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A Nonbinary Approach to Biomechanical Assistive Legs for Diverse Mobility Needs

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Abstract—**According to projections by the year 2050, there will be an excess of 2 billion people globally, who will be 60 or older, and mobility will certainly be one of the most significant public health challenges. Although the average lifespan of good health is increasing, so too is the period marked by frailty, falls, disability, and loss of independence. In developed countries such as the United States, sedentary lifestyles have accelerated declines in health span, however, studies have shown that physical activity can increase years free from disability. Mobility is not binary - rather, it exists along a continuum influenced by physical, cognitive, social, and environmental factors. As such, many current assistive devices (wheelchairs, walkers, and canes) are solutions to specific needs, can lead to increased muscle atrophy, and are unable to provide mobility across multiple terrains in context of accessibility. This paper discusses BALANCE (Biomechanical Assistive Legs with Advanced Navigation and Control Engineering), which proposes a hybrid robotic mobility assisting device that lies between simple mobility aids and complex robotic exoskeletons. BALANCE contains two subsystems, the Assistive Leg Framework, which is a dual wheeled and leg assisted mobility frame that provides structural support to the user while isolating shocks; and the Adaptive Control and Navigation Suite, which includes LiDAR, sonar, 360° cameras, and computing capabilities to provide real-time mapping and travel for the user. Other features include a hip-centric modular frame, biometric monitoring, lithium battery management, capability to collapse, and a user interface that allows the user to receive assistance from partial to fully facilitated support. The proposed design suggests that BALANCE could improve mobility over uneven surfaces, facilitate rehabilitation by preventing atrophy, and enhance independence across the mobility continuum. With the holistic B.A.L.A.N.C.E. framework as their guide, this system frames mobility as more than moving; it frames mobility as a means of independence, rehabilitation, and social participation.**

Keywords—Robotics, Biomechanical Engineering, Assistive Technology, Rehabilitation, Atrophy Prevention, Aging Population, Mobility Continuum, Independence

I. Introduction

As the world's populations get older, there is a call for more interesting mobility options with estimates indicating that over two billion people will be aged 60 or older by 2050 (United Nations, 2017), the importance of innovating mobility systems has become a pressing public health issue. Age not only continues to increase in incidence, but it is changing in outcome. People are living longer, however not aging healthier, with a growing gap between our total lifespan and healthspan (Beard et al., 2016). In many developed countries, diminishing replacement rates are placing additional pressures on the socioeconomic impacts of increased aged populations, which is further straining healthcare systems and social infrastructure (Xia et al., 2021). Together, these trends have elevated mobility impairments as an essential issue, creating a reiterative relationship to physical decline, cognitive decline, and social isolation (Rule et al. 2025). Mobility aids used traditionally - walkers and wheelchairs - help less to meet the new and changing mobility requirements of older adults - particularly, in environments with irregular surfaces or inadequate infrastructure.

In high-income nations such as the United States, modern sedentary lifestyles are defined by accumulated sitting time or minimal activity. Sedentary lifestyles lead to significant mobility-related health issues for older adults. Sedentary time leads to increased risk for mobility disability, frailty, and falling. Older adults with the most sitting time (greater than 10 hours a day) had over three times greater odds of experiencing a fall than older adults who did not engage in sedentary behavior (Jiang et al., 2022). Notably, longitudinal research has found that accumulated physical activity has positive effects on aerobic fitness, reduces disability, and increases disability-free life expectancy in older adults (Gretebeck et al., 2012). The evidence shows that, without compensatory physical activity, sedentary behavior is an important contributor to declines in mobility and independence in older adults.

Older adult mobility exists on a continuum, which can vary over the life course. Longitudinal studies indicate that mobility limitations (e.g., slower gait, less life-space, difficulty completing activities of daily living), are common with aging, highly prevalent, and predictive of adverse outcomes like hospitalization and falls (Freiberger et al., 2020). This presented a particularly compelling example of life-space mobility as there are cognitive, physical, psychosocial, and environmental determinants that coalesce to determine not only how far older adults travel from home but how frequently they do so (Webber et al., 2010). These observations suggest that mobility exists as a continuum, rather than a binary state, and even exists on a continuum that is furthermore dynamic, and can change abruptly and/or gradually, and is influenced by multiple determinants, which suggests the importance of being flexible in assistive solutions when and where interventions occur along the continuum to maintain independence.

