Intelligent Assistive Mobility Walker for Rehabilitation

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***Abstract*— This paper presents a new generation of walker for rehabilitation purpose for patients in hospitals and rehabilitation centers. The design features a full frame walker that provides secured and stable support while being foldable and compact. The smart features can provide communication and patient activity recording to help physiotherapist monitor the patient activity from nurses' station.**

Keywords - ***walker; rehabilitation; gait; balance; smart; physiotherapist; hospital.***

I. INTRODUCTION

The rapid ageing population in Singapore starts to affect the society in many aspects. The ageing population and associated healthcare problem is one of the most pressing issues that the government is facing. Based on the research done by National University Hospital[1], it has been estimated that 85 percent of the common injuries were due to falls. 49 percent of the fallen elderly were admitted to hospitals.

Once a person is diagnosed with gait and movement balance disorder, therapy is required. The use of walker is always a good solution to help in their gait and balance ability. Walkers are widely used in hospitals and families to help with rehabilitation. The design of walker can give the user a good support for him to get used to gait training and know how to balance his body. Figure 1 shows a standard walker commonly used and sold in the market.

Figure 1. Standard Walker

Nowadays, walkers commonly used are purely mechanical with 3-side frames which are cheap and light. For patients in severe condition, it is almost impossible for them to use the walker independently. This type of design will result in unnecessary stress on the patient's body. During the process of gait training, a physiotherapist is required to accompany the patient in order to supervise and monitor his progress. Sometimes two physiotherapists are seen supporting a patient on walking rehabilitation along the corridor of the hospital with one physiotherapist supporting the patient who is using a walker while the other physiotherapist pushes a wheelchair along including a pressure monitoring equipment on trolley as the patient may need to rest on the wheelchair and have his blood pressure taken when he becomes tired. With a rapidly ageing population, this mode of therapy operation is not sustainable and will eventually result in the shortage of physiotherapists as the supply of quality physiotherapists is limited. Therefore, it will be good for a user-friendly and productive walker to be invented in order to improve productivity in the hospitals, rehabilitation centres and nursing homes.

The mechanical design of the standard walker should be improved to allow most of patients to utilize it independently. With the help of telecommunication and sensors technology, numerous smart features have been integrated into the smart walker described in this paper. It enables the user to communicate freely with the physiotherapist who is stationed at the physiotherapist station. At the same time, the physiotherapist will be able to remotely monitor the training progress of multiple users of the smart walkers in real-time which will result in the increase in efficiency and productivity of the physiotherapists.

II. OBJECTIVE

The goal of the project is to design and develop a unique walker with intelligent features incorporating electronics and telematics technology besides mechanical aspects. This integration of technology will allow a more stable and safer environment for the user to exercise and perform rehabilitation as well improving the productivity of the physiotherapists in that one physiotherapist can now monitor several walker users instead of 2 physiotherapists looking after a single walker user.

III. EXISTING DESIGN

There are three types of walkers commonly sold in the market.

A. Standard Walkers

A standard walker (see Figure 1) which is also called folding walker and it is the simplest walker for the elderly. It has four legs, two handles and no wheels. Four legs are wrapped with rubber to prevent sliding. This walker is usually folded into half in order to be stored in the trunk of the car for transportation or in the storage room when not in use.

Any user who is able to balance his body when standing or walking will be suitable to use this type of walker. A standard walker can provide full support to the elderly to assist them in walking.

B. Front Wheel Walker

The front-wheel walker is also called two-wheel walker (see Figure 2). Instead of having four legs, two front legs are replaced by two big wheels. It is easier to slide across the ground compared with a standard walker.

Figure 2. Front Wheel Walker

Any elderly user who does not have sufficient strength to lift the mass of the standard walker will be suitable to use this type of walker.

