Group No: 40

Literature Review Report

ME4202

Design and Development of a Multi-functional Robotic Walker

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1 Introduction

The aging population worldwide presents a significant challenge for healthcare systems and caregiving. Mobility assistance devices, such as walkers, are crucial to maintaining independence and improving the overall well-being of individuals facing mobility issues. Autonomous robotic walkers represent a revolutionary approach to address these challenges by offering features like automated navigation, intelligent guidance, and adaptive mechanical structures. This literature review aims to provide a comprehensive understanding of the state-of-the-art in the development of autonomous robotic walkers. It encompasses the latest advancements and key contributions in Navigation, which focuses on the rollator's ability to move autonomously and safely. Active Guidance explores the system's capability to provide real-time support and adapt to user needs, while Mechanical Structure details the physical design and construction of the rollator.

The review is structured into three distinct sections, each addressing a vital aspect of autonomous robotic rollators. We will begin with Navigation, examining the technology and algorithms utilized to ensure obstacle avoidance, localization, and path planning. Active Guidance will then explore how the system offers support and aids users in various scenarios. Finally, Mechanical Structure will detail the components and materials required to build a reliable and user-friendly autonomous robotic rollator. As we delve into these domains, this review will expose the existing challenges, potential breakthroughs, and the broader implications of advancing the field of mechatronics engineering in the context of healthcare robotics.

2 Aim and Objectives

Aim - To improve the daily lives of individuals with mobility challenges, using assistive robotic technology.

Objectives -

1. Study the existing problems associated with mobility and identify key focus areas and research gaps.
2. Design and development of an appropriate mechanical structure for the platform of walker.
3. Development of the autonomous navigation system, walking guidance system, and standing assistance system of the walker.
4. Testing and validation of the developed robotic walker.

3 Autonomous Navigation System

Upon studying the literature related to autonomous navigation, a few key areas of importance become clear. These areas are as follows:

1. Map building
2. Path planning
3. Localising
4. Obstacle Detection
5. Software Platform

The last two areas typically encompass some of the 3 previous areas as well- but the 1st 3 areas are standalone and are essentially parameters of whichever navigation technology that is being used. Thus, analysis of the existing technologies will be conducted systematically focusing on each area.

Autonomous navigation became a mainstream staple in the late 2000s with the development of *BigDog* [1] by Boston Dynamics for Defence Advanced Research Projects Agency (DARPA).

Figure 3-1: BigDog [1]

BigDog, at its time, stood as the standard for autonomous navigation, with its navigating capabilities unprecedented. It has been usurped by Spot[3] & Atlas[4], also developed by Boston Dynamics. Nevertheless, the principles and technology used for autonomous navigation remain the same.

Map building of BigDog is done using 2 sensors: a LIDAR and a Stereo Vision System (SVS). The 3d point cloud received from the LIDAR and the 3d disparity maps generated by the SVS are used in the map building algorithm, which is a point cloud segregation algorithm. The lidar produces a new point cloud every 13ms and the stereo vision cameras to follow a similar frequency. Using these streams of data, the segregation algorithm works to visualise the environment around the robot and to determine the presence of any obstacles. Once such obstacle points are detected, a previously created 2d cost map is updated with the values for each square in it. Object points have a high *lethal cost,* while areas in the vicinity have a cost related to the distance from the object.

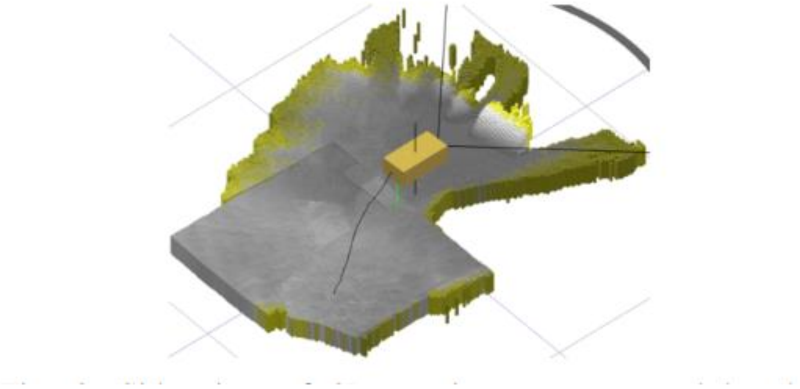

Figure 3-2: Map generated by Stereo Vision and Segregation Algorithm [2]

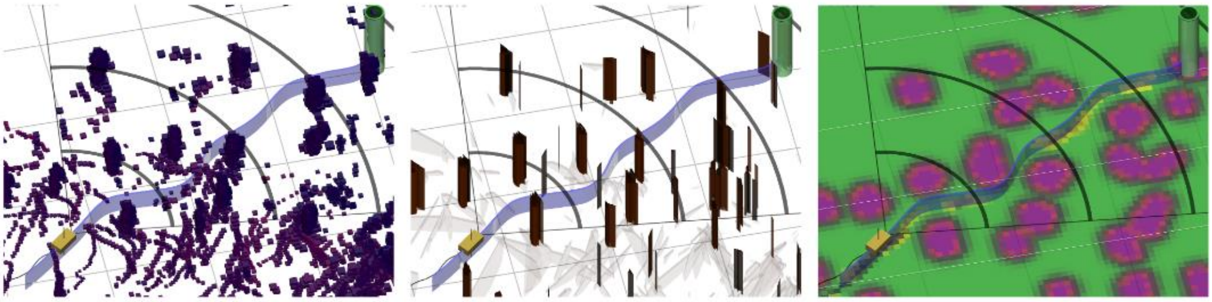

Figure 3-3: Map Building and Refining Using the Algorithm [3]

Path Planning on BigDog, along with path following, uses an adapted version of the classic A* algorithm. The A* algorithm is a quite popular algorithm that works on finding the shortest distance between a starting point and a goal location[5]. A further spline smoothing algorithm is used to smooth the path. The use of the A* algorithm with the spline smoothing algorithm ensures that the path generated by the robot is traversable and the robot avoids any jerky movements. Using the cost map that was derived earlier, the robot plans the path so as to avoid obstacles. This is done by keeping the robot at an appropriate distance away from obstacles. This is a robust and effective path-planning technology. The issue though- that effectiveness and reliability are possible at the expense of great computational power and the need for memory.

Localisation on BigDog is done using the following pose-sensing architecture.

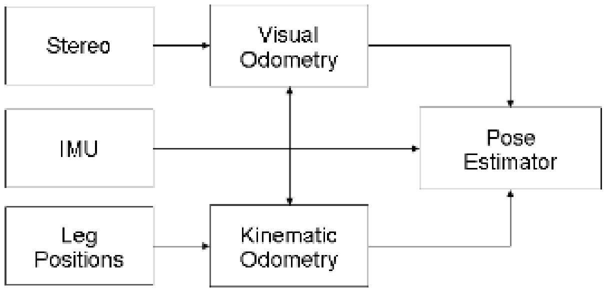

Figure 3-4: Pose Estimation Architecture [4]

BigDog is equipped with state-of-the-art force sensors and joint sensors that let the robot visualise the exact leg positions and dynamic pose of the robot. The *kinematic odometry* system uses these data to estimate robot motion. The stereo camera is used to detect the environment and compare it with the built map to get *visual odometry*. Both these systems use the IMU as an orientation aid. Finally- the pose estimating algorithm works to combine these data and make it as reliable and as accurate as possible. Besides being a simple linear combination, the algorithm works on weighted values. Prominence is given to visual odometry at lower speeds and kinetic odometry at high speeds. This is to minimise the weaknesses of each system- drop-out of the stereo camera and drift of the legged odometry.

Finally, as a roundup of the technologies used in BigDog, the *software architecture* is looked at in Figure 3-5.

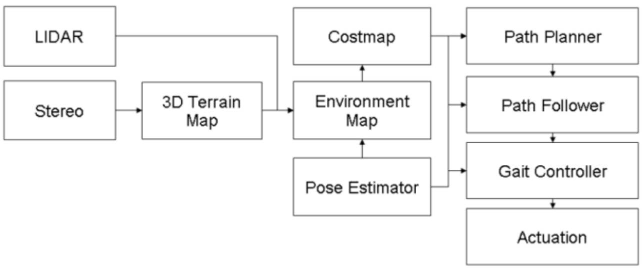

Figure 3-5: Software Architecture of BigDog [4]

This heavy software architecture runs on 2 computers, a PC104 stack and an Intel Core-Duo CPU. Next, the *DALi's C-Walker* [6] is considered. Unlike BigDog, this is a robot that is directly in the field of rollators and is an interesting application. Its key features can be recognized as follows.

1. Identifying a path that best supports user preference.
2. Detection of anomalies along the way.

3. Observation of humans in the area and prediction of their future positions.
4. Local reshaping of path to avoid obstacles.
5. Rich interface.

Of interest is that the research has been considered specifically focusing in navigation in social environments- thus analysis of human behaviour and 'their future positions' has been taken into account.

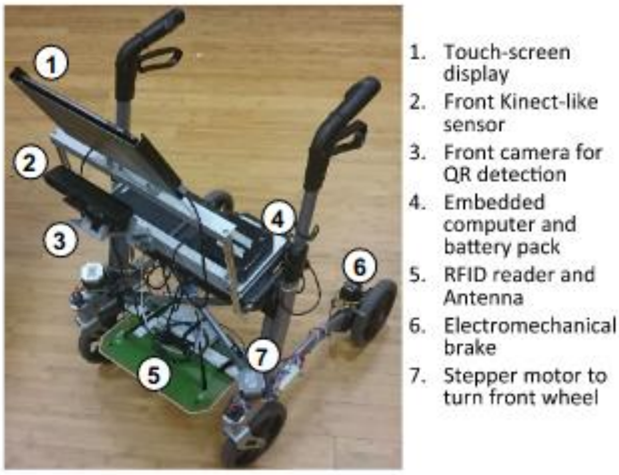

Figure 3-6: The DALi C-Walker [5]

Map building of the C-Walker is done on the assumption that a previously prepared plan view of the area to navigate already exists. Extracting information from that, a mixed metric/topological map is built detailing free space and a connectivity graph linking adjacent cells together. Later, 2 additional layers are added based on the learnings of the C-Walker, the 1st being points of interest (like washrooms) and the 2nd being dynamic obstacles (e.g., people). Using *Cell Decomposition* Method, a structured representation of free space is made and is used to populate a geographic database like PostGIS. This can be used during the path planning process later.

