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The i-Walker: an intelligent pedestrian mobility aid

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Abstract. In this paper we focus on the development of an intelligent pedestrian mobility aid that we call *i-Walker* for elders. This target population includes, but is not limited to, persons with low vision, visual field neglect, spasticity, tremors, and cognitive deficits. *SHARE-it* will provide an Agent-based Intelligent Decision Support System to aid the elders.

1 Introduction

It is clear that one of the most important and critical factors in quality of life for the elderly is their ability to move about independently and safely. Mobility impairments due to age, injury or disease cause a downward trend in their quality of life. Lack of independence and exercise can have dramatic results. One of the *SHARE-it*, an EU-funded research project, main objectives is concerned with developing an Intelligent Walker, that we called *i-Walker*, to assist the elderly and increase the ease and safety of their daily mobility. The benefits to the user include assistance avoiding dangerous situations (obstacles, drops, *etc.*) and help with navigation through cluttered environments but well-known environments. Many older adults use walkers to improve their stability and safety while walking. It is hoped that this assistance will provide the user with a feeling of safety and autonomy that will encourage them to move about more, incurring the benefits of walking and helping them to carry out the Activities of Daily Living (ADLs).

Another related problem is the lack of strength in target population. Doctors make us conscious of the possible uneven loss of strength in the extremities. This of course is the main reason for having troubles in arising from a chair, in walking, being unable to steer a normal walker, being unable to standing still, *etc*.

We have developed a robotically augmented walker to reduce fall risk and confusion, and to increase walker convenience and enjoyment. Among of the *SHARE-it* objectives is to build different *i-Walker* workbench platforms, oriented to demonstrate their feasibility, and gain the confidence to support the specific disabilities [3]. An important issue to be considered is that before starting experiments with elders the whole system has to be approved by a Ethical Committee. We had use the original agent-based control elements in an experiment with volunteer inpatients in Fondazione Santa Lucia, Rome, using Spherik an intelligent wheelchair [1]. In this paper, we generalize it to be used in the *i-Walker*. Although, the experimentation with elders has to start the whole system is already in place.

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The rest of this paper is organized as follows: In §2 we introduce our ideas on Shared Autonomy related with the support to the elders. In section 3 we introduce our new intelligent pedestrian mobility aid that we call *i-Walker*. We also introduce in this section the agent-based control elements §3.2.

In §4 we introduce the generic scenarios where the *i-Walker* is currently in limited testing, to assure its safeness and soundness, before to go to a full-scale testing with real users from the target population. In §5 we present our conclusions and future plans for this research in the frame of *SHARE-it*.

2 Shared Autonomy: A vision

Autonomy for the elderly or people with disabilities does not only rely on mobility terms, but on a set of domains influenced by functioning, activity limitations, participation restrictions and environmental factors. Life areas related to activities and participation are such as learning and applying knowledge, general tasks and demands, communication, mobility, self-care, interpersonal interactions and relationships as well as community and social life. All these domains can be affected by aging or disabilities and are the base of personal autonomy and the satisfactory participation on them reflects on the self well-being. Assistive Technologies (AT) are of special interest, as the average age of the population increases fast [2, 10]. AT can participate in these activities in order to enhance the user's autonomy, gathering all the environmental information and making use of it properly.

Our idea is based on the notion of a *Shared Autonomy* between the user and its own agent-based mediator with any information system at hand. Existing telematic healthcare systems that provide integrated services to users are not, to our taste, enough flexible to allow a real personalization and maybe now it is too expensive to change them.

The shared autonomy concept is scarcely explored in literature and often it is misunderstood as shared control (*e.g.*, [12, 7]). In the personal autonomy and disability context, two different scenarios of the shared autonomy can be distinguished.

