# Multisensor guided walker for visually impaired elderly people

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***Abstract*—Assisted living for people with disabilities remains a current research challenge. Many systems have been developed to help disabled and frail people gain their self-sufficiency during their activities of daily living (ADL). In this article, we propose a new design concept to help visually impaired (VI) elderly patients move in their home environment. The system is made of a light-weight medical walker where sensory components and processing electronics are installed and operated. Behavioral and environmental information are collected using proper sensors mounted on walker's frame. Direction data are provided using audible notification. The system uses a hardware guiding technique based on ultrasonic and optical sensors for obstacle detection and accelerometer for fall and vibration detection. The algorithm developed for this purpose triggers an audible notification to alert the patient if there is an obstacle ahead. While many developed walkers are complex, expensive and require training to be used, our electronic walker gathers flexibility, reliability, ease of use and future expendability. Unlike other products, the electronic walker is also suitable for indoor and outdoor use. The results obtained after testing the system proved effectiveness. The use of low cost components makes our walker affordable as a final product.**

***Keywords*—Assisted living, Aging, Smart walker, optical and ultrasonic sensors.**

## I. Introduction

Aging is a common natural process characterized by the decrease in functional abilities inducing an increase in dependencies. Referring to its progressive nature, assistance in activities of daily living (ADL) becomes an important challenge for elderly people. Assistance can be exhibited by humans and/ or technological interventions. The former has the problem of expensive cost while the latter is being more and more considered as an alternate. The framework of this technological intervention is to address the needs of elderly persons in terms of heath, security, communications, mobility, etc. The outcome of this assistance shall be measured in terms of gain of independence and improved quality of life.

In this context, the objective of this research is to develop an assisted living solution to help improve the mobility of elderly people in the vicinity of their home environment. The proposed solution is a classical medical "walker" customized to provide assistance for elderly people with visual impairment. Although there are several related solutions in the market, our proposed approach introduces a new hardware guidance technique not found in previous works. This article offers a detailed description of our hardware system design solution. Section II searches the related work found on the market. Section III, highlights our design approach with respect to existing products. Section IV, briefly presents the prototype and discusses results obtained from experiments. Section V finally concludes the paper.

## II. Related Work

Many products have been developed for assisted living. Each of them addresses a particular issue and answers a medical need. Solutions such as those assisting the elderly in their gait and maintaining their balance are many; however, those that also consider impairment are few. The quadcane with adjustable stance in [1] has the simple design of an extendable rod with a handle. The extremity of the rod ends with a 4-paws design that can support a person weighing up to 136 kg. This design offers good stability. The cane has a limited portability and a heavy weight (more than 2Kg) which may induce fatigue. Controversially, the well-known medical walker offers more stability and balance [2]. The light-weight, wide frame, 4-legs design surrounds the patient and helps better support his weight to a maximum of 180 Kg. The walker can be folded and the 2nd set of handles can help the patient get up from his seated position. Modified version of this design hosts electrical motors to assist the subject in his gait [3]. This modified design is not successful due to vibrations induced in the chassis that may lead to dismantling the walker. Extra weight is also added from the motors.

The previous designs are purely mechanical. Their key concept is to assist the elderly during walking; however these solutions do not answer the issue when patients suffer from physical impairments such as loss of vision. In this case, other design constraints such as obstacle detection and notification must be considered. The traditional cane usually used by blind seniors is effective but not quite reliable for it is dependent on the user learning of his environment. Electronic versions of these canes with obstacle detection capabilities also exist. The earliest version and largely used is the white cane (or white stick) [4]. These improved canes with obstacle detection capabilities are made possible by using different sensor technologies. The UltraCane [5], the K-sonar [6], the GuideCane [7] are all solutions that use ultrasonic sensors to detect obstacles. The smart walking stick [8] invented by S. Gangwar

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and his team has infrared sensors. Handheld telemeter devices such as Teletact [9] are designed with laser technology to assist blind people. Recently, effort is made by a team of students at the University of Birmingham in UK to develop a cane with face detection and recognition capabilities. The XploR mobility cane is able to identify acquaintances as they approach. This will add the challenge of image processing to the design. All the previously mentioned systems use either audible notification or tactile vibration feedback to alert the user.