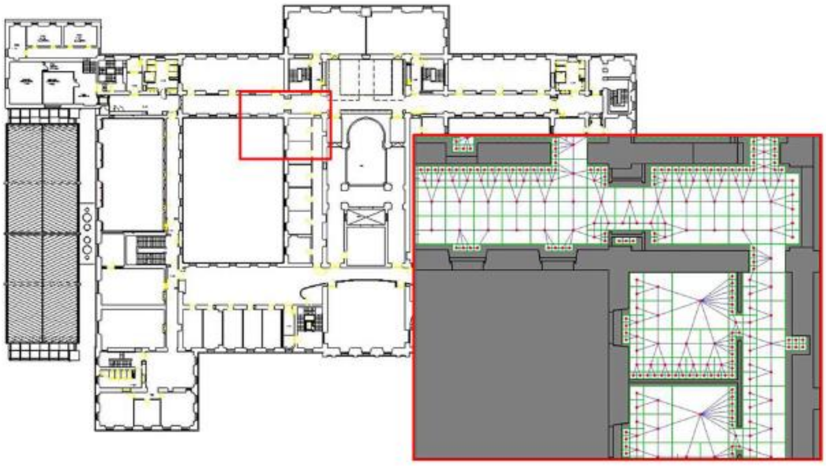

Figure 3-7: Map built using Cell Decomposition Method [5]

Localisation in the C-Walker is an interesting application. Unlike in most other Autonomous Mobile Robots (AMRs), the C-Walker has 2 means of localisation- *relative* and *absolute.* The architecture is depicted in Figure 3-8.

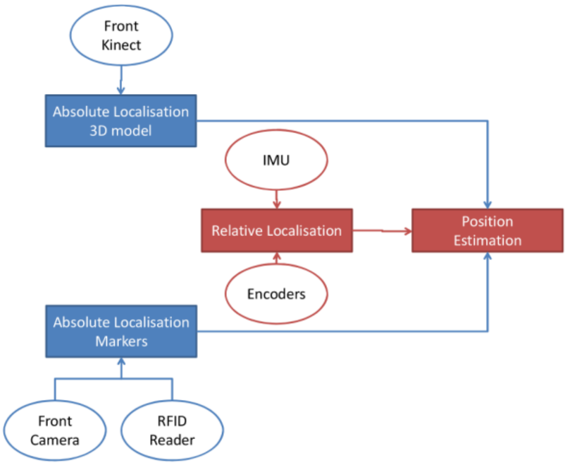

Figure 3-8: Multi-localisation Means of the C-Walker [5]

Relative Localisation is done through the integration of IMUs, and Encoders as shown in Figure 3-8. This enables high rate pose estimates. The issues found are as follows.

1. Initial position cannot be observed.
2. Noisy measurements- thus unreliable.

Therefore, *Absolute Localisation* is used as a means of rectifying this. Through the presence of RFID tags and visual markers in the navigating area, which are triggered when the walker is in the vicinity of these, absolute localisation according to the previously prepared map is done. If the walker doesn't encounter any such visual cues and the level of uncertainty passes a specific threshold, then absolute localisation based on 3D Modules is used as a last resort. Using the Kinect Camera, a visual of the immediate environment is developed and this is compared with the pre-existing map to localise the walker.

Finally, we look at the *Path Planning* of the C-Walker. It follows 2 approaches here- the 1st being *long term* and the next being *short term.* The long-term planner considers the previously built map and preferences of the user (such as travelling closer to washrooms, etc…) and builds a path. The path planner is based on the Dijkstra Shortest Path Algorithm. When the user is traversing down this path, any and all anomalies and dynamic obstacles that come up are handled by the short-term planner. Using Social Force Model and Statistical Model Checking, the short-term planner works to avoid these obstacles and devise a path that returns to the long-term path as quickly as possible.

Another interesting rollator application is the *I-Walk Assistive Robot* [7].

Figure 3-9: I-Walker in Action [7]

The I-Walker has been developed under 2 scopes as lightweight and heavy weight. The *lightweight* version is essentially a subset of the heavy weight version.

Of interest is that the I-Walker is completely based on the Robot Operating System (ROS) as its *Software Architecture.* ROS runs on Ubuntu Linux for this robot, and the central processing unit for this platform is a TX2 Jetson. A further Intel NUC 7567U is used for additional functionalities such as the guidance system and to increase the precision of the odometry. The system architecture is attached given in Figure 3-10.

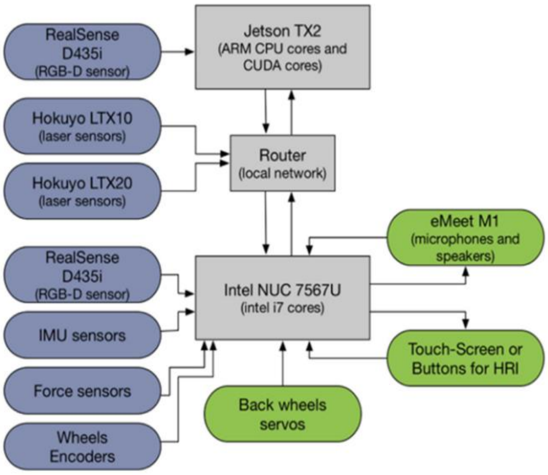

Figure 3-10: System Architecture of the I-Walker [7]

The software architecture for the robot is as follows:

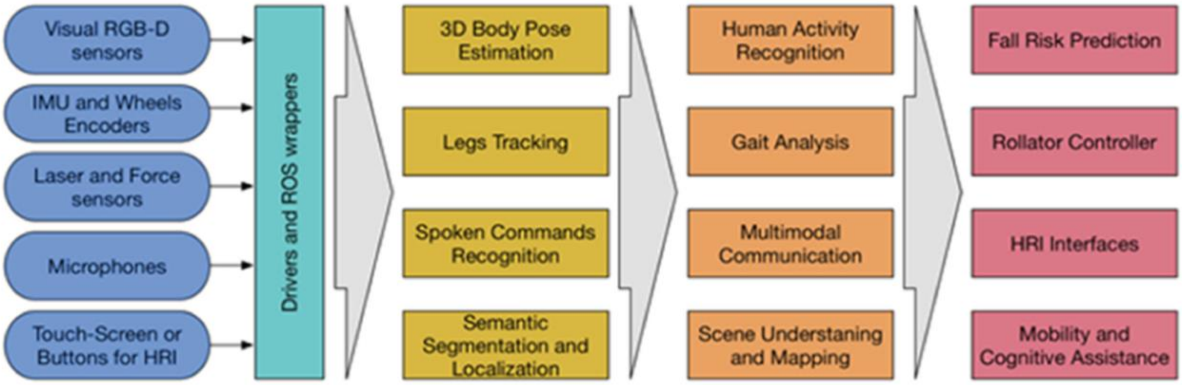

Figure 3-11: Software Architecture of the I-Walker [7]

Initial *map building* is a functionality that is not been seen in this robot. The I-walker uses an already existing map for this purpose. Nevertheless, it still works on processing this map and building a *Global Obstacle Cost map*, that is to be used in the path planning process.

Path Planning consists of 2 layers: a local planner and a global planner. Unlike the previous works that were considered, here, both these modules are built using the in-built functionalities of ROS. The *Global Planner* uses Dijkstra's Algorithm[8], also used in the DALi Robot, to traverse the Global cost map and to build the best path. This is an extremely fast interpolated navigation framework. By tuning certain parameters of the cost map, it is possible to define how close the walker gets to an obstacle. Once the global planner maps out the optimal path, the local planner, through means like Trajectory Rollout and Dynamic Window Approach[9], works to provide the appropriate velocity commands for the robot. Through forward simulation of the robot's motion, it continuously tests the path provided. Further, the local planner works on a local cost map which is dynamic and includes the obstacles detected by the global cost map along with any 'new' dynamic obstacles.

Figure 3-12: Planned Path [8]

Localisation of the robot is done using the Adaptive Monte Carlo Localization (ACML) available on the ROS navigation stack. ACML is an algorithm that employs a *particle filter* to determine the pose of a robot. Given a map and some means of sensing its environment, and depending on the odometry data from the wheels, the module works continuously registering the robot's pose on the map and to correct any odometry errors.

3.1 References

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4 Walking Guidance System

A walker designed by Zhao et al. [1] tracks individuals in front by detecting lower limb motion and offers close proximity walking safety support. By measuring force pressure on a specifically created soft-robotic interface on the handle, the walker may sense human intentions and foresee emergency scenarios, such as falling. An infrared temperature sensor and a lidar sensor are used to collect the gait data in order to achieve user tracking from the front. From time-serial gait data, a neural network (NN) model is trained to understand the user's intention. After learning the user's intention, the walker's target position is computed to make sure that one of the user's feet is on the walker's rear-wheel axis and that its forward motion is parallel to the foot's orientation.