C. Rollator

Rollator is a kind of walker with the configuration of four wheels, two braking system, a seat and a basket/bag (see Figure 3). It replaces the four rubber legs with four wheels. This will also allow movement to be easier on uneven ground or carpet. Therefore, this design of the walker works well in either indoor or outdoor environment. Any elderly person can utilize the walker as long as he is able to walk quite independently without support.

Figure 3. Rollator

D. Limitation of Existing Product

The above three types of walkers are widely used at families or in therapy sessions. The advantages of the three types of walkers are that they are reasonably cheap, light and convenient. However, all these walkers still exists some hidden issues and limitations.

The standard walkers have rubber legs that can prevent sliding by using the concept of applying the majority of the patient's weight on it. The elderly person is required to lift his/her arms and shoulder in order to tilt the walker by moving in a side-by-side motion. For those elderly persons whose arms are not strong enough, it is almost impossible to utilize the standard walker alone. At the same time, it will give unnecessary pressure or strain to their arms and shoulders while using the walker for either rehabilitation or for moving from one point to another. For the elderly person who could not control the walker properly, someone must be present to help and accompany him.

The rollator can move easily on the ground with the integration of the four big wheels. It also has a seat for the elderly to sit down when they are feeling fatigue or tired. However, the wheels' design may cause stability issues if the elderly person did not hold the brake handles properly or firmly.

E. Walker Version 1.0 Prototype

After reviewing the literature and studied the basic walkers, a better designed mechanical walker version 1.0 prototype was developed (see Figure 4). The design of the four-sided frame can prevent elderly from falling. The turning wheels could rotate 360 degrees and allow the walker to move smoothly and easily on the ground. A waist belt is provided for safety and to assist the elderly user to stand up in the optimal posture for either the rehabilitation or exercise. The design also allows the user to rest both arms on the two arm rest at the sides. This walker has been evaluated at different local hospitals, won awards in project competition and presented in a healthcare exhibition as well. Many visitors from hospital and healthcare center liked its design and has provided various useful feedbacks.

Figure 4. Walkie Version 1.0 Full-Scale Working Prototype

Useful feedbacks received from visitors and hospital users:

1. *Bicycle seat is not comfortable and interfere with users' gait while walking.*
2. *Foldability is required for storage and transportation.*
3. *Smart features like telecommunication and user's activity monitoring are required.*

IV. WALKER VERSION2.0 PROTOTYPE

A new version of walker (see Figure 5) was designed with the integration of the smart features based on the considerations and feedbacks of the walker version 1.0. The height of the walker body’s frame has been lowered compared with version 1.0 in order to increase the stability of the new walker. Various sensors were implemented into the walker system to detect fall, distance monitoring, etc. Telecommunication and monitoring system were implemented on the new walker so as to allow users to communicate with the therapist station at any point of time either from a short distance range or long-distance range. All of the real-time activity information will be sent back to the monitoring system and stored in the form of excel datasheet to help the physiotherapist comprehend the rehabilitation status and the exercise progress of the patient. An emergency alert feature is added into the walker system to alert the physiotherapists if any accident occurs or if the user requires any form of assistance.

Figure 5. The Smart Walker Prototype

A. *Mechanical Features*

1) *Foldability*

The folding mechanism is controlled by the metal bar and the nuts structure as shown in Figures 6 and 7. The rectangular shape metal plate requires an upward force in order to bent and fold the walker. The size of the walker can be reduced approximately to half when folded to save space and it also allows easier storage as well as providing convenience for transportation in a car.

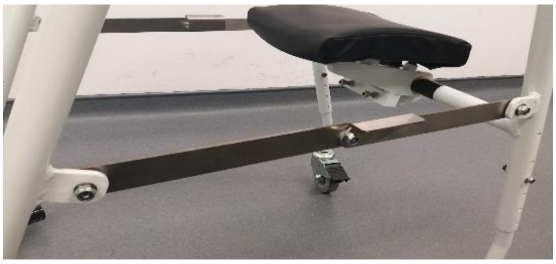


Figure 6. Folding Structure

Figure 7. Folded Walker

2) *Retractable Seat*

The seat is fabricated in a shape of a square to increase the contact surface area so as to allow the elderly to feel more comfortable compared to a bicycle seat (see Figure 8). To overcome the walking interference issue in walker version 1.0, this seat can be flipped up to give more space for users to perform walking exercise. The magnetic mechanism of the walker will hold the seat in place which will result in stability and prevent the user from falling as there is sufficient space within the walker for the patient to maneuver.