Although the above systems have the obstacle detection and avoidance capability, they all suffer from the major lack of orientation assistance. Moreover, the cane system is only suitable for middle-aged blind subjects without frailty concerns. When functional abilities and frailty are the issues, they must be taken care of in a context aware, safe, reliable and robust application. From this outlook, conventional medical walkers can be customized to fit the needs of elderly with both disabilities and frailty issues. Many customized walkers work in indoor premises only. They require indoor WIFI connection and continuous monitoring from a backend user. Automatic assistance is not provided. Moreover, power consumption is not studied. Battery autonomy is critical in the case of a blind elderly subject. S. MacNamara and G. Lacey developed the PAM-AID (Personal Adaptive Mobility Aid) [10]. This smart walker increases the independent mobility with both manual and assisting modes of operation. It senses environmental data using laser and sonar sensors and provides audible notification to the user. The walker proved effectiveness in terms of safety, maneuverability and global comprehensibility. Despite its overall interpretability, this walker is not intended for outdoor environments and does not integrate fall detection functionalities. In addition, low obstacles are not considered in the design. The cost of the device is moderate to high seen the types of sensors deployed, the reason that it limits its usability to elderly homes only.

## III. Proposed System Concept

### A. General System Description

The proposed system approach is tailored to provide a solution that meets the requirements of an assisted living system. The aim is to restore self-reliance to frail and visually impaired people by developing a hardware guiding technique implemented on a conventional walker device. With this perception in mind, electronic modules and sensor devices are mounted on the chassis of a classical medical "walker". Sensor devices analyze environmental data and provide steering information to the patient by means of audible notifications to move in the correct direction and avoid obstacles. The system takes also into account possible sways on unstable grounds and potential falls or wall hits. The system must be reliable and robust, easy to use and affordable as a final product. Little training is required for the user to operate this walker. Figure 1 illustrates the general system concept of the electronic walker. The framework of the proposed solution comprises two stages, the electronic system hardware design and the orientation and supervision algorithm.


Fig. 1. Electronic walker proposed system concept.

### B. Electronic system hardware design

The proposed electronic walker brings together different functionalities that address the needs of an elderly blind subject and assist him during his ADL. The hardware design consists of integrating different modules onto one single electronic system. Each integrated module has a specific function. These functionalities are:

- Obstacle detection
- Fall and shock detection
- Alerts and notification

Figure 2 shows the hardware design block diagram of the electronic walker.

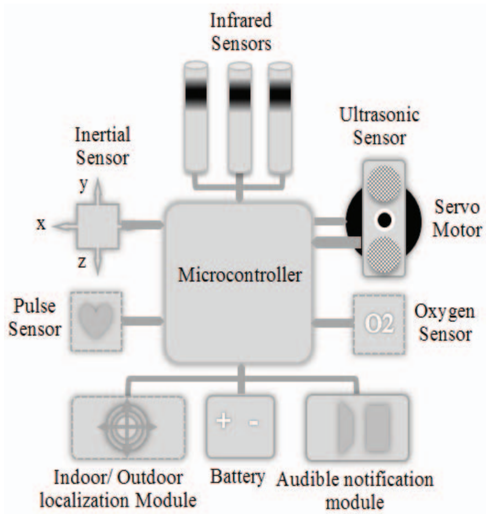


Fig. 2. Electronic walker hardware architecture

*1) Obstacle detection:* Since the elderly's vision is affected, he is at higher risk to run through obstacles despite his cognition of the environment. In this case, obstacle detection is very important. Low-height obstacles such as stairs, furniture, etc., are detected using optical sensors. These sensors function on infrared light to detect objects. They integrate an emitter-receiver circuit with a knob to adjust the sensing range. Besides their ease of use and low cost, these sensors have the advantage of detecting reflected light on almost any kind of surface which made them suitable for our application. Moreover, they are characterized by a narrow spectrum which provides concise figures on the direction of the object in the way. The walker is equipped with three infrared sensors fixed on a metal shelf connecting the two front legs of the walker at 11 cm above the ground. They can detect objects on the near right, left or front of the walker. The operating range of these sensors is fixed at 25 cm.

