Smart Walker

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Abstract

Context
- Patients suffering from traumatic brain injury are often asked to perform a 10m walk test during each physio session to see their rehabilitation progress

Problem
- There are no commercially available walker systems that provide real-time quantifiable metrics for rehabilitation monitoring

Solution
- Development of an electronic system to be attached to the walker which will provide real-time rehabilitation metrics on the associated app

Key Features
- Load cell embedded in a custom designed endcap to measure weight beared onto walker
- mmWave radar calibrated to measure distance walked and gait speed
- App developed to display data in real time via bluetooth connection with load cells and mmWave radar

Testing & Analysis
- Total circuit was tested on breadboard to ensure all connections and components were working as necessary
- Load cell calibration factor found, and cells were against incremental weights and against body weight on walker
- mmWave radar distance accuracy were compared against known distances

Background

The Client
- Daniel Kutschera
- Physical therapist in neurorehabilitation

Traumatic Brain Injury (TBI)
- TBI affects 50 million people worldwide and lead to 500,000 disabilities annually [1]
- Clinicians use standardized tests like 10-meter walk test through manual methods, but get subjective results
- Quantitative measurements required: weight distribution, timing/speed, and distance traveled.
- Real-time metric collection can reduce documentation time, and help both patients and clinicians track progress.
- Past designs compromised structural integrity and not easily replicable

Figure 1: 2024 Final Design

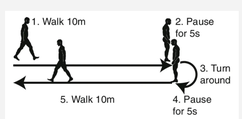

Figure 2: 2024 Final Design [2]

Competing Designs
- Bure Rise & Go Walker has power standing and transfer assistance, lacks gait measurement capability [3]
- Research prototypes has FlexiForce™ sensors and IMUs, but not commercially available

Figure 3: Bure Rise & Go Walker [3]

Fundamental Equations

$$R = \frac{Cf_{IF}}{2S} \quad [5]$$

$$R_{max} = \frac{\sigma P_t G_{TX} G_{RX} \lambda^2 T_{meas}}{(4\pi)^3 SNR_{min} kTF)^{\frac{1}{4}}} \quad [5]$$

R= Range
C= Speed of light
f_{IF}= Frequency of IF signal
S= Sweep rate
σ= Target cross section
P_t= Transmitted Power
G_{TX}= TX antenna gain
G_{RX}=RX antenna gain
λ= Operating wavelength
T_{meas}= Total measurement time
SNR= Signal-to-noise ratio
k= Boltzmann constant
T= Antenna temperature
F= Receiver noise figure

Problem Statement
- Clinicians lack objective tools to quantify walker use and track progress toward independence
- Limited mobility data makes Medicare/insurance documentation of functional improvement more difficult
- Device must measure load, gait speed, and walking distance
- Attachments must remain modular and compatible without compromising walker integrity
- System must be durable, compact, accurate, user-friendly, and provide real-time app-based data

Design Criteria
- Must be able to withstand up to 100kg
- Record walking speed up to 10km/hr
- mmWave Radar must detect distances up to 45m
- Easy fixation and removal of electrical housing units
- Real-time display of data onto phone app
- System must be operable for a minimum of 45 minutes
- Electrical housing unit must stay at 45° to allow for accurate distance sensing
- System must be able to display data with a lag time of up to 500ms [4]

Results and Discussion

1. Total Circuit
- **End Caps**
  - XIAO ESP32S3 Arduino is the microsystem controller with Wi-FI and bl
  - Microcontroller for system
  - Has Wi-Fi and Bluetooth capabilities
- **mmWave Radar**
  - TI AWIR1843 Boost
  - RX and TX antennas for emitting and sending signals
  - Has Wi-FI and Bluetooth capabilities
  - Emits frequency signal to measure range
  - Mathematically calculates range

Figure 11: AWIR1843 Boost mmWave Radar [8]

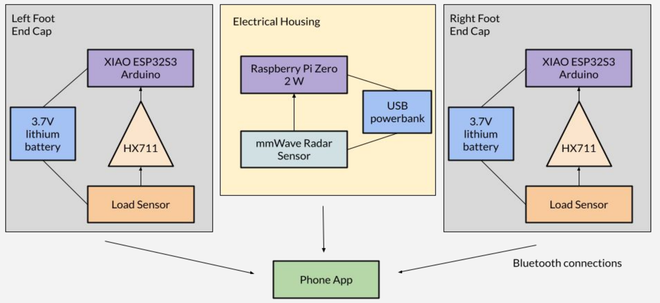

Figure 12: Electrical Workflow

2. Load Cell
- 10 reference loads from 20–180 lb were applied to the load cell
- Measured load cell values recorded on the app
- The load cells remained accurate until 120 lbs where the readings leveled off
- Average load error: 14.7% lb/lb
- The load cell exhibited systematic offset prior to calibration with linear response.

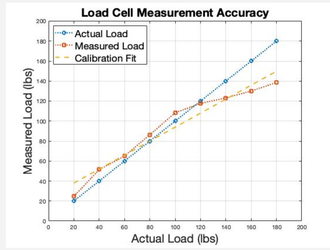

Figure 13: Load-cell measured vs actual load across the 20–180lb showing linear response.