- People presenting mainly physical impairments are able to define their own goals, but due to their restrictions they usually are not able to execute them, suffering a limitation in their autonomy. In this scenario the contribution of AT focus on physical devices, mostly mobility hardware, that allow them to reach their objectives. These devices may be controlled by multi-agent systems or through an agent supervised shared control if the user motor capabilities are not severely damaged. In this scenario, user interfaces are very important to detect the user intention, which is critical to define goals for the wheelchair to be able to assist him/her.
- People presenting mostly cognitive impairments may require a different kind of assistive aids, which may lead even a more rele-

vant role in the sharing of personal autonomy. In this scenario the user probably does not have very clear goals or is not capable of achieving them because he/she cannot remember *how* to do them. In these cases, AT may empower and complement their autonomy using agents that offer them a set of services, like reminding what kind of activities they can or should perform at a certain moment of the day or pointing them out how to achieve these activities. The main idea is to offer the users a set of cognitive aids, either rational or memory based, that can ease their daily living.

Roboticists have developed a number of mobility-enhancing assistive technologies. Most of these are active aids, meaning that they share control over motion with the user. Most are aimed at obstacle avoidance and path navigation [11, 5, 8].

3 i-Walker

With this context in mind, we introduced in [3] the design of an integrated architecture aimed at helping citizens with disabilities to improve their autonomy in structured, dynamic environments. The main element of this architecture is an intelligent agent layer that mediates between different technology components (robotic devices –as the *i-Walker*– ubiquitous computing, and interfaces) in order to provide the subject with the necessary degree of independent mobility to benefit from different assistive services and to reach goals determined by either the subject himself/herself or by medical staff.

The agent based control system provides an excellent means to model the different required autonomous elements in the patient's environment (from control elements in the wheelchair to care-giving services). Agents probe to be efficient in coordinating heterogeneous domain-specific elements with different levels of autonomy. Addressing the mobility problem and keeping in mind that different users need different degrees of help, a part of this agent based control layer has been focused on the development of a shared control for the robotic wheelchair that adapts to the user needs.

The *i-Walker* is an assistive device with four conventional wheels and two degrees of freedom (see figure 1). Two of these wheels, the ones placed closest to the user, are fixed wheels driven by independent motors. The other two wheels, the ones placed on the front part, are castor-wheels. They can freely rotate around their axis and are self-oriented. The *i-Walker* has two handles, that the user holds with both hands, to interact with it. The *i-Walker* is a passive robot as it will only move if the user moves it.

The mechanical analysis of the Intelligent Walker is focused on the interaction between a generic user and the vehicle, in addition to how the rear wheel motors -which are the only active control available- can modify the user's behavior and his/her perception of the followed path. For safety reasons, these motors will never result in pulling the *i-Walker* by themselves.

3.1 i-Walker Control Concept

The *i-Walker* has been designed to be passive, cooperative and submissive (see figure 2).

- Passive because it can only adjust the facing direction of its frontal wheels, *i.e.* it can steer. However, it has braked drive motors and so not only relies on the user for motive force. This allows the walker to move at the user's pace and provides for the user's feeling of control.

Figure 1. i-Walker

- Cooperative because it attempts to infer the user's path and uses this inference to decide how to avoid any obstacles in the user's path.
- Submissive because it monitors the users to see if they are resisting the actions (steering/braking) selected by the *i-Walker*. If they are, the movements are adjusted. This cycle continues until the user agrees with the motion (*i.e.* does not resist it) or manually over-rides it. This interaction forms the basis of the feedback loop between user and agent. Similar approach is [13].

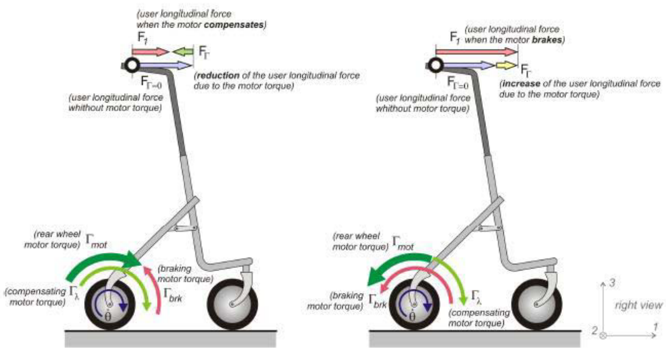

Figure 2. *i-Walker* Control

The manual brakes have also been replaced with an automated braking system. The walker can sense the user's steering input via sensors in the handles that detect the difference in force on the two handles.