Figure 8. Retractable Seat pull down/up

B. *Smart Features*

1) *Emergency Button*

The emergency button is the red button on the black box mounted on the right-hand side of the walker (see Figure 12). Once the button is pressed by the user, the Graphical User Interface (Figure 9) at the therapist’s station will produce a loud and sharp sound and the emergency window will pop-up to inform the physiotherapist that an emergency has occurred on that particular walker. This sound will last until the physiotherapist closes the emergency window and presses the ‘OK’ button on the monitoring interface to confirm that he/she has acknowledged the alert.

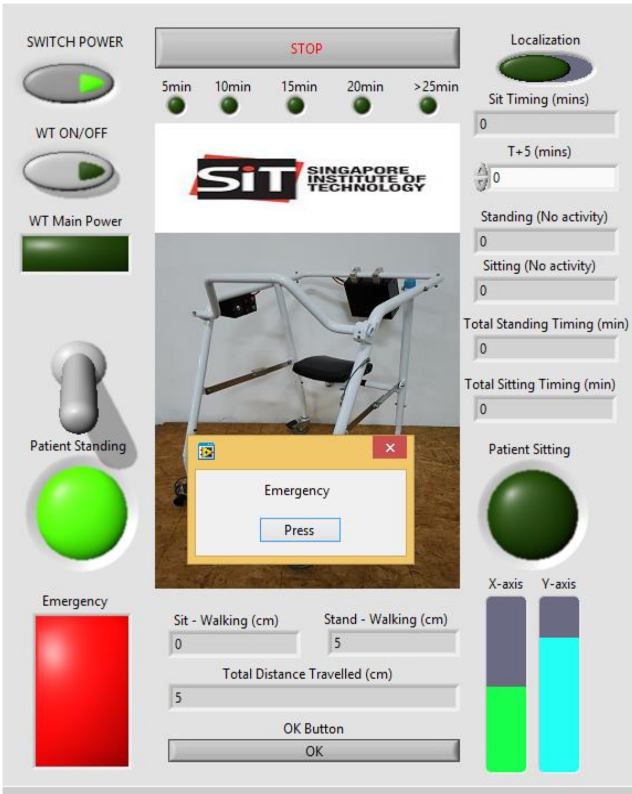


Figure 9. Graphical User Interface (GUI)

2) *Telecommunication*

The green button on the black box is the communication function (see Figure 12). Users can communicate with the therapist's station at any point of time in the hospital when this button is being pressed. The two square-shape red buttons on the walker can be used to adjust the volume for the speaker.

3) *Activity monitoring*

All activities will be recorded and shown on the Graphical User Interface that is installed at the therapist's station (see Figure 9).

Activities Monitored: sit-walking distance, stand-walking distance, total distance travelled, sit time (no activity), stand time (no activity).

An activity report will be generated automatically after each training session has been completed (see Figure 10).

	A	B	C	D	E	F	G
1	Total Distance	Stand-Walking Value	Sit-Walking Value	Total Sit WalkingTiming	Total Stand Walking Timing	Sitting (No activity)	Standing (No activity
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0

Figure 10. Sample Report Generated after therapy

V. ELECTRONICS AND TELECOMMUNICATION

In order to make the walker a smart device, several electronics have to be integrated into the walker. It allows the controller to perform the necessary processing. Sensors are incorporated to measure parameters such as distance walked, walking speed, patient's resting time, patient's mode of walking (sit-walking or stand-up walking) and duration. It also allows voice communication between the physiotherapist and patient when the physiotherapist is at the physiotherapist station.