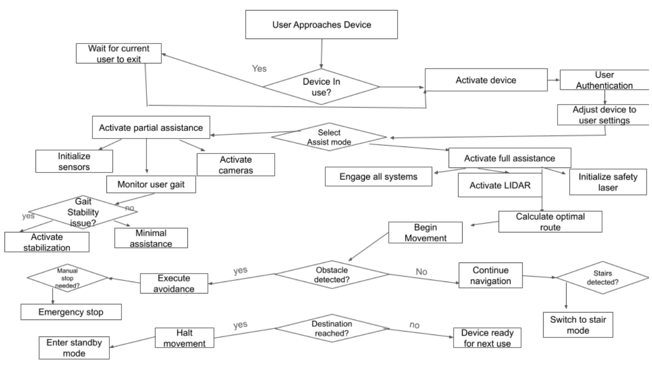
Traditional mobility aids, including powered and manual wheelchairs, can provide invaluable support to users with severe mobility challenges but they are habitually designed in binary forms where users are either fully seated or fully ambulatory without options for the segment in between. Other research shows stationary wheelchair use prolonged and without concomitant physical rehabilitation activity may lead to additional muscle atrophy, poorer cardiovascular fitness, and lower probability of returning to independent mobility (Gianoudis et al., 2015). Portable solutions for wheelchair travel are very limited and hinder travel and mobility in tight spaces as well. This problem is often compounded in low- and middle-income countries, where lack of accessible infrastructure limits the opportunities for many wheelchair users to experience good social participation in workplaces, public transport, or community spaces. Even in high-income countries, with fuller accessible infrastructure, older dwellings, rural locations or poorly maintained inner cities can still create accessibility barriers (Li et al., 2011). Alternative mobility solutions provide some portable solutions such as walkers and canes but are poorly suited for unstructured uneven terrain or long distance travel, interfering with one's ability to maintain balance and even lead to falls (Bateni & Maki, 2005). Therefore, the focus on adaptivity leveraging technology may present a more globally scalable model to expand mobility for various populations better than large, expensive infrastructure based solutions.

Now that the world is looking at the issue of an aging population, mobility as a public issue is being discussed at every level- from urban populations to the rural population, where people are not only living longer but not living much healthier as they age, and the gap between the lifespan and the healthspan continues to grow. In the developed world, particularly in the US where sedentary lifestyles exacerbate the age-related declines: frailty, an accelerated and chronic cycle of falls and loss of independence and a body of literature showing that, on the other hand, physical activity can improve disability-free life expectancy. However, mobility cannot be defined simply as either ability, or disability; mobility exists along a continuum and it is influenced and shaped by physical, cognitive, social, and environmental factors and needs to be supported with flexible options that enable independence. Existing mobility aids (wheelchair, walker, cane) are often too limiting and can even be detrimental, at times hastening decline or restricting access to the very places that support movement.These limitations point to much-needed next-generation approaches; the B.A.L.A.N.C.E framework is where it is at. B.A.L.A.N.C.E is by promoting Balance across biological, adaptive, lifestyle, accessibility, networking, community, and environmental dimensions. The B.A.L.A.N.C.E framework is a comprehensive holistic framework for reimagining mobility solutions that are flexible and technology-enabled, and empowering for older adults across their full mobility needs (driving, active and assisted).

II. Methodology

The Biomechanical Assistive Legs with Advanced Navigation and Control Engineering (B.A.L.A.N.C.E.) apparatus is a biomechanical robotic system utilizing mechanical actuation, adaptive control, and user design. The hip-based frame encapsulates the onboard processor, power supply, and biofeedback sensors that coordinate four robotic leg actuators and collapse to facilitate designated tasks, including user weight support and shock mitigation in diverse terrain. The adaptive navigation features LiDAR, sonar, inertial measurement unit (IMUs), and 360° imaging to map the environment and adapt the gait pattern of the user through closed loop structural feedback. The dual operation in wheeled or leg operation allows for seamless transition between states to keep the user safe. The adjustable assistance and rehabilitation mode engage user musculature to prevent atrophy, promoting a compact, modular form that promotes stability, adaptability, and independence in movement practice while engaged in various mobility tasks.