- Pushing with more force on one handle (left or right), the walker will turn in the opposite direction.
- Applying of equal force on both handles will move the walker straight forward or backward (which direction can be determined by the *i-Walker*'s wheel encoders).

One of the main objectives of *SHARE-it* is helping the users in orienting them when handling the *i-Walker* in a known environment. The user will receive help from a screen, but the innovative idea will be steering by moderate braking, for helping in navigation. Apart from the multi-modal (in particular speech) interface, we will experiment with moderate brake on the *i-Walker*'s wheels to gain the experience on *how* to better guide the user by allowing s/he sharing with the computer the steering actions.

3.2 Agent Layer

The *i-Walker* sensing devices provide the means to precisely track the user's intention in every situation. We are assuming that the users of the *i-Walker* follow a daily schedule that include all their ADLs. All the information gathered supports the agent layer that will process this data and use it to provide the services that users might need using the computer device attached to the *i-Walker*. The agent layer delivers three main kind of services: monitoring, navigation support and cognitive support.

The monitoring services gather all kind of data from the sensors (walking behavior, forces exerted, environment, localization if available, ...). The information related to the user will be processed and analyzed by medical partners with possible rehabilitation uses. Also, with the step behavior and forces on the handlebars observed the agents can determine the user intention, be it in navigation terms or even if the user is trying to get up from a chair or just trying to get the walker closer to the place where they are resting. Monitoring also covers security issues, like being aware if the user or the *i-Walker* fall to the ground, and taking the according measures.

Among the navigation services the users have on disposal a map of the environment and their localization on it. They can ask for a route to reach some destination and real time indications to follow it. If navigation is interrupted by non avoidable obstacles, the agents can suggest a new route or offer to ask for help to a caregiver. The way help is requested, depends on the environment (tcp, msg, sms,...).

The *SHARE-it*— agent layer offers a series of cognitive aids focused mainly on memory reinforcements and ADL support. The user has an ADL agenda, a skeleton of daily activities that the user performs like waking up, going to the toilet, having breakfast, etc. The monitoring services keep track of the sequence of places (*i.e.* rooms) that the user has visited, and the order is also tracked, so for instance the agent knows if the user has visited the kitchen for breakfast after waking up. Comparing his daily behavior with the user's usual agenda, the agent can send some activity reminders to the user in case he forgot.

The user's agent can also trigger help request messages to the caregivers if some abnormal agenda activities happen, for instance if the user has not visited the kitchen in all the day, probably meaning that the user has not had any meal at all. There will be a special attention to the medical reminders, like having the medication at the right time, RFID tags on some environment items like the medicine box will support this service. Some people with moderate or heavier cognitive problems, can forget how to perform some ADLs or just get confused while performing them, so they can ask their agent a tutorial on how performing a daily activity (*i.e.* washing your hands).

The ultimate goal of the interaction between robotics, Agent Systems and the user is to enhance autonomy and up-grade the quality and complexity of services offered. The degree of control exhibited by the *i-Walker* control agent depends on the abilities of the user at each time and situation. Nevertheless, some important topics as safeness and security have to be redefined in the future in order to broaden the applicability of this approach [4].

4 Generic Scenarios

Devices have been used to *assist* people with cognitive and/or physical disabilities to complete various tasks for almost 20 years. What represents a change and challenge is the abilities embedded in a new generation of tools that are able to cooperate with the user to complete a task. This implies that these new tools are context-aware and are able to learn from the interaction with the user.

Cooperation for problem solving between users and their *agent* and the cooperation between *agents* among themselves requires some kind of model which at least describes *what to expect from whom* in terms of questions, actions, *etc* and that uses previous experiences and trust.

Scenarios appear to be an easy and appropriate way to create partitions of the world and to relate them with time. Scenarios allow actions to be performed in a given time. For example, Mihailidis *et al.*, in [9], studied the *hand washing* scenario where a full instrumented environment was used to provide users with cues to support the completion of this task.