A. *Controller*

NI-MYRIO is a hardware developed by the National Instruments, Texas used to acquire and process real-time signals. It consists of a dual-core ARM Cortex –A9 processor and a Xilinx FPGA embedded in it and it is compact. It consists of two expansion port (MSP) known as Connector C. In both the cases, there are certain pins that carry primary and secondary functions. Signals can be acquired and processed in LabVIEW and the generated signals can be used in real-time. NI-MYRIO has 3.3V, 5V, +/-15V power output. It provides connectivity with the host computer either over USB or wireless connectivity. It has an inbuilt accelerometer and special functions like Pulse Width Modulation (PWM), Universal Asynchronous Receiver/Transmitter (UART), Audio input and output terminals. Figure 11 depicts the pin out diagram of the mini system port from which digital/analogues signal can be generated to trigger the end result.

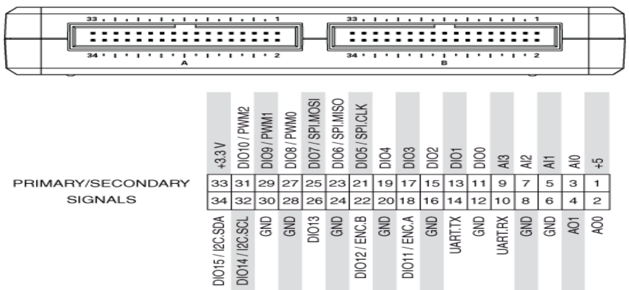


Figure 11. Pin out diagram of NI-MYRIO mini system port

B. *Sensors*

Tracking and monitoring of the patient's movement is important for the therapist in order to have an idea of the progression of the rehabilitation activity of the patients. Sensors have to be implemented to retrieve information and gather the data for processing.

There are several sensors and devices that are required to achieve the objectives of measuring distance that is walked by the patient per therapy session, of knowing the duration of the patient has rested or doing the therapy at a sitting down or standing up position and if the patient has fallen down.

- **Fall Alarm System** – An accelerometer is used to detect vector magnitude and direction of the proper acceleration, as a vector quantity, and can be used to sense orientation, coordinate acceleration, vibration, and shock. When a force is applied above the preset threshold of the system, an alarm will be sounded and a message will be sent to the therapist through the Graphical User Interface (GUI) in order to provide the assistance for the patient (Figure 9).
- **Sitting Detection** –In the event when the patient is feeling fatigue or does not have the energy to continue the therapy through standing, he/she would be able to utilize the seat of the Smart Walker System, which allows the patient to continue the therapy by sitting down and walk. This would significantly reduce the amount of pressure that is supplying to the leg and at the same time, the patient can still continue the therapy by pushing along with the walker. A force-sensing resistor (FSR), whose resistance can be varied by varying the force or pressure applied to it, is embedded in the seat cover with minimal footprint. With the combination of the FRS and a polyethylene foam, the user will not be able to feel the electronic components that are embedded under the seat cover.
- **Standing Distance Measurement** –When the user is standing while moving, the Graphical User Interface (GUI) will capture the amount of distance travelled. The data will be reflected into the system and tabulated into an excel sheet in order for the therapist to monitor the rehabilitation progress of the patient.
- **Standing Timing Measurement (No activity) –** When the user is standing without any activities, the program will activate the counter to start the timing and reflect it into the system. This will allow the system to capture the time duration and store the data into an excel sheet for further analysis of the patient's progress.
- **Sitting Distance Measurement –** When the patient is feeling tired or fatigue but yet to give up on the treatment, he/she will be able to utilize this sit-walking function where the patient could rest on the seat of the Smart Walker System while he/she continues his/her rehabilitation therapy.

This allows the system to capture the amount of distance walked while the patient is seated and walking. After the exercise, the data will be collected and stored in an excel sheet for the therapist to monitor the rehabilitation progress of the patient.