A. General Design Being Proposed



1. BALANCE Flowchart (self-drawn)

B. Functionality of System

The BALANCE system operates using an integrated system of sensors, actuators, and control mechanisms designed to provide comprehensive mobility assistance in all terrains and situations. At its heart is the power source and battery management system, which ensures efficient power distribution to all core systems, balancing leg actuators, sensors, and the onboard computer. A cooling system, with heatsinks and fans, makes sure all components maintain optimal temperature.

When the user approaches the device, a wireless connectivity module allows for a connection to be established and the user to be authenticated and activate the system. There is a user interface screen that then allows for the user to choose between two assistance modes: either partial or full assistance. Settings can then be further adjusted based on mobility requirements. Full Assistance Mode will fully take control over all movement leaving the user to relax and not having to worry about initiating any movement. Partial Assistance Mode will allow the user to maintain a greater amount of control and be able to physically initiate movement while the device will only offer support as needed. Leg actuators, powered by electric motors, control the movement of the robotic leg beams and joints, and also control the positioning and movement of the front and rear anchoring legs, allowing for greater stability on uneven and unstable terrain.

On flat surfaces, wheels with a flip-out mechanism allow for incredibly smooth mobility, while on stairs or uneven terrain, the multiple leg joints and associated actuators ensure stability. Shock absorbers within the hip module reduce the impact on users, making for a comfortable experience.

The onboard computer uses real-time data from a variety of sensors, including but not limited to cameras with 360 degree coverage, A rear sonar, and a safety scanning laser. These work together to provide a fully comprehensive view of the environment. Additional systems like the low front laser allow for redundancy, ensuring that even the smallest obstacles on the ground are not missed. The onboard control system combines all this sensory information to smoothly and dynamically adjust movement, ensuring safe navigation. A protective housing is additionally in place to protect sensitive components like the sensors, onboard computer, and control system.

For the user's safety, the device comes equipped with an emergency stop mechanism that can halt all operation instantly in case of an emergency, either manually or automatically. Audible alerts are combined with tactile & haptic feedback to provide the user with real-time notifications, such as obstacles being detected or the battery running low. A biometric device in the hip frame constantly monitors the user's vitals to check for emergencies and adjust movement based on the user's physical condition.

When the device is not in use, or once the intended destination is reached, BALANCE collapses into a compact form for easy transport, facilitated by specialized mechanical locking mechanisms in the joints and an articulated hinge in the hip module to allow for quick access, and ease of entering or leaving the device.

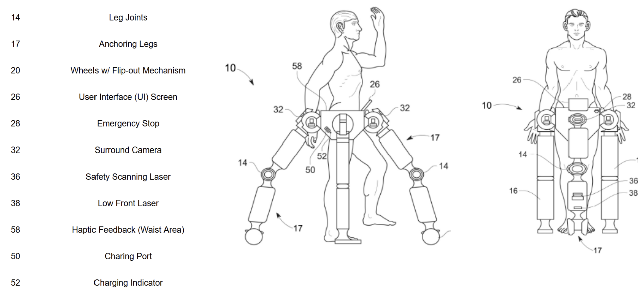
The charging port, along with an indicator, is placed in the hip module for further convenience, along with a nearby collapsible handle, so that the device can be moved similar to a suitcase when in its collapsed form.