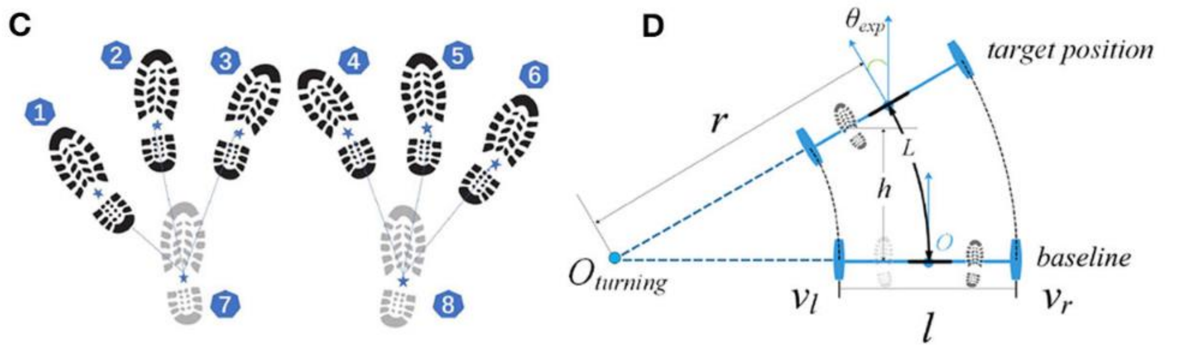

Figure 4-1 Detection of the position of feet [1]

Instead of the walker's handle, a soft robotic layer serves as the user interface. To transfer the load to the main frame, the rigid foundation constructed of acrylic board is used in the handle's core. Multiple air pressure measuring bellows joined by air pressure sensors make up the handle's inside.

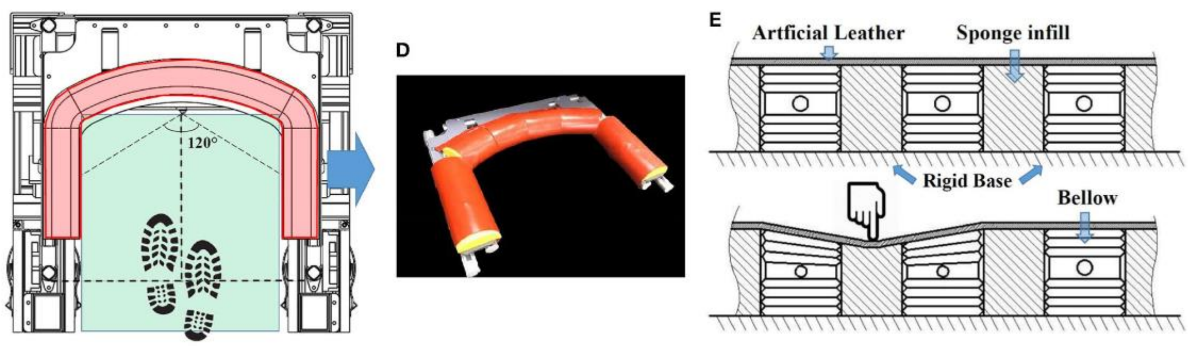

Figure 4-2 Soft robotic handle [1]

We can determine the information about pressure changes and the rate of changes from each pressure type given in Figure 4-3. This data is used to determine the user's purpose and whether or not they are experiencing an emergency.

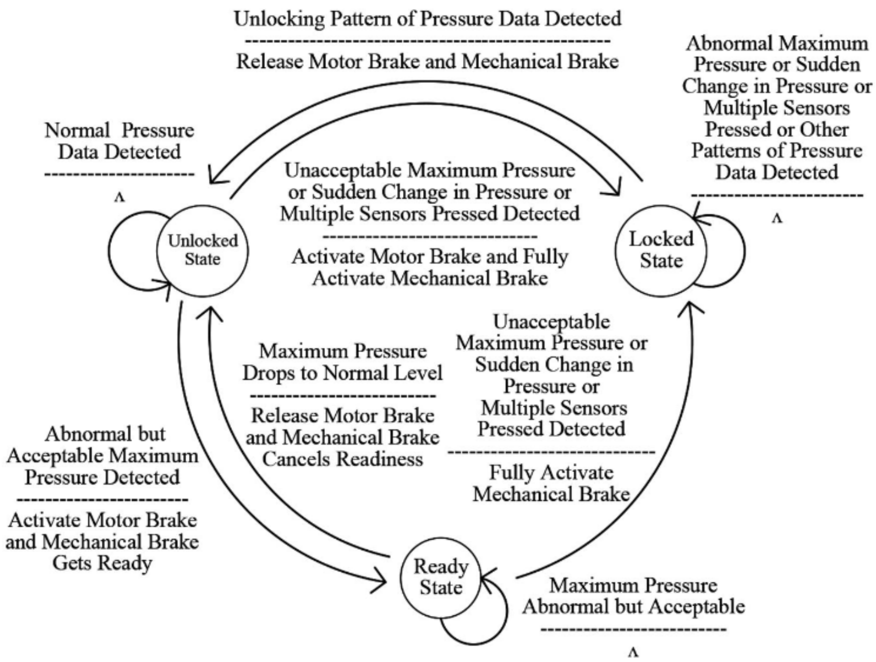

Figure 4-3 Finite State Model (FSM) of the Soft Robotic Handle [1]

The user may effectively manage the speed of the walker with the help of the soft haptic handle. By pressing two sensors on the handle, the user can choose from five pre-programmed speed settings. The handle's left and right-side sensors are the two sensors in question. The first is employed for acceleration, while the second is utilized for deceleration. For the user's safety, the walker will only respond to one button at a time; that is, if one button is pressed, it won't respond to the other sensor. The speed level of the walker won't keep changing if one button is depressed and then held down. When the speed control button is pressed, a distinct pressure peak value appears on one sensor, but the pressure on the other sensors is weak. Because it differs from previous patterns, this pattern of pressure data can be employed when the FSM is keeping an eye on the user's condition.

The guidance system implemented by Aggravi et al. [2], [3] has the purpose of gently inviting the user to follow the planned route. The user must perceive the force feedback as soft, and it must be suitably regulated when the user approaches the borders of an area of interest in order to increase comfort during navigation. Mechanical, haptic, and audio-based approaches are used in conjunction to implement guidance. The design of mechanical guiding follows the paradigm of passive robotics. User is allowed to push the walker as necessary but to steer the walker along the recommended course, the control system can selectively engage two electromechanical brakes that are installed on the back wheels. The control rule has been created by solving an optimal control problem in which the braking actions must be minimized in order to limit the intrusiveness of the guidance as much as possible.

Only infrequent and gentle corrective actions are used as long as the user keeps their movement within a safety zone surrounding the intended path. When the walker strays from the trail and approaches potentially dangerous regions, the control becomes more authoritative. Since mechanical feedback can be found as disturbing for some users vibrotactile feedback has also been implemented to alert the user to turn right or left with the use of two identical wearable haptic wristbands. Two cylindrical vibro-motors in each wristband are separately controlled by the Bluetooth protocol. The arm, just below the elbow, can be fitted with each vibrotactile bracelet. This arrangement has shown to be quite effective at separating haptic stimuli from the walker's inherent vibrations.

As shown in Figure 4-4, the walking support function incorporated by Jeong et al. [4] maintains indoor walking posture and provides walking assistance. The walker's plush armrests enhance a care recipient's posture while they walk or carry out a simple chore while standing up straight. To help with driving and braking when negotiating flat surfaces, steps, and slopes, two flat and compact drive wheels with brushless motors are used. The drive wheels have a locking mechanism installed to stop the walker from moving in an unfavourable direction while walking and carrying out chores that support the care recipient's upper body weight on the armrests. A solenoid that is controlled by a Hold-to-run (HTR) button on the gripper, locks or unlocks a toothed plate that is fixed to the internal gear. Since the solenoid is of the normally closed type, when the power is switched off the wheels are automatically locked.

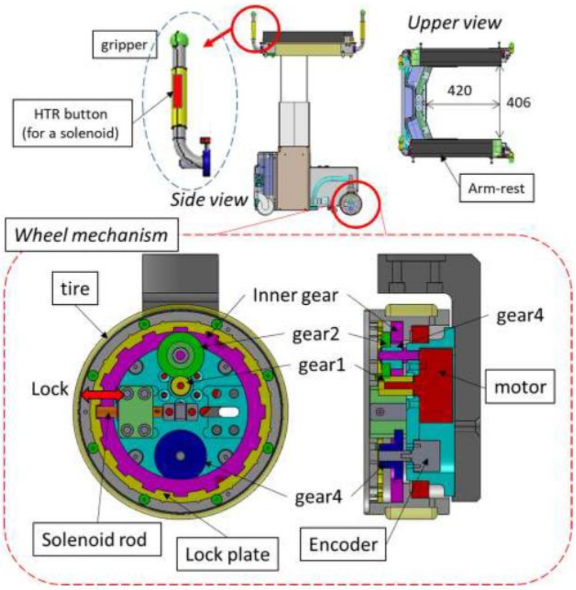

Figure 4-4 Wheel locked/unlocked operated by Hold-to-run (HTR) button on the gripper [4]

Here a velocity-based walking support controller is adopted, which is given by Eq. 1.1,

$$\tau_{rw} = K_v(v_d - v) + K_{\dot{\phi}}(\dot{\phi}_d - \dot{\phi})\ \tau_{lw} = K_v(v_d - v) - K_{\dot{\phi}}(\dot{\phi}_d - \dot{\phi}) \quad \text{Eq. 4.1}$$

where τ_{rw}, τ_{lw} are the control inputs to the left and right wheels, and $K_v, K_{\dot{\phi}}$ are the differential gains, respectively. $v_d, \dot{\phi}_d$ are the reference forward and steering velocity, and $v, \dot{\phi}$ are the real forward and steering velocity of the walker.

In a braking control mode, the reference velocity is set to 0 and the wheels produce brake torque proportional to the walking speed. The differential gains are adjusted in accordance with each velocity threshold to change the braking torque in two steps.

