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The application of robotics to a mobility aid for the elderly blind

Gerard Lacey *, Kenneth M. Dawson-Howe [1]

Department of Computer Science, Trinity College, Dublin 2, Ireland

Abstract

In this paper we describe a novel application of mobile robot technology to the construction of a mobility for the frail blind. The robot mobility aid discussed in this paper physically supports the person walking behind it and provides obstacle avoidance to ensure safer travel. As in all Assistive Technology projects, a clear understanding of the user's needs is vital and we summarise the main user requirements for our device. We then describe the mechanical design, the user interface, the software and hardware architectures of our robot. We describe the results of evaluations carried out by both mobility experts and users and finally we outline our plans for further development. © 1998 Elsevier Science B.V. All rights reserved

Keywords: Mobile robot; Human robot interface; Mobility aid; Blind and elderly; Shared control

1. Introduction

In this research we are developing a novel robot mobility aid, the personal adaptive mobility AID (PAM-AID), which physically supports a walking user and provides obstacle avoidance to ensure safer travel (Fig. 1). The objective of the robot mobility aid is to allow frail blind users to take exercise independent of carers and thereby regain their personal autonomy. The robot design concentrates on achieving user acceptance. The priorities are to reduce the cognitive load on users and ensure they feel in control at all times. To achieve this we are concentrating on the provision of flexible control strategies and multi-modal user interfaces which facilitate customisation for each user.

This research is motivated by the fact that frailty when combined with a visual impairment has a devastating effect on the ability of people to move around independently. The elderly and infirm blind find it difficult to use common mobility aids such as long canes

Fig. 1. An artist's impression of PAM-AID.

* Corresponding author. E-mail: gerard.lacey@cs.tcd.ie.

[1] E-mail: kenneth.dawson-howe@cs.tcd.ie.

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and guide dogs. Consequently they are often bed-ridden "for their own safety". This sedentary lifestyle accelerates their physical degeneration and can lead to severe psychological problems due to their increased isolation [4,7,19]. In Europe 65% of all blind people are aged over 70, therefore this represents a serious issue [18,20].

This research began in 1995 with an analysis of the user requirements and the development of the PAM-AID concept. Since that time we have constructed several prototypes which have been evaluated by a laboratory trials and a field test. Current work is concentrating on the design of a shared control system and an effective user interface. In this paper we will review the user requirements for this type of device, we will then describe the technical details of the PAM-AID prototype and report on the findings of the evaluations. Finally we describe our intentions for further work.

2. User requirements

To ensure the validity of our research from an Assistive Technology standpoint we investigated the target user group and examined the aids they use. In addition, we researched the effects of aging on manual dexterity, short term memory and learning as this has a direct impact on the ability of the elderly to accept new technology. This research was conducted by consulting the available literature, interviewing potential users and talking to mobility experts from the National Council for the Blind of Ireland (NCBI).

2.1. Mobility aids

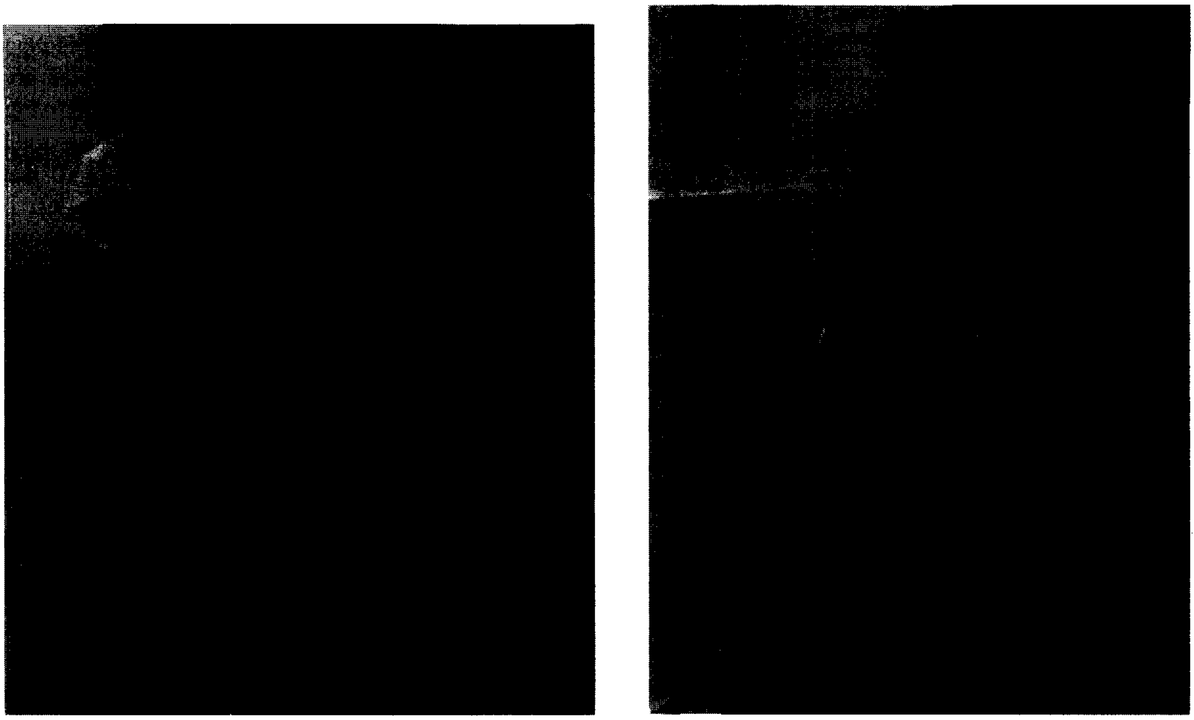
The guide dog user's visual impairment must be so severe as to prevent their seeing obstacles before the dog avoids them. This is because without sufficient reinforcement the dog will become lazy. Guide dogs walk at a relatively brisk pace and require an active lifestyle to remain fit and healthy. Most elderly visually impaired do have some remaining vision and in cases of frailty a guide dog is generally not a suitable mobility aid.