C. Systems Applied in BALANCE

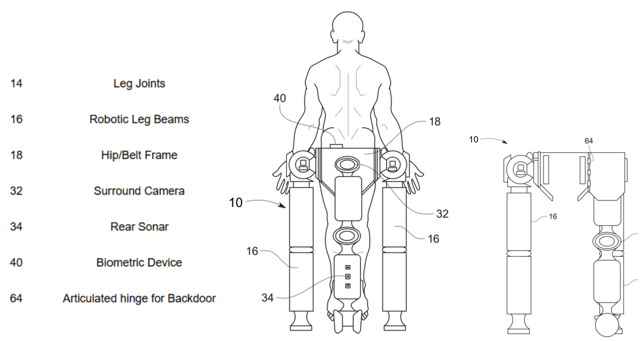
Module	***Function***
Side Leg Attachments	This module includes the leg actuators, joints, shock absorbers, mechanical locking mechanism, and collapsible handle. Together, they enable the biomechanical movement of the legs, absorb shocks during walking, ensure secure locking of joints, and allow easy transport when collapsed.
Front & Back Anchors	This module stabilizes and navigates the device. It features anchoring legs, rear sonar, multiple types of lasers (safety scanning, low front), articulate hinge for access, and wheels with flip-out mechanism. These parts ensure safe terrain interaction, obstacle avoidance, and provide a transport mode.
Hip Module	Includes the hip/belt frame, lithium battery, battery management system, charging port and indicator, emergency stop mechanism, wiring, cooling system, and housing. This module provides structural support, power, safety mechanisms, and thermal regulation, ensuring efficient operation and user protection.
User Interface	The user interface module facilitates user interaction and monitoring. It includes the screen, biometric device, speakers, haptic feedback, surround camera, wireless connectivity, onboard computer, and control system. These elements manage access, provide alerts, and coordinate navigation with sensory feedback.

Table 1: Systems of Balance and Their Functions

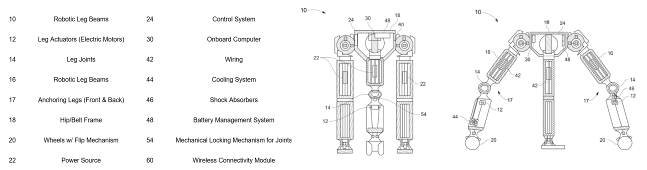
D. Structural Design



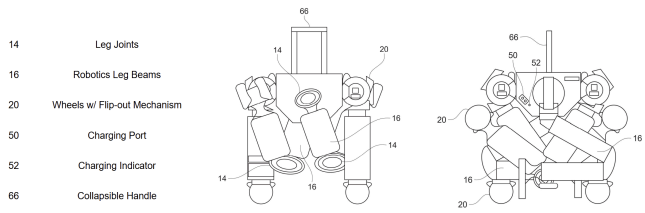
2. BALANCE Partial Assistance Front & Side Views



3. BALANCE Full Assistance Back View & Side View



4. BALANCE Sectional Legs Schematics



5. BALANCE Collapsed State Schematic

E. Assembly of Innovation

The first component assembled as part of the BALANCE system is the Hip/Belt Frame constructed from lightweight aluminum and carbon fiber components. The frame structure not only bears the user's weight as well as dynamic forces during use but also is extremely detailed for the mounting points for the robotic leg beams, actuators, and electronics enclosures.

Multi-degree-of-freedom leg joints and leg actuators are included in the robotic leg beams for natural movement and flexibility. For additional stability further down slopes, anchoring legs are affixed to the anterior and posterior ends.

At the lower extremities of the legs there are wheels equipped with flip-out mechanisms that facilitate seamless transitions between traversing on irregular terrains or steps and navigating on level surfaces. The flip-out mechanism is subjected to rigorous testing to ensure reliable mode transition.

Assembled as part of the power system are the charging port, the charging indicator, and the battery management system comprising a lithium-ion battery pack integrated into the hip frame. The actuators, sensors, and control units exchange information with one another by the use of precisely routed wires.

To ensure optimal operating temperatures, the cooling system, including the heat sinks and fans, is positioned optimally near critical components such as the actuators and the onboard computer.

The sensors-low front laser, scanning laser for safety, rear sonar, and 360° surround cameras-are positioned carefully and hooked up to the onboard computer, which sits encased. To allow for navigation and collision avoidance, these yield real-time environmental data.

To maximize user interaction and provide protection, several user interface elements are also integrated, such as haptic feedback modules, sound alerts, emergency stops, and display touchscreens.

While in transport or static modes, the leg joints are held by means of multiple mechanical lock mechanisms. The devices go through a remote diagnostic via wireless connectivity. The collapsible handle located at the hip module provides easy transport when the unit is stowed, and an articulated hinge provides simple access for entry and maintenance.