For forward velocity,

$$\{0 < |v| < v_{th1} \quad K_v = K_{v0}\ v_{th1} \le |v| \quad K_v = K_{v1} \quad \text{Eq. 4.2}$$

For steering velocity,

$$\{0 < |\dot{\phi}| < \dot{\phi}_{th1} \quad K_{\dot{\phi}} = K_{\dot{\phi}0}\ \dot{\phi}_{th1} \le |\dot{\phi}| \quad K_{\dot{\phi}} = K_{\dot{\phi}1} \quad \text{Eq. 4.3}$$

Where $K_{\dot{\phi}0}, K_{v0}$ are smaller than $K_{\dot{\phi}1}, K_{v1}$ respectively.

JAIST (Japan Advanced Institute of Science and Technology) active robotic walker (JARoW) by Lee et al. [5] is made to give potential users easy-to-use controls for moving it forward, backward, and around, even in confined spaces. Using the infrared sensors, we determine the user's lower limb states. Without the use of physical controls like joysticks or touchpads or electronic devices worn on the user's body, it allows automatic control of the JARoW velocity. According to the user's lower limb position in relation to the base frame, JARoW moves in the desired position and direction.

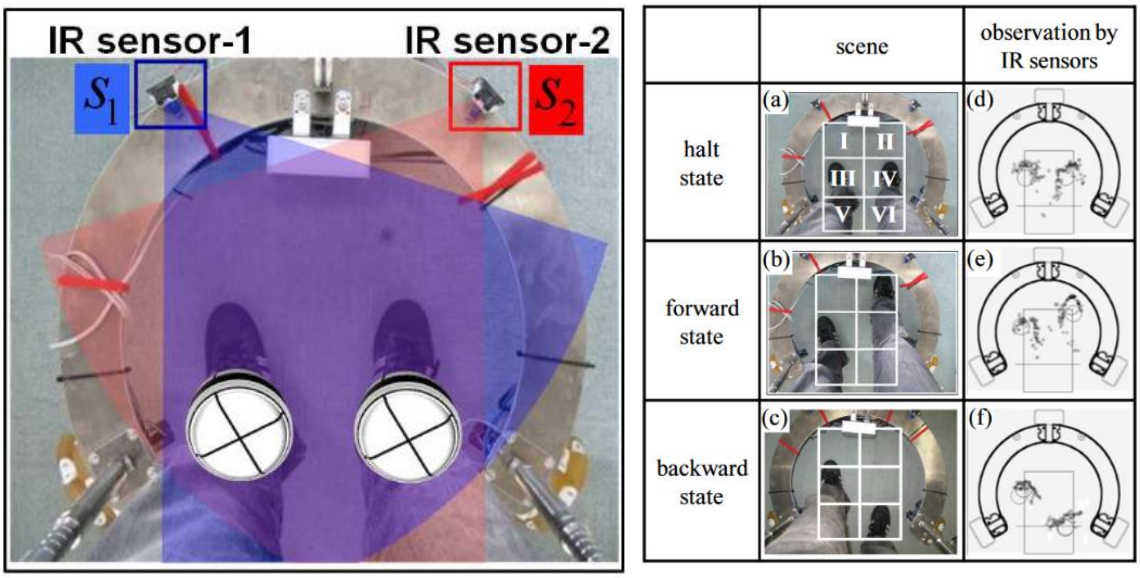

Figure 4-5 Mobility state identification by IR sensors [5]

The measurement of the shin position was discovered through experimentation as a fallback alternative after toe identification proved challenging since the shin data displayed a uniform distribution and a value that was close to constant. Modelling the lower leg as a cylinder with radius ‘d’ is possible. The shin location measurement can take into account distinct lower leg movements as a pair of infrared sensors spin at a certain angle horizontally.

Here, the base frame's area is shown as a 600x700 mm rectangle that is further subdivided into six rectangular grids. The numbers on each grid run from top left to lower right. Five patterns of shin location were observed empirically. The standstill state is assumed if the shins are found in positions III and IV. The left lower leg and the right lower leg are thought to be situated at the oddly and even grids, respectively. The forward state is assumed if one shin is detected at III or IV and the other at I or II. Likewise, it is deemed to be in a backward position if any of the lower legs is located at V or VI. The velocity matrix with all zero elements is output by the main controller for the halt state. The components of the velocity matrix take on a specific set of values depending on whether the forward or reverse state is determined.

As implemented by Ferrari et al. [6] the basic goal of "Simulated Passivity" is to share control with the user, with the motors only being turned on when they are actually required. In order to do this, two distinct control states—"user in control" and "robot in control"—are specified. The authority is borne by the user while the walker is in "user in control" mode because there are no motors running, making it completely passive and behaving like a regular walker. In "robot in control" mode, the authority over the walker motion is transferred to the robot, which calculates the user's walking pace in order to adapt to her/his velocity using the rear motors.

In particular, when the robot is in control, it actively manages the rear motor angular velocities and, as a result, steers the vehicle in the desired direction. At the same time it tries to maintain the forward velocity as close to the estimated value the walker operated at when it was in 'user in control' mode.

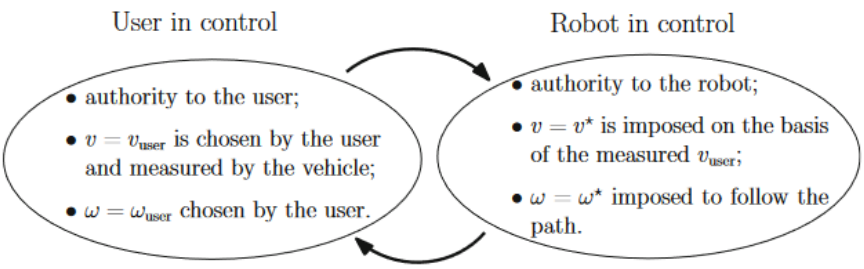

Figure 4-6 Authority sharing system [6]

Force sensors that were incorporated into the walker robot's handlebar frame make up the haptic interface created for the study by Morris et al. [7]. In ambulatory devices, handlebars offer support and stability and need a tight hold from the user. The user may hold the robotic walker steadily and control it in a way that is more in line with modern roller-based walkers. Here, a prismatic, motion-restricted handgrip is installed on each handlebar. In order to reduce the displacement that the grippers exhibit, semi-pliable foam is placed in between the handgrip. To detect pressure when force is applied along the handlebar, two force-sensing resistors are implanted into the foam. The planar rotational and translational velocities of these pressure values are converted. To keep the robot's control as simple as possible, a forward push on either of the handlebars causes it to move forward, while a differential push-pull combination causes it to rotate. A tug on either of the handlebars, however, stops the walker.

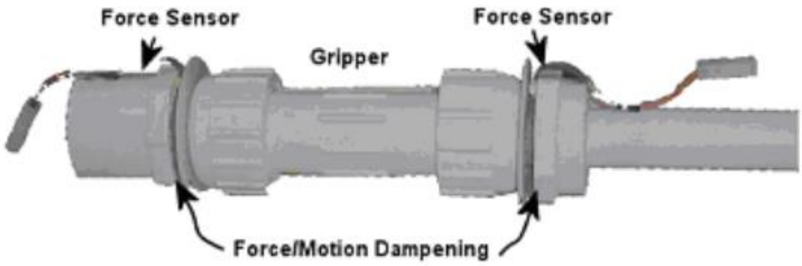

Figure 4-7 Haptic Interface implemented by Morris et al. [7]

The control methodology developed by Lu et al. [8] comprises of two force-sensing handles that measure the force applied by the user and an intelligent learning scheme that calculates the appropriate driving force from the measured grip force. As the measured grip force caused by the user's applied force is closely proportional to the driving force (torque), a relationship between the user's applied force and the walker's subsequent motion at various moving velocities can be established. In light of this, the learning scheme was created, using the robot's measured grip force and velocity as inputs and the driving force as an output. The fuzzy technique was used in this work to account for the fuzziness in the formulation, particularly the mapping between the user's applied force and the observed grip force.

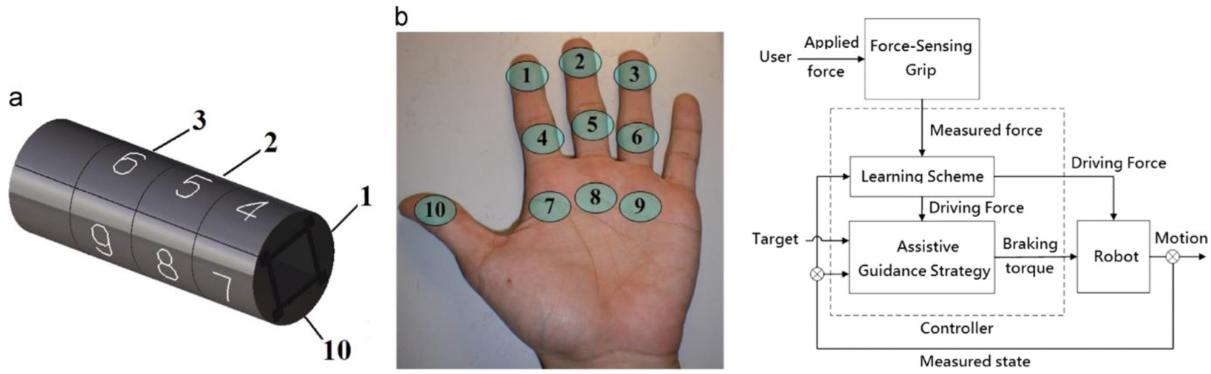

Figure 4-8 Force-sensing handles and system block diagram [8]

Following a similar approach of taking applied force for velocity regulation Chuy et al [9] introduces a system of states for operation which is given in the Figure 4-9. The key highlight is the use of an omnidirectional mobile base which enables lateral motion. The states of the system are active states and idle state. Active state can either be for translational or lateral motion. Lateral motion is useful in crowded environments or in situations where user wants to reach something at its sides. As visible by the figure, there is no direct connection between each active state as it can result in oscillations when the state changes.