- **Sitting Timing Measurement (No activity) –** When the user has been resting for a certain duration, the system will start to activate the counter and the timing will be recorded and stored in the excel sheet where the therapist will be able to further evaluate the patient rehabilitation progress.

C. *Transmission*

Since the patient using the walker must have the freedom to maneuver during the therapy session, both the internal and external circuitry of the telecommunication device cannot have any hard wires connected to the main controller where the therapist uses to monitor the patient's progress.

Therefore, the data information of the patient's progress has to be transmitted wirelessly. To perform such communication, a local Wi-Fi network has to be created so as to link the connectivity between the end user with the patient. In order to extend the coverage of the WI-FI connectivity, it is possible to include several router points.

D. *Tele-Communication*

With the usage of the telecommunication technology, the therapist need not have to be physically by the side of each patient. This is especially important if the care center/rehabilitation center is huge and the patient may be far away or even out of sight from the therapist's view. Therefore, the introduction of the voice communication has been set up to allow the therapist to communicate with the patient in the event of an emergency or any urgent matters. A simple existing technology has been integrated into this application to establish a voice communication such as using a pair of walkie-talkies.

- **Wirelessly Power Control –** In order to prevent a patient who might have cardiovascular problem where pace-maker is implanted into them, the therapist will be required to manually switch on the communication port via the Graphical User Interface (GUI) as the communication frequency might affect the functionality of the pace-marker.
- **Emergency Button (Red) –** The user will be able to alert the therapist through the Graphical User Interface (GUI) in the event when the user requires any form of assistance (Figure 9). The Emergency button (Figure 12) has been placed in the front of the Smart Walker System in order for the user to have easy access. In the event where the Emergency Button is pressed, a loud audio sound will be activated through the end-user PC which will be reflected in the Graphical User Interface (GUI). A pop-up message will be reflected on the therapist's PC (Figure 9), indicting them to activate the communication button.
- **Push-To-Talk (Green) –** A green push-button (Figure 12) has been placed in order for the user to communicate with the therapist in the event where both parties are out of sight.
- **Adjustable Volume Control -**Two square buttons (Figure 12) have been added to allow the patient to manually adjust the volume level of the speaker. Patient will be able to either increase or decrease the volume threshold for the speaker.

Figure 12. Control Button panel

E. *Software*

The lighting indicator on the front panel of the Graphical User Interface (GUI) is used to create awareness and the monitoring of the patient movement's activities. In the event where the patient is rested for a certain duration of time without any form of activity, the indicator will be lighted (Figure 9). A T+5 min algorithm has been programmed in order to allow the patient to have an allowance of time to rest before it activates the counter. The "T" refers to the time duration the therapist allocates to the patient before the counter starts to be activated as some individuals might require different resting timing based on their health condition.

In order to monitor the patient's progress over time to accurately determine if the patient's health condition is improving or deteriorating, the information for every therapy session of the patients has been be stored and recorded in the excel sheet for further analysis. The data (Figure 10) collected will be categorized into 5 segments namely: Total Distance Travelled, Sit-Walking, Stand-Walking, Total Sit-Walking Timing, Total Stand-Walking Timing, Sitting Timing (No Activity) and Standing Timing (No Activity).

A standalone executable file (.exe) for the Smart Walker System (Figure 10) has been created in order to ease the usage of the software. The approach is to allow any individual to readily use the software without any hassle of installing any driver.

V. DESIGN VALIDATION

SolidWorks was used to determine the integrity of the structural design.

A. *Static Stress Test and Weld Size*

Stress simulation was done using SolidWorks simulation. A load of 150 kg was applied on the seat of a simplified model as shown in Figure 13. The maximum stress, located on the weld joint is determined to be 99.6 MPa.

