The Smart Walkers as Geriatric Assistive Device. The SIMBIOSIS Purpose

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Abstract— **This paper presents a critical review of the most relevant robotic walkers in the literature, considering the navigation strategies and the sensors used to that purpose; and the human-machine interface used to communicate the device. Finally, based on the previous experience of the Bioengineering Group at IAI - CSIC on the development of robotic walkers, a new concept of human-machine interface to guide a smart walker is presented – the SIMBIOSIS project.**

I. Introduction

ONE of the problems that affect the most of the elderly population is the reduction of mobility [1]. The mobility is one of the greatest and most important human faculties, since it affects not only a person's locomotion capacity and the ability to realize personal tasks, but also is related to physiologic and personal questions, conditioning the interaction of a person with his surroundings.

There are basically two groups of assistive devices to help people with mobility problems: the alternative devices and the empowering (or augmentative) devices. These solutions are selected based on the degree of disability of the user. In the case of total incapacity of mobility (including both bipedestation and locomotion), alternative solutions are used. These devices are usually wheelchairs or solutions based on autonomous especial vehicles. Because of that, the wheelchairs are the focus of research of many groups all over the world. Advanced wheelchair-based devices constituting a doctrine body known as Autonomous Robotic Wheelchairs (ARW).

Nevertheless, the continuous and sometimes unnecessary use of wheelchairs cause problems related to the fact that the user remains for large periods of time in seated position. These problems are the loss of bone mass, osteoporosis, degradation of blood circulation and physiological functions (digestive, respiratory, kidney and urinary dysfunctions), skin sores, among others.

For this reason, in the case of a reduced mobility capacity, the person has to use augmentative elements. These elements can be portable (or wearable) devices, such as prosthesis and outhouses, or external, such as crutches, canes and walkers.

Among the external augmentative devices, the walkers assume an important place, due to the large number of users, considering its simplicity and rehabilitation potential. These devices are also interesting once they work as a supporting device during bipedestation and, in addition, use the person's remaining locomotion capability in order to move [2], avoiding the early and deteriorative use of wheelchairs. Besides of the physical benefits of maintaining the standing position, there are also other important psychological benefits, related to self-esteem and relationship issues that are increased, [3].

In this paper, the use of walkers as assistive device is discussed. First, in section II, the conventional walkers are presented. Due to the limitations of such devices, in section III, advanced robotic walkers, known as Smart Walkers, are addressed. In this context, a new device – the SIMBIOSIS Walker – is presented and discussed in section IV. Finally, conclusions are presented in section V.

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II. Standard Walkers

There are many types of walkers, considering their constitutive materials, accessories, sizes and structural configurations. Nevertheless, an important aspect that classifies conventional walkers is the ground contact configuration. There are devices that only have legs, others with legs and wheels and, finally, three or four-wheeled walkers (Fig. 1).

Fig. 1. The ground contact configuration in walkers.

In addition, G. Lacey presents in [2] a complementary classification of the standard walkers in three major types. The first one is the *Standard Walking Frames*. These devices are commonly known as *Zimmer* frame and are designed to provide a larger base of support to a person with lower limb weakness. Normally, these are four-legged devices. Special attention must be paid to the correct height of the frame to ensure good posture during gait.

The second type of walking frames is the *Rollators*. These are walking frames with wheels attached and there are many different configuration of base. *Rollators* are used where balance is the major problem rather than weight bearing. They are also used where upper limb strength is not sufficient to lift the walking frame on a regular basis.

Finally, the *Reciprocal Frames* are devices similar to the *Standard Frames* except that the frame is hinged on either side allowing the sides of the frame to be moved alternately. They are designed to accommodate a normal walking pattern with opposite arm and leg moving together. They are also used in domestic homes where space is confined.

However, the standard walking aids present problems related to: (i) the pushing energy required to move; (ii) the lack of stability (especially in braking); (iii) the possibility of collision with obstacles; and (iv) orientation. Considering the case of a walker with legs (Standard Walking Frames), another additional problem is the unnatural and discontinuous gait pattern. In this context, the assistance during the gait process is a clear application on the assistance robotic field, where advanced or robotic walkers and guiding devices, using a great variety of sensors and actuators, are presented as a solution to the problems previously presented. Also, navigation strategies, control, (auto-) localization, mapping and other concepts mostly used on the field of mobile robotics can be applied to solve some of the problems previously presented.