After being fully assembled, the system is put through a comprehensive testing process to assess its mobility, terrain adaptability, sensor accuracy, and safety compliance, guaranteeing its readiness for real-world deployment.

F. Hardware Design Description

All of the components in the BALANCE system are supported structurally by the hip frame, which is composed of lightweight aluminum and carbon fiber composites. To protect against environmental influences, a protective housing enclosing embedded electronic components surrounds the hip frame.

Depending on the terrain, the device's multi-joint robotic legs can dynamically adjust. Leg actuators driven by electric motors and leg joints with at least two degrees of freedom for organic movement are features of these robotic leg beams. To improve stability on uneven surfaces, the system also has anchoring legs in the front and back.

The BALANCE system incorporates wheels with a flip-out mechanism for mobility, enabling users to alternate between walking on stairs or uneven terrain and rolling on flat surfaces.

The power system is driven by a lithium-ion battery pack, managed by a Battery Management System (BMS), which distributes power to all components and displays charge levels through a charging indicator. A charging port allows for convenient recharging.

Navigation is supported by a sensor array which includes 360° surround cameras that assist with environmental awareness, Rear sonar sensors that work on detecting any obstacles that may cause issues, A front mounted safety scanning laser that detects any changes on the surface as well as other obstacles such as stairs, A low front laser that works on ground-level obstacle identification such as rocks and slopes, and finally a biometric sensor that monitors the user’s health and vitals.

An onboard computer processes sensor data in real time, optimizing movement using an adaptive control system. The user interface (UI) screen provides real-time status updates and allows users to configure assistance settings.

To address user safety and comfort the BALANCE system includes an emergency stop mechanism which can be manually or automatically activated, Shock absorbers to minimize the impact of movement, Cooling systems with heat sinks and vent to prevent overheating, and audio speakers and haptic feedback that give real-time alerts.

The device also features an articulated hinge for a backdoor, allowing users to enter and exit easily. When not in use, the BALANCE system collapses into a compact form, equipped with a collapsible handle for easy transport.

This hybrid robotic system seamlessly integrates legs and wheels, ensuring adaptability across multiple terrains while promoting user independence and active mobility recovery.