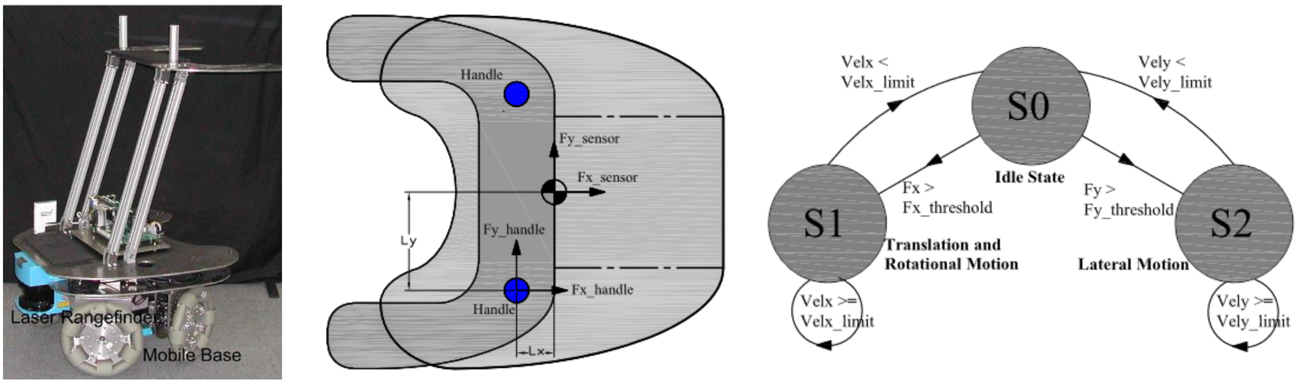

Figure 4-9 Omnidirectional mobile base, Sensor arrangement and state transition diagram [9]

The control architecture employed by Graf [10] is capable of stumble detection in addition to velocity regulation. The walker's forces are compared to earlier sensor data to look for significant variations. This suggests that instead of accelerating the robot, the operator should stop it after they may have stumbled. The stumbling protection will remain in place if a probable stumble by the walking assistance user has been detected until the user forces are at zero or are applied in a different direction. This makes sure the user has regained his balance and allows the walker to continue without risk. An off-the-shelf walker's acceleration is directly related to the applied user forces while making velocity judgments. The walker is slowed down by the friction of its wheels on the ground when it is not being pushed. The motion generator's mass model is based on the motion characteristics of regular walkers. The desired velocity of the walker induced by the user's input alone is computed by Eq. 4.4, depending on the maximum permitted forces and acceleration.

$$v_{User,t} = v_0 + \int \frac{a_{max} \cdot F_{User}(t)}{F_{max}} dt \qquad \text{Eq. 4.4}$$

The friction opposing velocity is calculated by Eq. 4.5 where $a_{Roll} = \frac{F_{Roll}}{m}, F_{Roll} = m \cdot g \cdot c_r$

$$v_{Roll\,,t} = \int a_{Roll}\,(t)dt \qquad \text{Eq. 4.5}$$

The velocity of the walker is computed by Eq. 4.6 since friction always operates in the direction opposite to the current motion direction.

$$v_{Veh,t} = 0;\ for\ |v_{User}| \leq v_{Roll} \qquad \text{Eq. 4.6}$$

$$v_{Veh,t} = v_{User} - v_{Roll}; for\ |v_{User}| > v_{Roll}$$

Wearable haptic bracelets [11] that include two cylindrical vibro-motors that produce vibratory signals to alert the user are used to implement haptic guidance. The patient wears one vibrotactile bracelet on each arm to optimize stimulus separation while maintaining the most natural-feeling discrimination process. When the right bracelet is activated, the user is advised to turn right, whereas when the left bracelet is activated, the user is advised to turn left. When neither band provides haptic feedback, the user is advised to go straight.

Figure 4-10 Haptic bracelet for guidance assistance [11]

The acoustic interface described in [11] by Moro et al. uses synthetic signals to send to the user through a headphone the direction they should go in. For instance, when the system wants to recommend that the user turn left, it generates a sound that the user perceives as coming from a place on her left that suggesting the move she should make. The use of the binaural theory has made this possible. Here the Audio Slave software module, which creates this sound, is given the spatial coordinates (S_x, S_y) of the spot that must serve as the sound source by a master. The audio slave transforms the cartesian coordinates into a pair (r,θ) of relative polar coordinates, where r stands for the angle of azimuth and for the distance between the listener's head centre and the virtual sound source.

The Left/Right Guidance and Binaural Guidance are two versions of the guidance interface that were both implemented using the binaural processing algorithm. Similar to a haptic interface, the Left/Right Guidance Interface reproduces only virtual sources set at 90° or 180° to indicate a turn to the right or left. Any position for a virtual sound source is acceptable with the Binaural Guidance Interface. The resulting recommendation includes more specific information about the precise direction rather than just suggesting a turn.

The research of Cifuentes et al. [12] suggests a sensor fusion architecture that integrates measurements of the reaction forces experienced by the upper limbs with the localisation of the legs to determine the walker control parameters. These variables serve as the control strategy's connection between the user and the walker. Given in the figure the distance to the centre between left and right legs (d) is measured directly using the LRF sensor after the legs' localization process is performed.

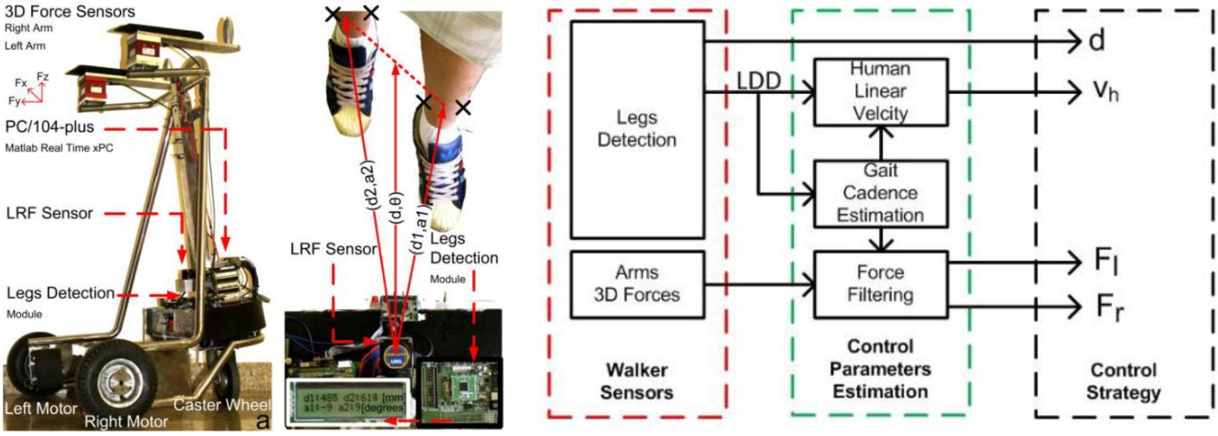

Figure 4-11 Robotic walker configuration and sensor fusion architecture [12]

The LDD (Legs Difference Distance), which is another measurement, is the separation between the left and right legs. (d1 - d2) It is utilized for both adjusting the adaptive filters and computing the human linear velocity (v_h). After the legs have been localized, the product of the gait cadence (LDD frequency estimation) and the gait step amplitude (LDD amplitude estimation) is used to calculate the human linear velocity.

A form of mechanical guidance as presented by Palopoli [13], [14] utilizes two different actuators: either the electrical brakes mounted on the back wheels or a stepper motor mounted on the front wheels. Using these actuators, a path-following control algorithm is put into practice. A path's geometry is known by path planning algorithm. Given the walker's dynamic model, path following tasks may only be completed by applying the desired torque values derived from a feedback control law if we had direct control over the torques given to the rear wheels. This is resolved by roughly estimating the user-imposed push and then employing a dissipative braking action in the absence of a motor to create such torques directly. To maximize the user comfort, the dissipative action is minimized by an optimization algorithm.

Here, the concept of a virtual corridor is another crucial component. The control action is loose when the user is in the middle, but it becomes more authoritative as the user gets closer to the limits. The user will feel as though they are still in control of the navigation process. The steering wheels have been set up using a similar control system. This is helpful when we want to take an authoritative control action and the user is very close to the corridor's boundary. The steering wheel control is simpler from a control theoretic perspective and is executed directly on the kinematic model of the moving platform.

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5 Standing Assistance System

In a study done in 2021 by Takeda et al. [1] in Japan, a care robot system was developed that can handle several motions, such as sit-to-stand, walking, and stand-to-sit and anomaly detection with a single compact robot. For walking and stand-to-sit motions, state estimation, and anomaly detection, a novel Centre of Gravity (CoG) candidate computation approach was put out. The built care robot was equipped with the suggested approaches, which were then tested in experiments. Figure 1 depicts the care robot used in this investigation. The robot that has been adopted resembles a walker and has an armrest, two wheels with brakes, and four casters. The user clutches the grippers while sitting or standing behind the robot, placing both arms on the armrest.