III. Smart Walkers

In the field of the robotic assistance of deficit gait there are many studies and projects regarding advanced versions of walkers, canes and guiding devices. Among these devices, probably the most developed ones during the past years are the robotic versions of walkers, known as *Smart Walkers*.

These devices provide assistance to the user at different levels, depending on the user's needs. In the following sections a classification of the functions realized by the smart walkers and the most relevant devices on the literature are presented.

A. Physical support

By its nature and the kind of aid in question, almost the totality of the smart walkers has some kind of physical support function among its characteristics.

There are manly two types of physical assistance: passive and active.

In this first case, the objective is to introduce mechanical or structural enhancements to the device improving stability during gait. Usually, the improvements performed consist on the enlargement of base of the device or the balanced placement of heavy elements (motors, batteries, electronics, etc.) at lower planes of the walker increasing the dynamic stability.

Other passive change, not as commonly observed as the presented before, can be the replacement of the conventional handles (hand grip) of the walker by forearm support platforms. This way, the degree of freedom of the elbow articulation is eliminated and a higher fraction of the user's weight is supported by the device, making it easier to push and increasing the friction component of the system, reducing the risks of glide.

Other possible enhancement concerning the reduction of gliding with the ground is the selection of materials with high coefficient of friction for the walker wheels.

Considering the walkers with three or four wheels, a common problem is the control of the device's free motion. More specifically, braking a conventional walker is a task that requires muscular strength, motor coordination and good reaction time, once these devices have usually a brake system similar to the installed on bicycles. If any of the before presented human faculties fail, there is a risk of an excessive acceleration of the device and consequently fall.

In addition to the breaking problems, it is important to emphasize that the strength necessary to push the walker can be high depending on the degree of disability of the user. In this case, it is important to provide external and controlled pushing energy to the system.

To prevent such situations active physical support functions are present at most smart walkers. Usually, these devices have motors installed on their wheels that are able to control the brakes, compensate gravity on inclined grounds and provide the pushing energy necessary to move the device. These motors are usually controlled by an advanced human-machine interface capable of detect and interpret the user's commands and translate them into motor actuation.

B. Sensorial assistance

The smart walkers can also be used as elements to provide sensorial assistance to the user. Normally, these advanced aids have ultrasonic, vision or infrared sensors capable of detecting static and dynamic obstacles. The control system assists the user to avoid them be it by sound or vibration alerts or operating directly on the device's actuators, momentarily changing the path introduced by the user.

This function is usually designed to help users with visual problems or to help navigation on environments with multiple obstacles.

C. Cognitive assistance

In this group, there are found the devices that assist user navigation and (auto-) localization in structured environments and outsides (using GPS, for an example). These smart walkers are very important to people that have cognitive issues and problems related to memory and orientation.

Some smart walkers are programmed to followed predetermined paths inside clinics or achieve a certain location in a map of a house or medical facility. Other devices are capable of creating maps of an unknown environment or auto-localization in a map using markers placed on the surroundings.

Also, the smart walkers can communicate bi-directionally with the user through a visual interface or voice commands, receiving directions from the user, or informing the same about the present localization in a map and the environment conditions, such as obstacles.

D. Health Monitoring

In more specific situations, the smart walkers can be used to monitor some health parameters of the user. This health information is used to keep a medical history of the user or inform through a wireless communication network a health center or the medical staff in the case that an emergency situation is detected.

E. Most Relevant Smart Walkers on the Literature

As it is known, many times the people who are destined to use a walker, specially the elderly, can suffer from multiple health issues needing support at more than one of the before mentioned functions. For that reason, most of the smart walkers on the literature are multifunctional.

A good example of a multifunctional walker is the Mobil [4]. This device (Fig. 2) is designed to offer extra support to the user through the use of forearm support platforms and motorized rear wheels. Also, it can be commanded by a remote control or follow the user if he/she uses an active belt that sends ultrasonic signals to the walker. This walker uses a second set of ultrasonic transducers to detect and avoid static and dynamic obstacles, acting as a sensorial assistance device.

Fig. 2. Mobil walker.

Nevertheless, the most important and most mentioned smart walkers in the literature are the several versions of the PAM-AID (PAM-AID, VA-PAMAID, GUIDO), the PAMM Smart Walker and the MARC Smart Walker.