G. Components of BALANCE and their functions

Component	***Mechanic***	***Function***
Stainless steel base frame (Stainless Base, USA)	Principal structural component that creates a corrosion-resistant frame	Serves as a foundation for BALANCE, and helps support weight of the user
Leg Actuators (12) (McMaster-Carr, USA)	Mobility Drive Systems	Provide powered movement to the legs for walking or terrain adjustment.
Leg Joints (14) (McMaster-Carr, USA)	Rotational Hinge Mechanics	Enable articulation and flexibility of the limbs during motion and stabilization.
Anchoring Legs (16) (Misumi USA)	Ground Stabilization Supports	Offer stability when the device is stationary or transitioning between movements.
Hip/Belt Frame (18) (Protolabs, USA)	Waist-Fitting Exoskeleton Structure	Distributes weight and anchors upper components to the userâ€™s body securely.
Wheels with Flip-Out Mechanism (20) (Robotshop, USA)	Retractable Rolling Assembly	Allow fast terrain travel or retraction for walking mode.
Lithium Battery (22) (BatterySpace, USA)	High-Energy Power Source	Stores and supplies electrical energy to all onboard systems.
Control System (24) (Digi-Key Electronics, USA)	Centralized Command Unit	Manages commands, actuator outputs, and system responses.
User Interface Screen (26) (Adafruit, USA)	Touch and Visual Interface	Allows users to interact with and monitor device status and functions.
Emergency Stop Mechanism (28) (RS Components, USA)	Fail-Safe Interrupt System	Instantly disables the device in case of malfunction or user emergency.
Onboard Computer (30) (NVIDIA, USA)	Embedded Processing Unit	Executes AI algorithms, sensor fusion, and system operations.
Surround Camera (32) (Intel RealSense, USA)	360Â° Visual Feedback System	Captures real-time visuals for navigation and environmental awareness.
Rear Sonar (34) (SparkFun Electronics, USA)	Backward Proximity Sensor	Detects obstacles behind the device to prevent collisions.
Safety Scanning Laser (36) (SICK Sensors, USA)	LIDAR Safety Scanner	Provides detailed environmental mapping to ensure obstacle avoidance.
Low Front Laser (38) (Hokuyo, Japan)	Ground-Facing Laser Sensor	Scans ground textures and detects small obstacles or edges.
Biometric Device (40) (SparkFun Electronics, USA)	User Authentication System	Identifies the user via biometric input for secure access.
Wiring (42) (Digi-Key Electronics, USA)	Internal Electrical Network	Connects and powers all electrical and electronic components.
Cooling System Heat Sinks (44) (Mouser Electronics, USA)	Passive Heat Dissipation	Maintains optimal temperature of high-power electronic components.
Shock Absorbers (46) (Misumi, USA)	Vibration Dampening Elements	Absorb impact and vibrations from movement to improve user comfort.
Battery Management System (48) (Adafruit, USA)	Power Regulation Circuitry	Monitors battery health, usage, and safety operations.
Charging Port (50) (Mouser Electronics, USA)	External Energy Inlet	Connects to the power source for battery recharging.
Charging Indicator (52) (SparkFun Electronics, USA)	Visual Charging Status Light	Displays charging progress and battery level notifications.
Mechanical Locking Mechanism (54) (McMaster-Carr, USA)	Joint Locking Latches	Locks leg joints in position for safety during transitions or when powered off.
Speakers for Sound Alerts (56) (Adafruit, USA)	Audio Output Components	Emit warning sounds or audio notifications for user feedback.
Haptic Feedback (58) (Precision Microdrives, UK)	Waist-Level Vibratory Modules	Provide physical feedback through vibration for user alerts or guidance.
Wireless Connectivity Module (60) (Mouser Electronics, USA)	Communication Transceiver	Enables device-to-device or device-to-network data exchange.
Protective Housing for Electronics (62) (Polycase, USA)	Environmental Shielding Shell	Safeguards internal electronics from dust, moisture, and impact.
Articulate Hinge for Back Door (64) (Sugatsune, Japan)	Flexible Rear Access Joint	Facilitates easy access to internal systems or battery compartments.
Collapsible Handle (66) (McMaster-Carr, USA)	Retractable Gripping Mechanism	Allows for easy transport and storage when the device is not in use.

Table 2: Components of Balance and Their Functions

H. Mechanism of components

1) Activation and Initiation:

After the user approaches BALANCE, the Wireless Connectivity Module establishes a secure connection. This is done to authenticate the user and to activate the system. Once the user enters the User Interface Screen, they are prompted to choose partial or full support modes as well as the settings to allow their personal mobility requirements. Upon being activated, the system quickly carries out a diagnostic survey to ascertain that all the safety measures, actuators, and sensors are all functioning effectively. This initial setting makes the BALANCE specific to the user before movement commences.

2) Full Assistance Mode:

In full assistance mode, movement is fully handled by BALANCE. Leg Actuators propel the Robotic Leg Beams and the Anchoring Legs, adjusting immediately to changes in terrain. On even ground, retractable wheels provide gliding travel. As you face stairs or uneven terrain, the flip-out mechanism activates the actuators and joints to stabilize. Shock Absorbers within the hip module dampen the impact and make movement easy.

BALANCE relies on the Onboard Computer for its complex navigation capabilities. This computer interprets input received from a range of sensors, including 360-degree Surround Cameras, Rear Sonar, a Safety Scanning Laser, and a Low Front Laser. They combine to identify obstacles, grades, or uneven terrain. This information is then interpreted by the Control System, which immediately alters your movement, so your system is always safe and stable.

Power is provided by a lithium battery that is controlled by the Battery Management System, balancing the demands of the actuators, sensors, and computer. Heat sinks and fans within the Cooling System avoid overheating during use. Protective housing protects delicate electronics from dust, moisture, and impact, allowing the unit to operate reliably in various surroundings.

Safety is still the core of BALANCE. A Manual/Automatic Shutdown through an Emergency Stop Mechanism is possible. Acoustic warnings and haptic response inform you about obstacles or a low battery. While the Biometric Device in the hip frame tracks your vital signs, adjusting the system settings correspondingly and summoning emergency services if necessary.