The long cane provides a one stride preview of the ground immediately ahead of the user. Its main limitation is that it does not scan all the space through which the body moves, in particular overhanging obstacles and holes in the ground are missed. In the case of the frail the long cane can be used both for support and mobility, but it can be quite heavy and consequently lead to rapid fatigue. Using a long cane and a walking stick in tandem results in both hands being occupied and thus an increased risk of falling. In long term care facilities long canes pose a risk of tripping the other residents and this can discourage independent mobility.

The deficits of the long cane has prompted much research into electronic travel aids (ETA) such as the Laser Cane [2], the SonicGuide [11] and other such devices. Several reviews of this research have been carried out such as [15] and [20] which reviews mobility devices in depth. However no ETA has yet achieved widespread acceptance among the blind community primarily due to poor user interfaces or poor cosmetic design. Robotic ETAs have been developed by Tachi [12], Mori [8] and Borenstien [5]. These devices guide the blind person using proprioception, that is, by exploiting the users physical perception of robot direction in the same manner as with a guide dog. As of yet no robotic ETA has been accepted for use by blind people.

2.2. The elderly visually impaired and technology

Wellford in [3] reports that the speed and accuracy of elderly people for simple motor tasks is quite good but this deteriorates rapidly as the task complexity increases. This is particularly true if there is an extended time between the stimulus and the taking of the corresponding action. In general, where possible, the elderly shift their concentration from speed to accuracy in an attempt to maximise the use of limited physical resources. Kay in [3] examines learning and the effects of aging. Short term memory is very dependent on the speed of perception and thus a deterioration in perceptual abilities will produce a consequent deterioration in short term memory. Learning in older people consists of the modification of earlier experiences as opposed to learning from new stimuli. This consists of a process of adapting the previous routine to the new task and features the continuous repetition of small errors.



(a) (b)

Fig. 2. First and second PAM-AID prototypes.

Among the elderly, motivation for learning is much reduced as the acquisition of a new skill may not seem to be worth the effort given the limited life expectancy. Karlsson in [10] notes that *perceived usefulness* rather than usability is the limiting factor in the adoption of new technology by elderly people.

Many aids fail to be accepted due to poor user interfaces. The examples are headphones used in some ETAs to create a *sound image* of the environment. The headphones can occlude important sounds from the environment thus making them potentially dangerous. Alternatively an aid can be rejected because it attempts to replace some of the users remaining abilities and as a result their overall performance at a task is reduced. Each potential user can have a different disability or combination of disabilities and their personal preferences vary considerably. During interviews we found many conflicting preferences for user interface configurations among potential users. In consultation with mobility experts this was identified as a need for user interface customisation.

3. The personal adaptive mobility aid (PAM-AID)

Our research into the user needs led to the personal adaptive mobility AID (PAM-AID) concept, a robot which physically supports a user and avoids obstacles. In this section we will outline the main features of the design i.e. its mechanical design, user interface, hardware architecture and software architecture.

3.1. Mechanical design

The main objective of the mechanical design is to provide support to the user. The initial prototype on the left of Fig. 2 was built around a Labmate robot base to which we fitted a handrail for user support. During evaluations in the laboratory by the mobility experts from NCBI the overall size of robot and the orientation of the handles were identified as areas where improvements could be made.

The second prototype, the right of Fig. 2, was built by adapting a Days Medical Aids rollator (an aid similar to a walking frame but with wheels). We supplied power to each of the rear wheels by means of two DC motors and a drive belt. The motors were controlled by a custom motion control system based around a MC68332 micro controller. The advantage of this configuration was that it was 30% smaller and 50% lighter than the Labmate. It also provided us with handles which could be adjusted in height and provided support directly under the user's shoulders.