The Personal *Adaptive Mobility Aid (PAM-AID)* is robotic mobility aid designed to augment the independence of people that have visual impairments and mobility problems, [5]. Several versions of the PAM-AID Smart Walker were developed as it can be seen at Fig. 3.

One of the focuses of the project is that the user had to have the maximum control of the device at all times. This way, the PAM-AID doesn't have motorized locomotion. The electronic system only controls the orientation of the front wheel, based on the guidance information acquired by an intuitive user interface.

This user interface is similar to the handlebar of a bicycle that can rotate +/- 15º. The handlebar is spring loaded and when no torque is applied it will return to its zero position.

To assist on the guidance of visually impaired people, the device is equipped with ultrasonic and/or laser sensors depending on the version of the device. Also, information about the environment state is provided by the walker in the form of two types of voice messages, one regarding the description of the environment and the other informing the presence of obstacles.

The PAM-AID has two operation modes [6]. The first one is the manual. In this case, the system never controls the steering of the device, only providing the two types of voice messages. The second operation mode is the assistive, in which the device provides the voice messages and, in addition, controls the front wheel avoiding obstacles.

Fig. 3. Different versions of the PAM-AID Smart Walker.

In the year 2000, Haptica Ltd. started the commercialization of the PAM-AID Smart Walker. The Department of Veterans Affairs (USA) purchased five devices and introduced some minor modifications and evaluated the safety and performance of the device, renaming it as the Veterans Affairs Personal Adaptive Mobility Aid (VA-PAMAID), [7].

In another commercialization intent, the PAM-AID was renamed *GUIDO Smart Walker*. The device became more statically attractive, more ergonomic and some new functions were contemplated. A third mode of operation, parked mode, also present on the VA-PAMAID, is introduced in which the front wheel of the device is positioned to break it in order to assist the transfer of the user from a chair.

Map navigation, mapping and auto location techniques were also introduced on the device [8]. Considering the user interface, the spring loaded handlebar was replaced by force sensors used to identify navigational intents of the user, [9].

Other important system on the literature is the *Personal Aid for Mobility and Monitoring (PAMM)*, [10]. The PAMM comes in two versions, a cane-based device *(PAMM SmartCane)* and a smart walker *(PAMM SmartWalker)*. In this work, the focus is set on the PAMM SmartWalker (Fig. 4), but both devices are very similar.

Fig. 4. PAMM SmartWalker.

The PAMM SmartWalker is designed to offer extra support for walking, guidance, scheduling (reminding the time of medicines, for an example) and health monitoring for elderly users. The main idea is to provide a complete system to help the elderly in the normal problems of the senility, such as loss of memory, disorientation, musculo-skeletal weakness, lack of stability during gait and monitoring of vital signals such as electrocardiogram (ECG). Also, the device features enable it to be used as rehabilitation device for younger patients.

The PAMM has a set continuous health monitoring sensors. These sensors can detect short term changes as well as long term health trends. The PAMMs can record the user's activity level (speed and applied forces), which over time can help physicians better monitor the user's health. Also, a robust noninvasive ECG-based pulse monitor was developed for the SmartWalker. An ECG-based monitor was used because of its high tolerance to mobility disturbances. Experiments were also performed using the force/torque sensor of the PAMM systems along with odometry information to study the user's gait and to detect risks of falls.

For the locomotion, the device is equipped with four wheels; two of them are castor, and the other two motorized omni-directional wheels. This way, the PAMM SmartWalker can move in any direction, improving the displacements in confined indoors spaces.

Three types of sensors are used in order to control the navigation of the device: a sonar array, a CCD camera and tridimensional force/torque sensors. The sonar array installed on the front of the device is used in order to avoid obstacles. The CCD camera is used to detect marks placed on the ceiling of a structured medical facility or nursing home. Finally, the force/torque sensors installed on the handle of the walker are used to capture the user's navigational intents, the level of support and to determine stability parameters of the user when pushing the device.

An important question approached in this device is how to give the maximum control to the user taking into account the possible cognitive degenerations of the user. In one hand, the PAMM walker can be fully guided by the user, trough the application of forces/torques on the handles of the device. In the other hand, it is capable of navigating automatically in a structured environment.

The solution adopted was a shared control algorithm that takes a greater control of the device when the user starts to diverge from the path calculated by the electronic system.

Initially, the user has to introduce a destination. The system generates virtual forces/torques that are proportional to the deviation of the programmed path. Such forces and torques are added to the forces applied by the user and an admittance controller converts the resultant forces and torques on motor velocity moving the device.