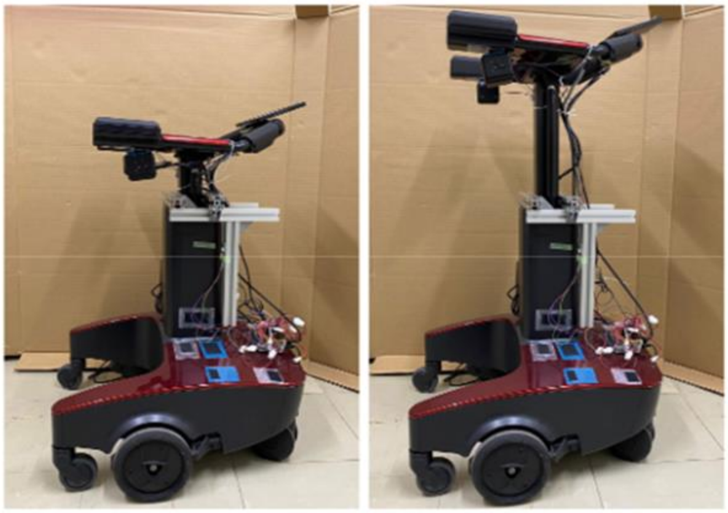


Figure 5-1: Care Robot by Takeda et al. [1]

When the user leans forward against the care robot, the armrest moves up and down to support standing up and sitting down. The robot is required to operate according to the state transition. In the following sections, the CoG candidate calculation method is elucidated as a basis for state estimation. The armrest on the care robot slides up and down to help stand up and sit down when the user leans forward against it. The robot must respond to the state transition to function. The CoG candidate computation approach is explained in the parts that follow as a foundation for state estimate.

5.1 CoG Candidate Calculation Using Knee Positions

An innovative method for calculating CoG candidates using knee positions is presented in this section. For estimating state during walking, information about the lower limbs is crucial. It was found through the examination of the robot user actions that standing and sitting did not appreciably change the ankle position. Therefore, ankle information is not optimal for a welfare system that supports standing, walking, and sitting with a single robot. The position of the knee is more crucial when standing and sitting, and it's also thought to be equally crucial when moving around. As a result, measurement sets that contain knee position data are thought to be appropriate for state estimation during walking and anomaly detection in terms of the accuracy of the CoG candidates. The novel measurement sets include the following, as shown in Fig. 2:

Figure 5-2 Novel Measurement Sets. The black points represent points where the position is measured. [1]

- Positions of wrists: touch sensors of the grippers
- Positions of elbows: touch sensors of the armrests
- Positions of knees: distance sensors
- Position of one point of body link: distance sensor

The left and right grippers and armrests are equipped with one touch sensor each. Three distance sensors are used to measure the upper body and the left and right legs. Because these sensors are mounted on the robot, they are not a burden to the user.

5.2 Leaning Estimation

The robot helps the user sit and stand by adjusting its armrest in response to leaning. Leaning estimation is crucial before beginning to move the armrest. From the sensor data and the features used as the SVM's input, the robot derives the CoG candidates, which are used for state estimation. State estimate is done for each of the remaining data points. Learning models are developed using data acquired 10 times for each action per person. Leaning when sitting and standing are estimated from the measurement data using the data for normal sitting and sitting with a forward lean, as well as the data for normal standing and standing with a forward lean.

5.3 Anomaly Detection While Standing Up and Sitting Down

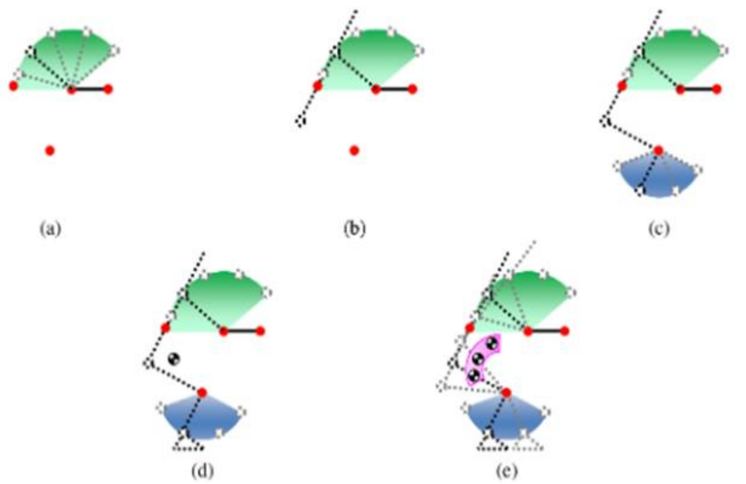


Figure 5-3 Novel CoG Candidate Calculation Procedure. (a) All shoulder joint candidates; (b) Corresponding hip joint candidates; (c) All ankle joint candidates; (d) Corresponding CoG candidates; (e) All CoG candidates of entire human body. [1]

An abnormal standing or sitting condition is one in which the user cannot stand or sit normally. Each sensor can find the anomaly on its own when the hand or arm is taken out of the armrest. As a result, we assume that the anomaly in the standing and sitting states happens when the user's arms are on the armrest and only the armrest raises or lowers, as seen in Fig. 4.

(a) (b)

Figure 5-4 Overviews of the Anomaly. (a) Only armrest rising during sit-to-stand; (b) Only armrest descending during stand-to-sit. [1]

5.4 Implementation And Validation Experiment Using Care Robot

The robot is equipped with touch and distance sensors to detect anomalies during user assistance. When an issue is detected, the robot adapts its assistive function, halts the actuators, and applies brakes based on state estimation. Users are encouraged to regain normal function by discontinuing the robot's assistance early when an issue arises. For standing up, users hold the armrest, lean forward after a countdown, and the robot raises the armrest, lifting the user. The countdown duration depends on anomaly detection. If an anomaly occurs, the robot stops the armrest and applies brakes. The robot also identifies anomalies when the user's legs are not in sync with the robot, leading to automatic braking to prevent falls. The brakes are released when the user returns to a normal state. Additionally, when the user is in a normal standing position, the robot checks for leaning, but this starts 2.0 seconds after standing to avoid premature sitting. The process is similar for sitting down, with the armrest lowering. If an anomaly is detected while the armrest is descending, it stops.

In another research done by Jeon et al. [2] in 2021, an indoor robotic walking care device to assist the daily activity of the elderly was proposed. The suggested robotic walking care device was developed using a modified V-shaped technique using the International Classification of Functioning to help daily tasks, particularly standing-sitting, walking, and using the restroom. Based on the concept, a prototype of the suggested device was developed, featuring a lifting mechanism and power-assist wheels.

5.5 Functions of the Device

Function 1: Maintaining indoor walking posture and walking assistance.

● Use the armrest of the walker as a support as you walk (forward, backward, twisting, etc.)

● Walk while using the walker's drive wheels for power assistance to climb stairs and inclined surfaces.

● Utilize the walker as a support while carrying out simple tasks while standing (washing hands, putting away clothes, operating doorknobs, etc.).

Function 2: Power-assist functions for standing up from and sitting down on a bed, a chair, etc.

● A care receiver adjusts their position to be able to stand up by holding onto the device's armrest after some time spent sitting down.

● Using the lifting device, one can stand up and adopt an upright posture by resting their upper bodies on the top of the device and bearing their weight there.

● Apply body weight to the lifting device when standing up, then use it to sit down.

5.6 Structure of the Prototype

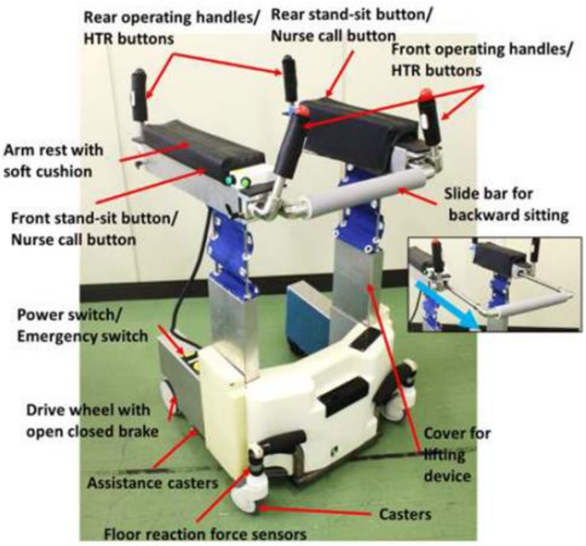


Figure 5-5 Prototype of walking care device [2]

Fig. 5-5 shows a prototype of the walking care device that was created using concepts linked to human behaviours (Section 2) and the functional needs of the device (Section 3) while the overall control system configuration is depicted in Fig. 6. The device's floor occupation size is

600 mm (W) 600 mm (D). It is a four-wheeled form of walker, with two front wheels that can roll freely and two driving wheels on the back. Between the walker frame and each wheel, there is a sensor that measures the floor reaction force.

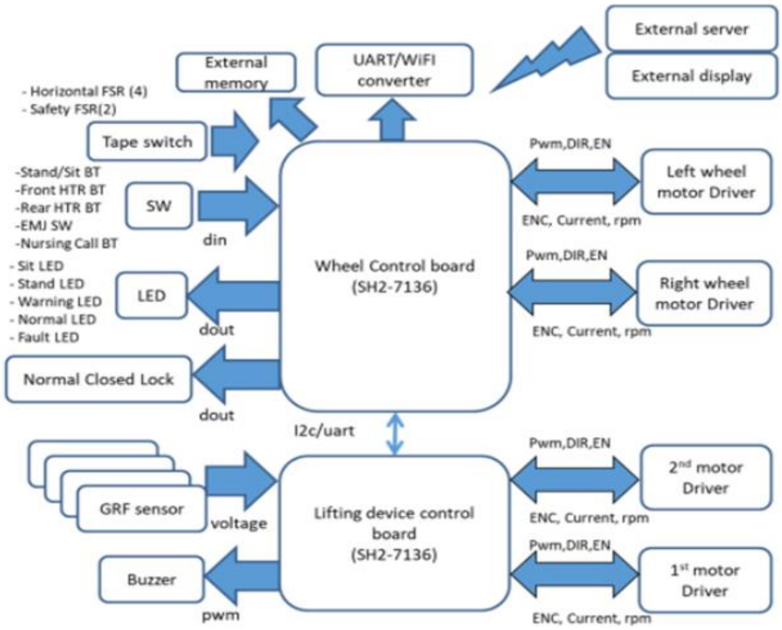


Figure 5-6 The configuration of the control system of the robotic walking care device prototype [2]

The device could be moved by lifting the drive wheels off the ground with the casters even when the drive wheels are locked thanks to the two-auxiliary casters that are situated between the front and rear wheels. The armrests' height can be adjusted from 450 mm to 950 mm to support the sit-to-stand motion. Two batteries are positioned at the bottom of the side armrests, and the control board is in the device's front part. A locker-style power switch was fitted, allowing power to be turned on or off with a single action to prevent error. At the front and back ends of the armrests are two switch boxes with standing-sitting support buttons and a nurse call button, as well as two handles with hold-to-run (HTR) buttons, which activate a system while pressed. These front and rear operational devices do the same task, allowing a care recipient to use it in both forward and backward positions. The drive wheels and the hoisting mechanism are managed by two control boards.