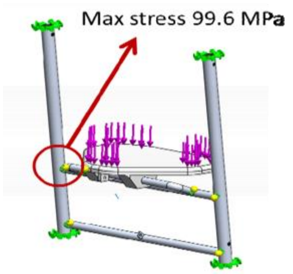


Figure 13. Simplified Model for Simulation

It is essential to determine the weld sizes for the weld joints. Minimum weld size can be analyzed and determine via the usage of the same stress simulation and conditions as presented in Figure 14. A minimum of approximately 2.7 mm weld size is shown in Table 1 to prevent failure.

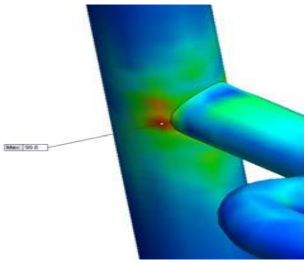


Figure 14. Maximum Stress Results from SolidWorks Simulation

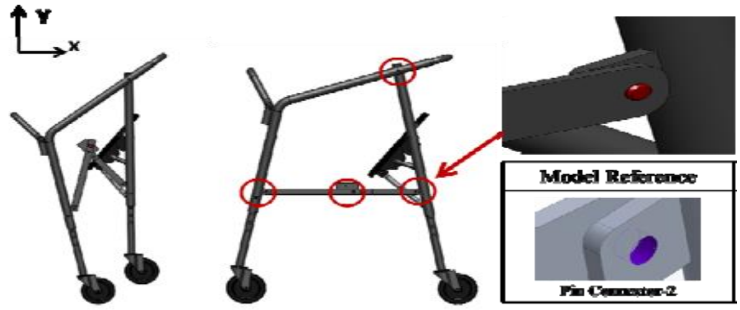
Type	Min	Max	Mean
Weld size (mm.)	0.75289	2.7287	1.8243
Weld throat size (mm.)	0.75289	2.7287	1.8243
Joint normal force (N)	-1.4162E+005	1.2877E+005	-1702.1

Table 1 Weld Size Simulation Results

B. Minimum Pin Diameter

Several pivoting pins are added to the new design to ensure the walker is foldable. The location of the pins is shown in Figure 15. Shearing is the most common failure that can occur for these kind of joints. Therefore, it is important that the minimum diameters of the pins are determined to prevent failure.

SolidWorks simulation was also used to calculate the reaction forces exerted on the pins when a load is applied on the seat. Figure 15 also shows the maximum shear forces for the x, y and z component acting on the pins on location A. These pins experience the maximum amount of forces in the simulation and therefore it is critical that their minimum diameter be determined.



Type	X-Component	Y-Component	Z-Component	Resultant
Shear Force [N]	0	679.38	-2.6135	679.39

Figure 15. Shear Force Results for Pivot Pins

As the diameters of all pins on the new walker are the same, the maximum shear force, 679.38N is identified and used for the calculation. For single pin shear, the shear stress is found using Equation 1.

$$\tau = F/A \quad . . . . \quad (1)$$

where,

τ : shear stress [Pa]

F : shear force [N]

A : cross-sectional area [m^2]

For a force of 679.38N (maximum shear force from simulation) and using AISI 1045 steel as the material, the minimum pin diameter is obtained as follows.

Yield strength $\tau_y = 450$ MPa

Assuming safety factor of 5, the allowable shear stress is,

$$\tau_{allowable} = \frac{450 \text{ MPa}}{5} = 90 \text{ MPa}$$

Area of pin,

$$A = F/\tau_{allowable}$$

Therefore, minimum diameter d is 3.1 mm.

VI. Conclusion

In this paper, the problems associated with existing mobility devices were identified and discussed. A detailed discussion of the new smart walker design was presented. The utilization of the smart features such as distance sensing, telecommunication, monitoring rehabilitation activity and the duration of sitting and standing including the hardware aspects involved were also discussed and explained. This smart walker is the first of its kind to be developed and is in line with the development of today's smart ward in a new hospital setting.

Acknowledgement

The authors would like to thank Singapore Institute of Technology and Kwong Wai Siu Hospital for funding and supporting this project.

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