The *Medical Automation Research Center (MARC) Smart Walker*, [11], is a device based on the modification of a commercial three-wheeled walker (Fig. 5). On the handle of the walker a pair of tridimensional force/torque sensors was installed in order to measure the interaction between user and the device.

Based on the forces and torques applied, the current state of the walker and the environment conditions (measured by sonar and infrared sensors), the control architecture of the MARC Smart Walker estimates two signals called user intent and walker intent as it is shown on Fig. 6. The control logic balances these two signals in order to generate the control of the orientation of the front wheel.

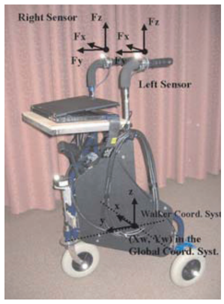

Fig. 5. MARC Smart Walker.

Similar to the PAM-AID, the MARC walker doesn't have motorized locomotion, so the pushing energy has to be supplied by the user.

An interesting study was realized with the MARC walker and a camera motion analysis system (VICON) in order to determine gait characteristics from measured forces and moments, such as the heel strike, toe-off, double support, and single (differentiating from right and left foot) support detection, [12].

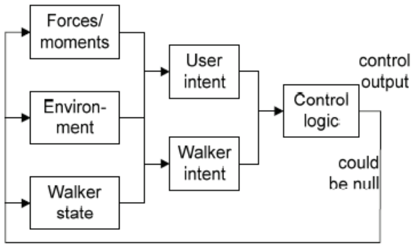

Fig. 6. Control architecture of MARC Smart Walker.

IV. THE SIMBIOSIS PURPOSE

The aspects related to the user's physical support were addressed in the project *Andador Pseudorobótico de Alta Seguridad (ASAS)*, a smart walker designed to rehabilitation and the maintenance of the natural mobility developed by the Bioengineering Group at IAI – CSIC [13], shown on Fig. 7.

Fig. 7. ASAS smart walker developed by IAI - CSIC.

The ASAS smart walker is a modification of a commercial device. The passive mechanical improvements adopted in the project were the enlargement of the width of the base of the device, replacement of the handles of the walker by a forearm support platform, balanced placement of the heavier elements in a lower plane close to the ground. These improvements increase the system stability during gait. In addition, dc motors were installed on the rear wheel of the device, adding at the same time pushing energy to the system and braking control. The motors were controlled by push-bottoms installed on each handle.

Although the results achieved on the clinical validation of this project were very satisfactory [14], the system was poor considering the user interface. In reality, in this application, each motor is controlled by its corresponding push-bottom, meaning that pressing the right hand one the right motor is activated. So, to go in a straight line, the user had to push and maintain pushed both bottoms and to turn, the user had to press only one of them.

As it can be seen, the control of the device is not natural. This way an evolution/continuation of this project is the SIMBIOSIS project, a multisensory biomechanical platform for predictive human-machine cooperation. The idea is to develop a series of biomechanical sensors in order to detect and identify user's gestures, postures and intentions to build a platform to guide robots. This platform is validated in a smart walker designed to help people with reduced mobility. At present, the project is being developed at IAI – CSIC, Spain. In the following sections, the concept of the SIMBIOSIS walker is presented along with some initial results of the project.

A. Subsystems of the HMI

The human-machine interface (HMI) of the SIMBIOSIS walker is divided in (Fig. 8): *(1)* feet/user relative position subsystem (blue), *(2)* lower-limb kinematics subsystem (red), and *(3)* upper-limb force interaction subsystem (green). Following, each subsystem is presented.

Fig. 8. Subsystems and a picture of the SIMBIOSIS walker.

1) Feet / User Relative Position Subsystem

This subsystem in development is designed to determine the relative position of the user in relation to the walker. It consists of a vector of 40 kHz ultrasonic emitters and receivers that scans the space between the user and the walker using the pulse-echo technique in order to determine the specific spherical coordinates of each leg in a reference system placed on the walker.

The information obtained by this subsystem will be used to modulate automatically the velocity of the motors of the device and also be used to stop the device on the case of excessive separation to the walker, avioding the risks of falling.

A proposed method used for the determination of the position of user's feet is based on the segmentation of the space in verticall and horizontal angular sectors and determine in each one of them the distance to the leg measuring the Time of Flight (ToF) of the 40 kHz ultrasonic wave by three receptors (R1, R2 and R3) in a triangular configuration.