As in Mihalilidis' approach we are looking to support those tasks that are needed to perform the most important ADLs. In particular, those related with mobility but not only.

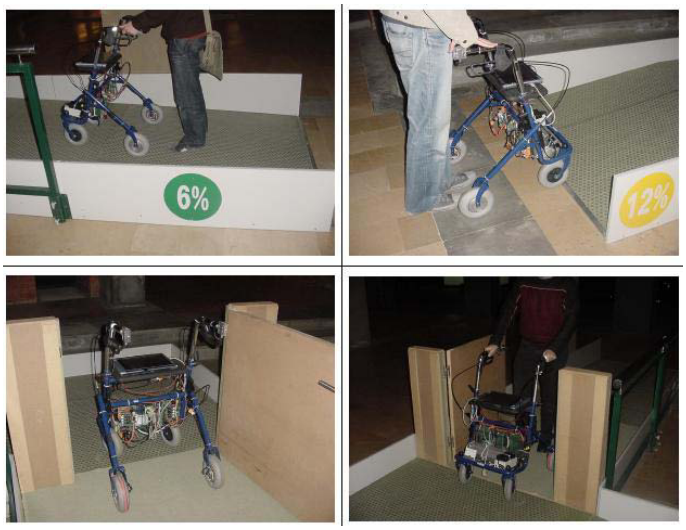

Figure 3. *i-Walker* workbench

4.1 Scenarios for the i-Walker

Experimentation for the *i-Walker* is to be realized in a 5x5m practicable platform that allows a maximum slope of 16%. The task to be

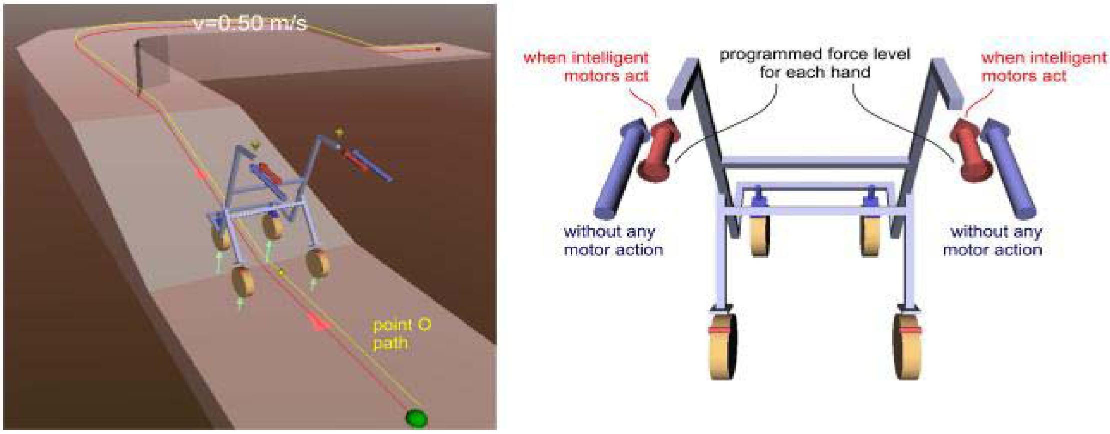

Figure 4. Example of a real path that a user may need to follow

performed is very simple: *Starting in one end walk into the platform and, following a path, to describe two complete circles and then get out from the other end*. The main objective of this experimental scenario is to gather information about the users gait and the forces s/he exerts on the handlers, as shown in Figure 4. The basic measure for each user will be using the platform as a horizontal plane, and then we will repeat the experiment with a different elevations.

Another generic environment has horizontal and inclined surfaces over which the user can walk along. On inclined surfaces, the user may follow the maximum slope line or any other direction. In addition to this, it is useful to be able to know the absolute position of the *O* point and the orientation of the vehicle.