3) Partial Support Mode:

In Partial Support Mode, the user has full control while the BALANCE system acts in conjunction with them. The Shock Absorbers and Leg Actuators continue their role of regulating movement and reducing strain, allowing for natural movement with retained control. At the same time, navigational sensors continue to be active at all times, ready to act when balance correction or fall avoidance becomes necessary, especially near staircases or hidden obstacles. Power delivery is seamless through the onboard Computer and Battery Management System, thus allowing any motion to be felt as smooth and responsive. At all times during the course of usage, the Biometric Device continually readies the condition of the user and switches to full support automatically whenever wished or when increased support becomes necessary.

4) Storage and Transportation:

Once BALANCE is off the air or has reached the delivery site, it can be folded into a compact package to ease portability. Locking devices that are positioned at each joint keep the structure rigid as the unit folds. At the same time an articulated hinge that is positioned in the hip module allows controlled access as the user enters or leaves the system. This folding design allows the user to quickly and securely transition the unit from an active configuration to a storable package.

The hip frame is able to fit a conveniently located charging port that features an indicator. This way users can rapidly determine the condition of the battery. Moreover, a retracting handle is embedded within the hip module which allows the collapsed system to be moved like a suitcase. This feature greatly facilitates movement between varying sites. The combination of these intrinsic features assist the portability of BALANCE, convenience of recharging, as well as convenient storage, while keeping the system's overall strength and safety to the user. Altogether, these features augment the goal of BALANCE's autonomy as well as adaptable mobility, all while doing so without hindering convenience.

I. Application of BALANCE

When the user approaches BALANCE, the device will power on automatically as it detects the proximity with its sensors. The system then guides the user to authenticate via the User Interface Screen and subsequently loads any personalized settings including mobility preference, user support level etc. On authenticating, the user selects either the Full Assistance or Partial Assistance mode (according to their requirements).

A) Full Assistance Mode:

In Full Assistance Mode the user will input their destination into the User Interface Screen. Once the destination is set, the Control System activates the robotic legs and wheels The on-board computer evaluates the surrounding environment using Surround Cameras, Rear Sonar and Safety Scanning Laser determining the best route while avoiding any obstructions. At all times, the device will check whether to use the wheels on flat terrain or the robotic legs on stairs and uneven terrain. The Leg Actuators control the movement pattern while the Sound Alerts and Haptic Feedback monitor the conditions to alert the user of any changes of its surroundings. For example: prior to alerting the user of obstacles in its way, the device would enable a caution warning signal; and if/when the device were to activate low user battery and/or alert the user of insufficient fluid. At this point, the device will autonomously conduct all necessary movements to arrive at their destination.

B) Partial assistance mode:

In Partial Assistance Mode, the user retains the majority of control of their movements, whilst BALANCE assists with stabilizing and adding additional support. During operation, the Control System assesses the user's gait based on their sensory data from the Leg Joints and Anchoring Legs, providing support as needed. The Wheels with Flip-out Mechanism allow propulsion on smooth terrain while BALANCE continually scans the user's environment. In this mode, the user can walk with their natural gait pattern, with BALANCE only needing to intervene if it senses instability. The Control System will determine whether/when/how much support to apply based on input from the Biometric Device to maximize the user's safety and maximum comfort during ambulation.

When a user is finished with the device and needs to enter/exit, they will have access to the Articulated Hinge for Backdoor to access their wearable hip module. The hinge mechanism allows the user to step in and out with minimal effort. At this point, the Collapsible Handle for Transport is ready to be deployed, allowing the user to easily transport the device like a suitcase or so that it can be stored when it is not in use. When the user reaches its destination, BALANCE may be collapsed for easy storage or transport. The Mechanical Locking Mechanism for Joints allows for the robotic legs to be locked in place, and the device to fold in a compact form that can be transported or stored.

The Charging Port is available when the electrical components of the device require recharging, and with the Charging Indicator, the user is aware of the battery status of the device. When the device may have to be stored or transported, the device enters into standby mode, which is ready for use at any time.

In conclusion, BALANCE provides a versatile, intuitive user experience, intended to be easy to set up, and easy to use. Compatibility between the full assistance and partial assistance modes happens seamlessly; and, by being fully equipped with navigation and obstacle avoidance systems, users can navigate in complex terrains, showing confidence and independence.