3. mmWave Radar
- 5 distances between 2m to 10m were tested
- Measured distances of mmWave radar recorded on the app
- Actual distances recorded manually, and through Tracker Analysis app
- Measurements collected across 3 trials per distance
- Average distance error: 5.7% m/m

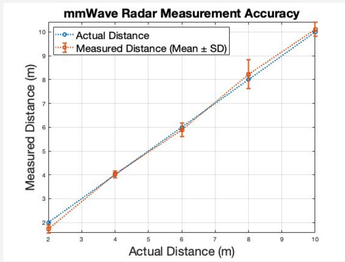

Figure 14: mmWave radar measured vs actual distance (mean ± SD) across the 2–10m

Final Design

1. Load Detection: Load Cell
- Each load cell is embedded into a custom housing unit which slips into the walker leg
  - Material: Polylactic Acid (PLA)
  - Dimensions:
- End cap uses commercial walker-compatible tip for ground contact
- Change electrical resistance when deformed due to pressure which is measured and converted to voltage
  - Load capacity: 100kg per load cell [6]
  - Max Safe Overload: 150% of load capacity
- Signals amplified using HX711 load cell amplifier
- Signals read by Seed Studio microcontroller

Figure 4: ATO Miniature Compression Load Cell (5 kg–100 kg) [6]

Figure 5: 3D printed disk to hold load cell

Figure 6: Walker endcap [7]

Figure 7: Load cell housing

2. Position Detection: mmWave Radar
- Radar fixed into electrical housing unit on walker body
  - Material: Polylactic Acid (PLA)
  - Dimensions: 6.8 x 3.9x 1.85 in
- Emits millimeter-wave RF signals that reflect off nearby surfaces to the antennas
- Radar mixes transmitted and received signal to produce IF signal [5]
- IF signal utilised to calculate range

Figure 8: mmWave Radar Electrical Housing Unit

3. Mobile App
- Distance is cumulative and resets to 0 with every trial
- Units set to client preference
- Connected via bluetooth to the load cells and mmWave radar
- Weight L and Weight R refers to the weight on each walker leg
  - Allows for gait stability analysis

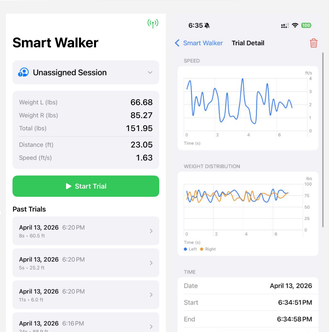

Figure 9 and 10: IOS App UI and Data Display

Conclusion

The Smart Walker system integrates with any clinical walker while providing real-time data for patients through an mobile app. The modular design embeds dual load cells within custom end caps and an with a mmWave radar to quantify weight-bearing, distance, and speed.

Future Works
- Alter load cell housing unit to minimise friction between the components
- Develop an algorithm to track non-linear motion through the mmWave radar

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References

[1]"New Framework for Classifying Traumatic Brain Injury (TBI) Could Transform Patient Care," *National Institute of Neurological Disorders and Stroke*, Sep. 29, 2025. https://www.ninds.nih.gov/news-events/directors-messages/all-directors-messages/new-framework-classifying-traumatic-brain-injury-tbi-could-transform-patient-care
[2]S. Lee *et al.*, "Identifying predictors for postoperative clinical outcome in lumbar spinal stenosis patients using smart-shoe technology," *Journal of Neuroengineering and Rehabilitation*, vol. 14, no. 1, Jul. 2017, doi: https://doi.org/10.1186/s12984-017-0288-0.
[3]"Bure Rise & Go Stand Tall Walker," *Johnpreston.co.uk*, 2026. https://www.johnpreston.co.uk/bure-rise-go-stand-tall-walker?srsltid=AfmBOoqisTf_9X1V_BvNe3dP-rpj3cwA6H1U3OjOEt27MnbJ5vFWVyPU (accessed Apr. 23, 2026).
[4]"What is low latency? And why is latency important?," PubNub. https://www.pubnub.com/guides/whats-so-important-about-low-latency/
[5]A. Soumya, C. Krishna Mohan, and L. R. Cenkeramaddi, "Recent Advances in mmWave-Radar-Based Sensing, Its Applications, and Machine Learning Techniques: A Review," Sensors, vol. 23, no. 21, p. 8901, Jan. 2023, doi: https://doi.org/10.3390/s23218901.
[6]L. Cell, "Miniature Compression Load Cell 5kg/10kg/30kg/50kg/100kg," *ATO.com*, 2025. https://www.ato.com/miniature-compression-load-cell-5kg-to-100kg?srsltid=AfmBOoqWvxiIyizJwiNEc3G582Z5A_ZAMOwBdOSndaEJDW61GpAX8Gcb (accessed Apr. 23, 2026).
[7]"SupreGear 4-Pack Walker Tips, Non-Slip Rubber Replacement for Walkers," *SupreGear*, 2025. https://www.supregear.com/products/b0brscg1b6-walker-tips?srsltid=AfmBOorpx6zP-QocskpmQ1TNosN0MZee1ME_cpafUXTALUpuNhd3-DC_ (accessed Apr. 23, 2026).
[8]M. Electronics, "Texas Instruments AWR1843BOOST Automotive Evaluation Module," *Mouse Electronics*, Nov. 22, 2023. https://www.mouser.com/new/texas-instruments/ti-awr1843boost-eval-module.