It is necessary to define a standard working path with the most common situations that a user will find when travelling with the *i-Walker*. To test the whole behavior of the *i-Walker*, this path should include:

- A velocity change from 0 to a nominal value: to study the starting process.
- A velocity change from a certain value to a higher/lower value: to study positive or negative acceleration processes.
- Positive and negative slopes: to study inclined surfaces and the *i-Walker* going uphill and downhill.
- Orientation change segments: to study the necessity of avoiding obstacles.
- A velocity change from a certain value to zero: to study the stopping process Examples of paths that fulfill these conditions are shown in Figures 3 and 4. The second illustrates what can be considered as a complex path for an elder.

Further research is needed to investigate the stability of the complete human user/*i-Walker* system and to infer the users stability.

An open topic is the acceptability of this technology. The work in *i-Walker* is important as after the cane is the most commonly used mobility device. Senior citizens facing some disabilities need to find this technology easy to learn to use as well as be confident with its usage in their preferred environment. This implies an effort to provide the appropriate infrastructure elsewhere, for example to provide connectivity in all the spaces the user is using. Also, it should be easy to adapt this technological solutions to different environments.

5 Conclusions and Future work

The existing functionalities of the *i-Walker* are divided in three areas: analysis, support and navigation *i-Walker* (aid to move in a well-known environment). The *Analysis walker* consists in gathering, real time information coming from different sensors: forces in the handlebars and normal forces from the floor, feet relative position towards the walker, tilt information, speed of rear wheels, mainly. The analysis of this information will allow the study about: the gait, how the patient lays onto the walker and how much force exerts on the handlebars while following a predefined trajectory. The support walker consists in applying two strategies to motor:

- A *helping strategy*. In the normal operation of the *i-Walker*, the user must apply pushing or pulling forces on the handlers to move around. The strategy of helping the user consists on relieving him from doing a determined percentage of the necessary forces.
- A *braking strategy*. It can oblige the patient to apply a forward pushing force in the handlers in a downhill situation instead of pulling force which can be less safe.

The amount of helping percentage and braking force in each hand can both be determined by a Doctor. Both strategies are not exclusive: we can have the user pushing the *i-Walker* going downhill and at the same time the *i-Walker* relieving him from part of the necessary pulling/pushing force to move around.

The *navigation walker* connects to a cognitive module that gives the appropriate commands to the platform in order to help a user to reach a desired destination indoors.

The *i-Walker* commands will consist in moderate braking for steering the *i-Walker* to the right direction. Other information will be shared with the cognitive module like: speed, operation mode *etc*. The *i-Walker* platform can be used manually by a walking user, but it is also capable of performing autonomous moving. The platform can easily be adapted to accept commands to set a desired speed from a navigation module, when this is completed. Autonomous moving can be useful, for instance, to drive to a parking place for charging battery and returning to the side of patient when remotely called.

5.1 Future Work

The results obtained in our work suggested a new interesting scenario regarding rehabilitation. As a matter of fact many people use traditional walkers, not only as assistive devices, but also as rehabilitative devices during the rehabilitation program in order to recover functions as gait and balance. In this context, the possibility to detect, through sensors, the performance of hands and feet during gait, on smooth or uneven surface, could provide crucial information from the medical perspective. The opportunity to collect such information is decisive in the definition of different patterns of performance of different users in various scenarios; it could be also used - at an individual level - to modify and personalize the rehabilitation program and to follow changes.

There is a strong case for the use of the *i-Walker* inside the frame depicted by *SHARE-it* and, therefore, for the use of intelligent agents to support mobility and communication in senior citizens. Moreover, there is a clear evolutionary pathway that will take us from current AT to more widespread AmI where MAS will be kernel for interaction and support for decision-making.

The positive effects of assistive technologies on quality of life of elderly disabled people [6] have been largely proven. The growing numbers of disabled people will increase the demand for assistive devices in the elderly population.

We believe that passive robots combined with a MAS, as *i-Walker* is, offer a decisive advantage to the elderly because they leave (almost always) final control in the hands of the user. Our work seeks to help people who can and want to walk. In our view the *user* should only be assisted according to his/her profile: not more, not less.

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