Controversially, higher obstacles are detected using an acoustic sensor. The ultrasound transceiver module used for this purpose, constantly measures the distance between the patient and the object. The use of this sensor is well suited for stationary and moving objects in the surrounding area of the walker. It has a larger spectrum than the infrared sensor and wider area coverage. Practically, it has an operational range that varies from $d_{min}$ = 30 cm to $d_{max}$ = 4 m. Despite the relatively large region provided by the spectrum, left and right sides are not included in the detection scheme of the sensor as shown in figure 3. To solve this problem, the ultrasonic transceiver is mounted on a servo motor. The motor has a rotational field of 180° which makes a surface area of a semi-circle. This area varies with the distance to the object in the field of view (FOV) of the sensor. The threshold distance $d_{th}$ to detect an object is 80 cm. This value is adequately chosen to allow the patient to manoeuver locally without any difficulties. The threshold area covered by the sensor $A_{th}$ is shown in figure 3:

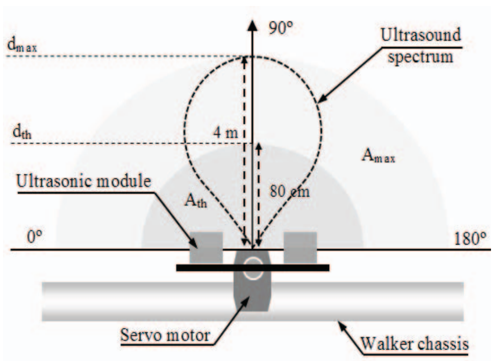


Fig. 3. Ultrasonic module detection scheme.

*2) Fall and shock detection:* Despite the postural stability and the obstacles detection provided by the walker and the sensors, the subject is still at risk to get stuck, stumble or fall. These incidents may happen in indoor as well as in outdoor environments. In fact, the walker legs may be stuck in a hole or reach an unstable ground of an outdoor walkway leading to a side sway and a potential fall, or the patient may drag the walker and carry along an indoor carpet which may cause his stumble or stuck. Low obstacle sensors mounted on the walker are helpless during these situations. To address these issues, an accelerometer sensor is provided in the electronic system. The use of this inertial sensor is double fold: First, for the fall detection scheme, the vertical front and side angles are constantly measured to detect a critical sway or an eventual fall. Second, for the stuck or hit, vibration may be induced on each axis of the accelerometer.

Figure 4 illustrates the fall detection scheme emphasized by the electronic system. Note that $\alpha$ and $\beta$ are the front and side angles measured in the (XOZ) and (YOZ) planes respectively. As stated previously, these angles are obtained

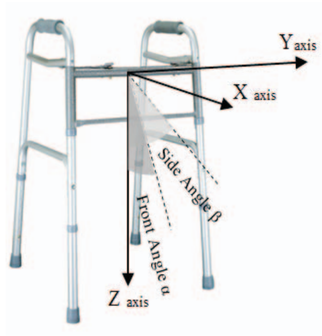


Fig. 4. Fall detection scheme with front and side angles $\alpha$ and $\beta$.

using acceleration data provided by the sensor. Theoretically, these components provide linear acceleration based on a fixed reference point. Our purpose is to obtain angular interpretation of the linear acceleration. Angular deviation can be easily derived from linear acceleration according to equation (2):

$$Angle^{\circ}_{(\alpha,\beta)_i} = \frac{(\arcsin{(\frac{A_i}{1g})} * 180)}{3.14} \qquad (1)$$

Where $A_i$ is the acceleration collected from each axis i ($A_x$,$A_y$,$A_z$). This acceleration is also used to detect stuck or hits. In this case, acceleration is interpreted as vibration or shock. It can be detected when the patient taps on the walker if he gets stuck or hits a side wall. Angular and vibrational data provided by the accelerometer can both alert a potential fall. As matter of fact, thresholds are fixed for each axis and for both $\alpha$ and $\beta$ angles.

*3) Alerts and notification:* Directional data are processed into audible notification. The patient is notified using audible messages. These short messages are sent from the controller to the notification module. The latter converts these messages into audible signals apprehended by the patient using a headset or earplugs. This module does not use prerecorded messages, but rather converts serial data into audio which makes it compatible with any type of controllers. Particular attention is drawn to the repetition of the message to avoid flooding. This module supports only the English language. There are two types of messages; obstacle and feature messages. Obstacle messages notify the height and the orientation of the obstacle while the feature messages indicate a trouble in the system such as low level battery or sensor wiring. these Messages are described below:

- Obstacle messages:
    - *Low obstacle in front (on the left or right)*
    - *High obstacle in front (on the left or right)*
- Trouble messages:
    - *Recharge your battery*

### C. Orientation and guiding algorithm

Before the conversion routine is executed, the accelerometer must be calibrated. A common reference is selected for the x, y and z to start the reading of analog acceleration data. Acceleration is afterwards converted to angular values using the above discussed equation. Angular values are processed, saved and compared to thresholds for fall or hit detection.