To obtain the mentioned sector division, a triple diferencial measurement among the receptors is taken (1-2, 1-3 and 2-3) combining the diference of phase of the ultrasonic carrier signal and the difference of ToF computed with a envelope signal of the ultrasonc wave.

2) Lower-limb Kinematics Subsystem

This subsystem is compound by a series of inertial sensors placed each segment of both legs of the user. Each inertial sensor unit has integrated accelerometers, giroscopes and magnetometes (all tridimensional) used to estimate the orientation and evolution of the lower limbs on the space.

All inertial units are connected through a CAN bus and the adquisition is managed by a portable concentrator that communicates wirellesly (bluetooth conection) with the smart walker.

Using these sensors, it is possible to have a portable gait analysis system to determine parameters related to the gait phases, and also spacial-temporal parameters such as, velocity and step lengths, besides from the detection of irregularities in the gait process. All these information is relevant to determine if the user's gait parameters improve by the use of certain control strategies.

3) Upper-limb Force Interaction Subsystem

Finally, the Upper-limb Force Interaction Subsystem is compound by a set of force sensors installed on the walker's handles. This subsystem is the most developed one at present and it plays an important roll in the multimodal system and takes advantage of the arm supporting platform. The force sensor platform is used to study the interface of force interactions between the user and the walker during the gait process, in order to obtain patterns during certain tasks executed with the device. These patterns will be used to infer the navigation intents of the user, defining basic commands to the robotic system.

After a study of the system characteristics and the range of the forces that can be measured, two groups of two strain-gage force sensors were selected (Fig. 9). The first group is installed under each forearm support platform and measure uniaxial forces applied normally to its surface, measuring, this way, the support load applied by the user. Each sensor measure forces up to 75 Kgf, supporting a total load of 150 Kgf, which is totally compatible with the application.

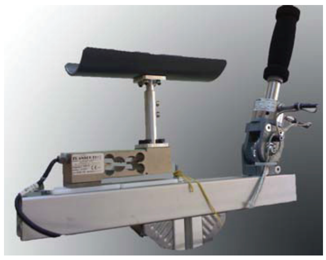

Fig. 9. Force sensors installed on the SIMBIOSIS walker.

The other sensors are placed on the handles of the walker, and measure biaxial forces in a geometrical plan almost parallel to the ground. By that, the forces applied by the user on each handle of the walker in both x- and y-axis are measured and the guidance information can be, them, inferred.

In both sensor groups, the amplification and conditioning circuits were adjusted to obtain an adequate measurement range and the best resolution on the A/D converters at the acquisition board. The amplified sensor data are collected by an acquisition board connected to a PC104 computer. The data are stored on an external computer through a network link for further analysis.

Preliminary results of this subsystem can be found on [15].

B. Electronic and Acquisition System Architecture

All the subsystems before presented are managed by a central processing unit based on the *PC/104-Plus* standard and an acquisition board. In this PC/104, a real-time system based on *MATLAB Real Time Workshop xPC Target* is installed. This real-time system communicates, trough an Ethernet cable connection, with a Windows notebook computer also embedded on the walker. This notebook is used to store all sensor acquired data and control the acquisition system. All the system can be managed through a remote desktop wireless LAN connection. This way, a very versatile electronic architecture is established, the incorporation of new sensors is done quickly, and any change on the behaviour on the system can be done externally, with the walker in use.

A radio link is also established between the central processing unit and a gait analysis laboratory equipped with infrared cameras and force platforms on the ground to acquire simultaneously the data from all the subsystems and the gait information from the laboratory.

V. Conclusions

In this paper it was discussed the use of robotic versions of walkers, the Smart Walkers, as mobility assistive devices along with a classification and a brief review of the most important devices on the literature.

Finally, the detailed presentation of a new device, the SIMBIOSIS walker, was discussed. At present, the mechanical structure is constructed and all the subsystems before mentioned are being developed and tested in parallel with the walker electronic architecture that is already validated, [15]. In addition, the *Upper-limb Force Interaction Subsystem* is installed on the walker and the interaction forces between user and the walker are being studied. The *Lower-limb Kinematics Subsystem* and *User Relative Position Subsystem* are in development and currently are being tested outside of the walker.

In the following months, all the subsystems will be mounted on the device and the information acquired will be used to control the DC motors installed on the rear wheels of the SIMBIOSIS walker.

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