5.7 Design of Walking Support Function

The prototype's design for a feature that assists with walking and maintains proper posture when indoors is explained. Fig. 5-7 depicts the layout of the components connected to the walking support. The walker's cushioned armrests enhance a care recipient's posture while they walk or carry out a simple chore while standing up straight. To help with driving and braking when traversing flat surfaces, steps, and slopes, two flat and compact drive wheels with brushless motors are used. With a total reduction ratio of 10, gears 1, 2, and an internal gear conveys the motor's output power (12 V, 30 W) to a tire. The drive wheels have a locking mechanism installed to stop the walker from moving in an unwanted direction while walking and carrying out chores that support the care recipient's upper body weight on the armrests. A solenoid that is controlled by an HTR button on a gripper lock or unlocks a toothed plate that is fixed to the internal gear. Since the solenoid is of the normally closed variety, when the power is switched off the wheels are automatically locked.

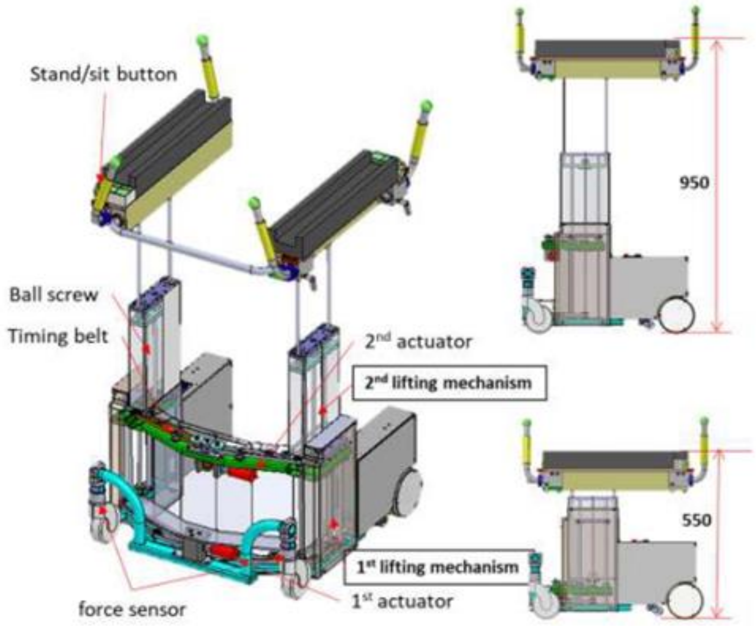


Figure 5- 7 The two-level lifting mechanism that change the height of the armrest with two low-power motors [2]

5.8 Design of Standing/Sitting Support Function

Lifting force and speed are significant design criteria to consider when creating a lifting device. A healthy person can stand up at a maximum speed of 400 mm/s with power assistance and walk freely if they have the leg strength to sustain 30% of their body weight. To evaluate the proper lifting force and speed of the device, they have carried out a pilot experiment involving assisted standing. Based on the findings of the experiments, the apparatus was created to have a maximum lifting force of 400 N, or around 50% of an 80 kg person's body weight, and a speed of 250 mm/s. These values consider the fact that the main users of this device are elderly people with reduced leg strength.

Additionally, for standing and sitting control, data from the four-floor reaction force sensors, which are positioned between each wheel and the walker's body frame, is used to determine whether the weight of a care recipient is appropriately supported by the device. According to the positions of each force sensor, as shown in Fig. 8, the floor response force's center location is computed. In another study done by Daisuke Chugo, Kunikatsu Takase of Kwansei Gakuin University, Hyogo and The University of Electro-Communications, Tokyo, Japan [3], a Robotic Walker for Continuous Assistance during Standing, Walking and Seating Operation was designed and developed.

5.9 Assistance Mechanism

An overview of the suggested support system is shown in Figure 5-9. The system consists of an active walker system and a support pad with three degrees of freedom. Four parallel linkages

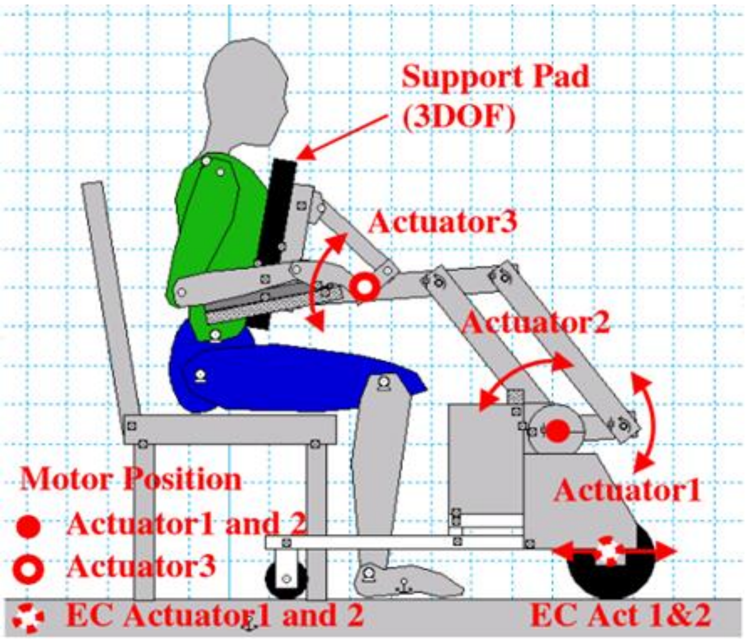
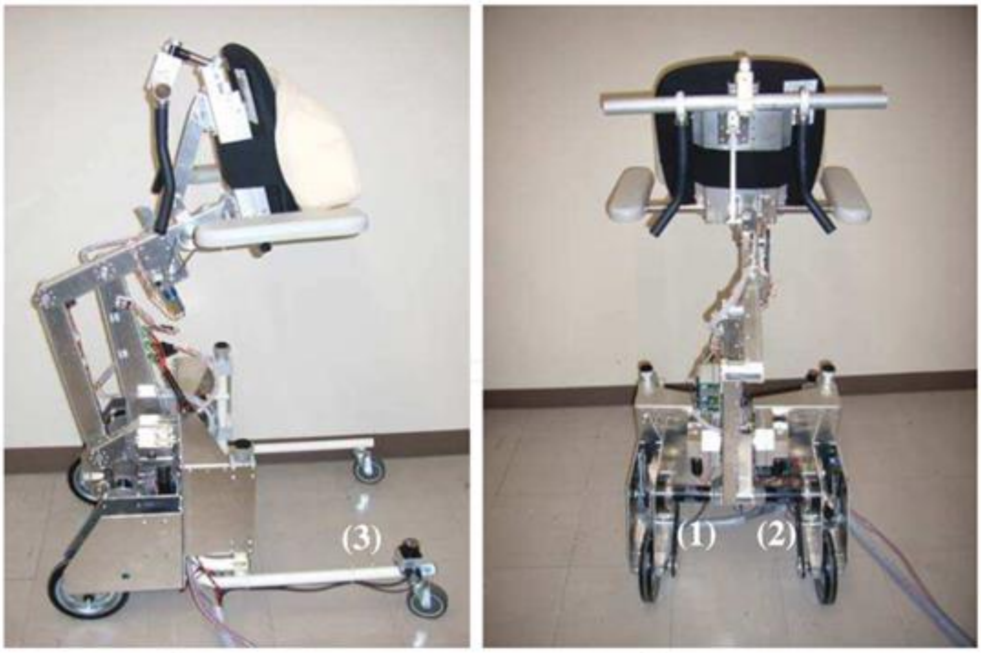


Figure 5-9 Overview of the system [3]

in a manipulator mechanism that operates the support pad give the necessary assistance. Patients rely on this pad to provide support while they stand. Two brushless motors, which will be discussed in more detail in the paragraph that follows, are mounted on each of the front wheels of the active walker and power it.

The system's prototype is shown in Figure 10. This prototype can support people weighing up to 150 kilos and raise patients to a maximum height of 1.8 meters. Additionally, it aids patients in walking by using its actuated wheels [4].



(a) Side View (b) Front View

Figure 5- 10 Developed Prototype [4]

Figure 5-10 displays the support pad created in response to suggestions from nursing experts at a welfare event (Chugo & Takase, 2007). The arm holders and low-repulsion cushion of the support pad both have handles. It is common knowledge that elderly people frequently have a fear of falling forward when standing, which negatively affects their ability to stand. Patients can confidently maintain their posture when standing by using this support pad, all but eliminating any concern of falling forward. The pad also has two force sensors built into its structure, which are covered in greater detail in section 3. Thanks to the data provided by these sensors, this cutting-edge technology is able to calculate the patient's body balance throughout the motion of standing up and measure the applied force.