Acoustic scanning is continuously performed for possible obstacle detection. The algorithm continuously rotates the motor shaft back and forth from left to right. If an obstacle is detected the motor stops and the user is immediately notified with the position of the obstacle so that he can easily decide his next direction. The system alerts the patient if an obstacle is within 80 cm range ahead. Low height obstacles are programmed using interruption routines. They are triggered when optical sensors detect low obstacles. Figure 5 illustrates the flow diagram of the orientation and guiding algorithm.

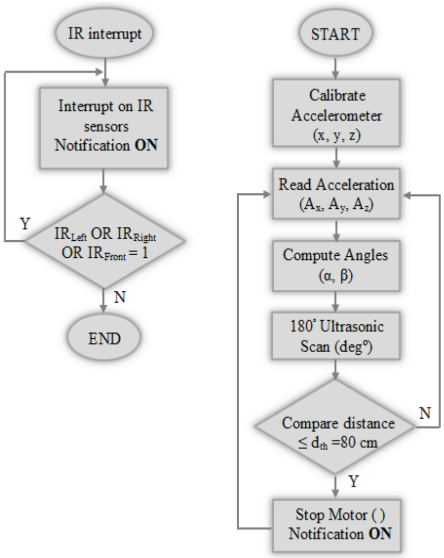


Fig. 5. Orientation and guiding algorithm flow diagram

## IV. Implementation and Evaluation

The control of all the sensors and the Input/Output (I/O) modules is made available using an embedded microcontroller. The choice of this microcontroller is highly dependent on the application needs and features. We used for this purpose the PIC18F452 microcontroller from Microchip. This microcontroller has a large package of digital and analog I/O, a bigger program memory, and an enhanced processing speed (up to 20 MHz). It has also a 10-bit Analog to Digital converter (A-to-D) and 3 external interrupt sources. In addition, Microchip microcontrollers are widely known for their low cost and ease of use. The rest of the modules are as follows: The infrared sensor, the ultrasonic module and the servo motor are purchased from DFrobot, the tri-axial accelerometer from Mikroelectronica, the text-to-speech synthesizer engine from DECtalk. These modules are also characterized by their low power consumption and low cost. These components were installed on a printed circuit board (PCB) mounted on the chassis of a passive walker. The system is powered using a 12V gel battery.

At this stage of the research, the prototype of the electronic walker is complete. All the components were assembled and tested independently. The algorithm is downloaded into the microcontroller and running. The prototype is ready for testing and validation. To validate the reliability of the system, we used a qualitative approach. Five students at the faculty of engineering volunteered to test the walker. They were requested to walk with eyes covered in the laboratory. After the test, the students were asked to grade the performance of the walker according to 3 criteria. The results are summarized in table 1 below.

TABLE I. Validation results on the walker's performance

| | |
|---|---|
| Sense of safety | 4 |
| Ease of use | 4.2 |
| Effectiveness | 3.8 |

## V. Conclusions and Future Work

The electronic walker developed in this research complies with the requirements of an assisted living system. According to the above results, the walker proved its reliability and effectiveness to provide assistance for visually impaired people. Young adults tested the electronic walker in indoor and outdoor environments. Future experiments need to be carried to validate results on elderly frail and visually impaired people. Minor modifications consist of adding wheels to facilitate motion. Front cover is also planned to avoid walk-through sharp obstacles.

The hardware board provides additional interfaces for future expansion and development. It has an interface for indoor/outdoor localization. This may be realized through wireless communication using Zigbee or Bluetooth for indoor or a GSM/GPS modem for outdoor. Body vital signals can also be conveyed through the walker's handlebars. In fact, the microcontroller has extra analog inputs for heart pulse and oxygen sensors. The board has also an LCD for the accelerometer calibration and an offline battery charger. Future work will consider online charging with small solar panels. Comparing to the PAM-AID [10], our developed electronic walker has a low cost (200usd) and can be affordable as final product.

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