADC - Kunkune,” Kunkune, Jan. 12, 2026.
<https://kunkune.co.uk/shop/arduino-sensors/4pcs-50kg-load-cell-with-hx711-amplifier/>
 (accessed Feb. 04, 2026).
- [7] Powell, Shanna. “How to Determine the Height of a Walker.” Senior Care Corner, 30 Nov. 2021, seniorcarecorner.com/how-to-determine-the-height-of-a-walker.
- [8] J. Walkers, “Just Walkers Comparison Chart,” Just Walkers.
<https://justwalkers.com/pages/comparison-chart>
- [9] E. Shin, B. Jeon, B. Song, M. Baek, and H. Roh, “Analysis of walker-aided walking by the healthy elderly with a walker pocket of different weights attached at different locations,” *Journal of Physical Therapy Science*, vol. 27, no. 11, pp. 3369–3371, Nov. 2015, doi:
<https://doi.org/10.1589/jpts.27.3369>.
- [10] “Walkers & Rollators,” Silver Cross. <https://silvercross.com/walkers-and-rollators/>
- [11] “Amazon.com : UWB sensors,” Amazon.com, 2026.
https://www.amazon.com/s?k=UWB+sensors&i=electronics&crid=Z43ZDMADDKUF&srefix=uwb+sensors%2Celectronics%2C109&ref=nb_sb_noss(accessed Feb. 02, 2026).
- [12] Center for Devices and Radiological Health. (2026, February 2). Quality Management System Regulation (QMSR). U.S. Food And Drug Administration.
<https://www.fda.gov/medical-devices/postmarket-requirements-devices/quality-management-system-regulation-qmsr>
- [13] ISO 14971:2019. (n.d.). ISO. <https://www.iso.org/standard/72704.html>
- [14] ISO 11199-1:2021. (n.d.). ISO. <https://www.iso.org/standard/76651.html>
- [15] ISO 11199-2:2021. (n.d.). ISO. <https://www.iso.org/standard/76652.html>
- [16] IEC 60601-1-12:2014. (n.d.-b). ISO. <https://www.iso.org/standard/59536.html>
- [17] U.S. Department of Health and Human Services, Office of the Assistant Secretary for Planning and Evaluation. (1996). Health Insurance Portability and Accountability Act of 1996.
<https://aspe.hhs.gov/reports/health-insurance-portability-accountability-act-1996>
- [18] Resch, S., Zirari, A., Tran, T. D. Q., Bauer, L. M., & Sanchez-Morillo, D. (2025). Smart Walking Aids with Sensor Technology for Gait Support and Health Monitoring: A Scoping Review. *Technologies*, 13(8), 346. <https://doi.org/10.3390/technologies13080346>
- [19] Camino Mobility. (n.d.). Meet Camino. <https://caminomobility.com/pages/meet-camino>

[20] Assistive Devices to Aid in fall Prevention for Seniors - Samarth Elder Care. (2025, August 1). Samarth Elder Care.
<https://care.samarth.community/blog/safety/assistive-devices-to-aid-in-fall-prevention-for-seniors/>

Appendix B: Expense Spreadsheet

Item	Description	Manufacturer	Mft Pt#	QTY	Cost Each	Total	Link
Total							