III. Results and discussions

The Biomechanical Assistive Legs with Advanced Navigation and Control Engineering (BALANCE) system has the ability to enhance the mobility of individuals with physical challenges or those requiring rehabilitation. BALANCE combines robotic leg-level mobility with wheeled mobility to address a whole host of challenges in real-world terrain while improving independence, safety, and adaptability for the users. Based on its conceptual design and predicted performance, numerous clear advantages and disadvantages have been identified:

A. Enhanced Mobility Over Difficult Terrain

The BALANCE device has a set of adaptive leg actuators, shock-absorbing joints, and anchoring legs that give the user stability when walking on unstable or uneven terrain. While traditional aids do not work going up or down stairs or slopes, this device alters its level of support dynamically to maintain balance and allow nonturbulent movement. This versatile device improves accessibility in both urban and rural environments where infrastructure is lacking and the risk of falling is highest.

B. Dual-Mode Navigation System

BALANCE incorporates a unique dual-mode navigation system that enables users to transition smoothly between powered (robotic leg) walking or using wheeled movement. This adaptability allows users to choose a different mobility strategy based on their environment, consisting of wheeled mobility (when on flat, open surfaces) or leg (robotic leg) assisted walking on stairs, uneven surfaces or narrow spaces.

C. Goal of Regaining Mobility

Unlike traditional wheelchairs that allow for a binary position of seated mobility, BALANCE allows for varying modes of movement. It allows users to preserve or recover partial ambulation and avoid muscle atrophy. BALANCE promotes an efficient system and engages the user physically, making it suitable for everyday use in a range of environments.

D. Personalized User Assistance

BALANCE adapts its assistance using its interface and biometric recognition system to fit the needs of each user and, when in either full or partial support mode, allows the user to adjust the level of assistance to their preferred degree and mode. This versatile solution allows for independence and discounts any risks of over-dependency that can arise while using other fully motorized options to gain independence.

E. Inclusive Design for a Variety of Mobility Needs

Traditional mobility aids, such as wheelchairs, are intended to help people at the later and specific stages of mobility loss. BALANCE is uniquely designed to aid a wide range of physical abilities, from the person with little instability to the one with more significant mobility disability. With its module and graduated level of support, it is not just a mobility device, it is a partner in assistance through the changing and evolving degree of mobility.

F. Portability and Travel-Readiness

Unlike electric wheelchairs or any other bulky assistive device, BALANCE, is made to be both foldable, and compact, so it can fit into cars, elevators and even overhead compartments on airlines. This level of portability means the user is never restricted by geography or logistics and is able to travel wherever they would like whilst maintaining a level of independence.

IV. Conclusion

Globally, the explosion of aging populations has necessitated mobility solutions that break the restrictions of traditional aids and match the growing disparity between life span and health span. In developed countries, such as the United States, sedentary lifestyles are leading to a medicated geriatric population that is creating further frailty, falls and loss of aging in place. Therefore, it is crucial that proactive strategies preserve functional mobility and add disability free years and quality of life! Mobility is on a fluid continuum and relies on the interplay of physical, cognitive, social and environmental attributes; hence, mobility innovations must account for flexibility within a continuum, not a dichotomy. Current mobility devices such as wheelchairs, walkers or canes offer little more than a new set of wheels and more often than not they encourage decline and prevent people from going places, which creates a pressing need for something scalable and flexible. The BALANCE system has been designed to address exactly this challenge by advancing biomechanical technology and innovative adaptive control in a new holistic way, across diverse terrains and user needs. In our work, we leveraged the B.A.L.A.N.C.E.-balance of biological, adaptive, lifestyle and accessibility, networking and community, and environment. We believe in opportunities for mobility that extend past simply moving toward undignified leisure, and instead frame mobility as a pathway toward independence, rehabilitation, and inclusion. The BALANCE system will create some new mobility space by bridging the gap between the traditional mobility aids and robotic space. This is not only a technology enabled and a forward looking model, but I also believe it has the potential to transform mobility for older adults and those with impairments around the globe.

V. Acknowledgments

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