5.10 Controller

The control system designed by the team is shown in Fig 11. Their active walker system and standing help system are the two main parts of their assistance walker. Three DC motors, three potentiometers, two force sensors built inside the arm holder, and three DC motors in each joint make up the standing aid system. Worm gears connect the motors to each joint, allowing the manipulator to maintain its position even in the case of a power outage.

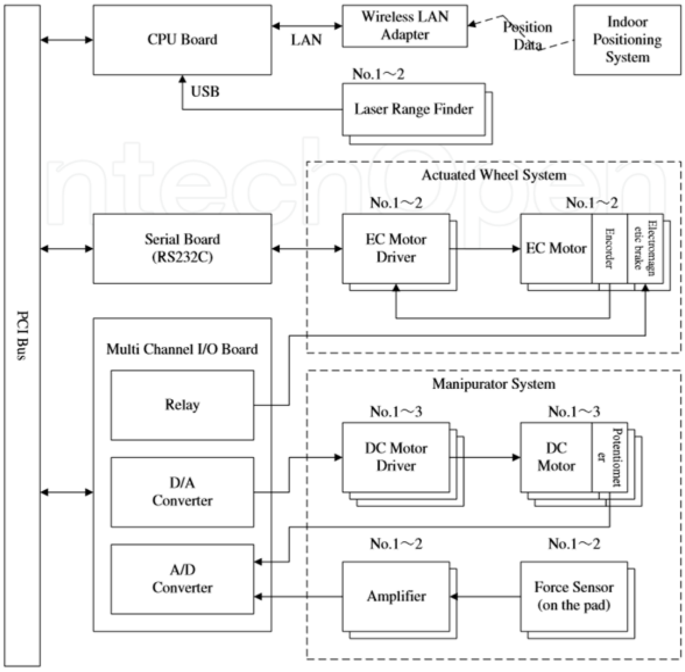


Figure 5-11 Overview of the control system [5]

In the active walker system, shown in Figure 10 (b) as (1) and (2), each front wheel is equipped with two Maxson brushless EC motors and two electromagnetic brakes. When the patient appears to be in danger of falling, these electromagnetic brakes act as a safety mechanism to stop the walker. Even when supporting a patient weighing up to 150 kilos, the brakes are made to keep the walker stable. When the patient pushes the walker ahead, the EC motors have the benefit of functioning with traction force constraints and can alter their movement to follow the patient's lead. These qualities are essential for the safety considerations of the active walker. Two laser range finders with a maximum range of 4 meters and a wireless LAN adaptor are added as further system enhancements. An indoor positioning system installed in the patient's room, can effortlessly transmit real-time position data to it [5].

5.11 References

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6 Summary

6.1 Autonomous Navigation System

This literature review delves into the fundamentals of autonomous navigation in robotics, concentrating on essential elements such as map building, path planning, and localization. It begins by discussing the historical context, marking the evolution of autonomous navigation technologies.

Map building, a crucial component, involves the use of various sensors, including LIDAR and cameras, to create maps that aid in obstacle detection and navigation. Path planning strategies are explored, encompassing algorithms like A* and Dijkstra's Algorithm, which determine the most efficient and obstacle-free routes. Localization, a pivotal aspect of autonomous navigation, utilizes a combination of sensors and algorithms to precisely determine the robot's position.

In addition, this review highlights the impact of software platforms and their role in enabling autonomous navigation. It offers valuable insights into these core aspects of autonomous navigation, providing a foundation for future developments in this field.

Finally, a recap of the different robots that were considered and their respective technologies.

Table 6-1 Recap of the reviewed Navigation techniques

Robot	Map building	Path planning	Localization
BigDog [1]	Point cloud segregation algorithm	Adapted A* Algorithm	Kinematic + Visual Odometry
C-Walker [6]	Cell Decomposition Method and existing map	Djikstra Shortest Path Algorithm Social Force Model	1) IMUs and Encoders 2) RFID Tags and Visual Markers
I-Walk Assistive [7]	Already existing map	ROS built-in algorithm, based on Djikstra	ACML on ROS navigation stack

6.2 Walking Guidance System

Table 6-2 Summary of Walking Guidance Systems

Author	User Interface	User Feedback	Sensors/ Actuators	Control Strategy	Safety Features	Notable Feature
Zhao et al. [1]	Soft robotic handle	Force pressure, lower limb motion	Infrared temperature sensor, lidar	Neural network (NN) model, Finite State Model (FSM)	Emergency scenario detection	Soft haptic handle, emergency detection
Aggravi et al. [2], [3]	Mechanical, haptic, audio	Force feedback, mechanical, haptic, audio	Mechanical, haptic, audio sensors	Optimal control, selective braking	Minimal intrusiveness, authoritative control	User-friendly control, gentle guidance
Jeong et al. [4]	Plush armrests	Drive wheels, locking mechanism	Infrared sensors, solenoid	Velocity-based walking support controller	Walker locking mechanism	Plush armrests, walker locking
Lee et al. [5]	Infrared sensors	Infrared sensors, base frame	Infrared sensors	Lower limb position relative to base frame	Safety zone, forward and reverse control	Automatic control based on user position
Ferrari et al. [6]	User control, robot control	User control, robot control	Not specified	User in control, robot in control	User-controlled and robot-controlled modes	Authority sharing system, user in control mode
Morris et al. [7]	Haptic handle	Force-sensing resistors	Force-sensing resistors	Differential grip force and velocity	Walker stoppage, rotation, and forward movement	Haptic interface with foam, force-sensing resistors
Lu et al. [8]	Force-sensing handles	Grip force, grip force learning scheme	Force sensors	Fuzzy logic, grip force learning scheme	User-applied force relationship	Grip force-based learning scheme
Chuy et al. [9]	Force-sensing handles	Force sensing, state-based operation	Force-sensing handles	State-based operation, lateral motion	State-based operation, lateral motion	State-based operation, lateral motion capability
Graf [10]	Force-sensing handles	Stumble detection, force measurement	Not specified	Stumble detection, velocity regulation	Stumble detection, user forces monitoring	Stumble detection, user feedback
Moro et al. [11]	Haptic bracelets	Haptic feedback, acoustic signals	Vibro-motors, audio signals	Haptic guidance, acoustic guidance	Haptic guidance, acoustic direction	Haptic and acoustic guidance
Cifuentes et al. [12]	Sensor fusion	Sensor fusion, reaction forces	Reaction forces, LRF sensor	Sensor fusion, distance measurements	Sensor fusion, user-walker control parameters	Sensor fusion, gait parameters
Palopoli [13], [14]	Electrical brakes, stepper motor	Path-following control, virtual corridor	Electrical brakes, stepper motor	Path-following control, virtual corridor	User-imposed push and optimization algorithm	Path-following control, virtual corridor

6.3 Standing Assistance System

Table 6-3 Technologies in Standing assistance systems

Aspect/Technology	**Takeda et al. [1]**	**Jeon et al. [2]**	**Chugo & Takase [3]**
System Description	Care robot system with multiple functions including sit-to-stand, walking, and anomaly detection.	Indoor robotic walking care device with lifting mechanism for daily activities	Robotic walker for continuous assistance during standing, walking, and seating operations
Sensor Technologies	- Touch sensors for wrists and elbows - Distance sensors for knees - Distance sensor for body link	- Floor reaction force sensors - Touch sensors in armrests - Distance sensors for floor reaction force	- Force sensors in arm holders - Potentiometers in joints - Force sensors in support pad - Laser range finders - Wireless LAN adaptor
State Estimation Technology	CoG candidate calculation using knee positions	Not specified	Body balance calculation based on applied force
Anomaly Detection Technology	Detection based on arm and arm- rest positions	Detection based on user's position and movement	Real-time positioning system with indoor positioning system
Walking Assistance	Robot adapts to user leaning to help with standing and sitting	Robot provides power assist for indoor walking and power-assisted mobility	Power-assisted wheels for walking Actuated wheels for patient stability
Design and Structure	Walker-like robot with armrest and wheels for user support	Four-wheeled walker with adjustable armrests	Active walker with support pad and front wheels with EC motors and electromagnetic brakes

6.4 Synthesis & Research Gap

State-of-the-art smart robotic walker navigation systems employ key features like map building, path planning, localization, and obstacle detection. The complexity and computational demands, posing scalability challenges is highlighted. The review indicates a gap in addressing these computational constraints for practical deployment. Furthermore, the need to investigate navigation in social environments with prediction of human behaviour is recognized. The integration of the Robot Operating System (ROS) in these systems showcases potential for open-source, interoperable software solutions. Future work must aim to balance advanced capabilities with efficiency, adaptability, and human-centric applications in this field.

The review on walking guidance systems highlights innovations in user-centred control, mobility enhancement, user control transitions, haptic and acoustic interfaces, force-sensing handles, sensor fusion, and path-following control. Identified research gaps include customizing control interfaces, optimizing user guidance algorithms, developing adaptive terrain analysis, improving control transitions, integrating sensory modalities, advancing learning algorithms, and enhancing sensor fusion. Further research can enhance user experiences, safety, and mobility for a wide range of users with different needs and preferences.

The literature on standing assistance systems highlights innovative approaches, including Centre of Gravity calculations using knee positions, leaning estimation, and anomaly detection. However, research gaps persist in integrating multiple functions, user-centred design, safety, real-time adaptation, cost-effectiveness, and accessibility. Future work should focus on comprehensive user-centric solutions that ensure safety and adaptability while remaining cost-effective and accessible to a broader user base. In conclusion the following table summarises the recognized gap for research.

Table 6-4 Identified Research Gap

Area of interest	Identified Research Gap
Autonomous Navigation System	User-centric, adaptable system capable of human behaviour prediction in social environments
Walking Guidance System	Improved control transitions, mobility support for a wide range of users with different needs and preferences and integrating sensory modalities
Standing Assistance System	Cost-effective, practical and reliable mechanism that ensure safety and independence of the user