During field testing the robot experienced some errors in the traction system. This was due to a combined effect of front castors and the drive train. When initiating a drive or a sharp turn there was a difference between the castor orientation and the drive direction. The castors aligned themselves with the drive direction only after some forward motion. During the alignment process they introduced a deviation from the planned path. In addition the front castors supported a large percentage of the weight of the motors and batteries and the alignment process required a large torque from the motors to overcome the friction in the castor bearings and the load applied by the user. Due to the torque exceeding specification the belt drive for the motors occasionally slipped. These issues have been addressed in the new custom mechanical design for the robot. The design uses a flexible chassis from Euroflex which places the majority of the load on the drive wheels.

An additional feature have been added to the robot as a result of the field trials of the second prototype. The users commented that one of their main difficulties was getting out of the chair in which they were sitting. To address this issue we have fitted a 150 Kg power lift to the handle system. Users grasp the handles and activate the lift system which pulls them up and forward, thereby assisting them rise from the chair.

3.2. User interface

The most critical element of the system is the user interface. From our background research we discovered that the majority of our potential users went blind after the age 65. Therefore very few know Braille or are familiar with mobility aids. In addition most users have never used a computer. Due to the short term memory and motivational problems identified in our research we realised to be successful we needed to have an extremely intuitive interface.

On the first prototype the user input device was a joystick and switch mounted on the handrail. Feedback was provided by means of audible tones which provided information to the user and/or recorded voice messages. To keep the cognitive load of the user tolerable, the number of audio messages was kept as small as possible. The audio feedback played two roles:
- *Command confirmation.* This type of message was activated in response to user input and informed them about the direction the robot was heading.
- *User information.* This type of message was generated in response to an event detected by the sensors. The message informed the user about the event, such as "obstacle directly ahead".

The robot operated in two modes: *direct human control* and *automatic wall following*. In direct human control the user indicated their desired direction via the joystick. The robot adopted this direction at a gentle speed only stopping if an obstacle was encountered. In wall following mode the robot autonomously followed the nearest wall performing obstacle avoidance along the way. The default mode was direct human control, wall following was selected by pressing the switch on the joystick.

After the initial evaluation by mobility experts the joystick option was dropped due to the lack of forearm support. Without this support there existed a potential oscillation between the robot and the user. We had performed a de-bouncing and low pass filtering of the joystick input, however this was not deemed sufficient. Following the evaluations the handrail gave way to two separate handles which provided support on either side of the user.

For this new handle configuration we developed two alternative and inter-changeable modes of user input, finger switches and instrumented handles. The finger switch option allowed the user to select the direction of the robot from the set *forward, backward, left,* and *right.* The switches were Velcro mounted, allowing them to be moved to positions comfortable for each individual user. In addition to the four main finger switches a fifth switch was used to invoke the wall following mode.

As an alternative to finger switches, instrumented handles were developed. Each handle was allowed a pivot on a 5° arc, micro switches were used to detect if the handle is being pushed forward, pulled back, or in neutral. The pivot was spring loaded to ensure that the

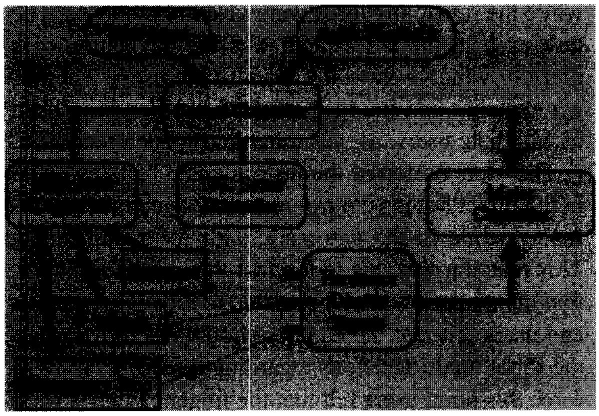


Fig. 3. Hardware architecture.

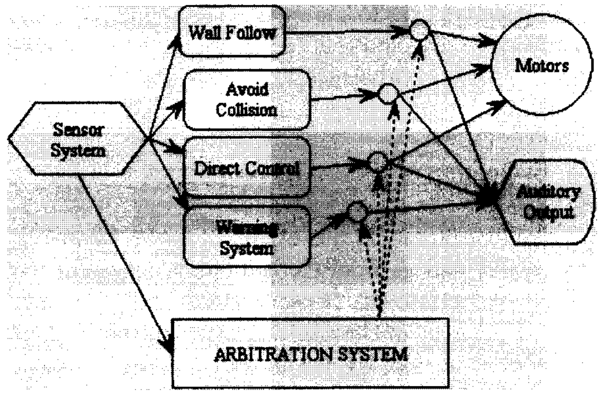


Fig. 4. Software architecture.

handle came to rest in neutral. The user indicated forward by pushing both handles forward, backward by pulling both handles backward and turned by pushing and pulling on alternate handles. For safety reasons the instrumented handle user interface had two finger switches. One of the switches acted as a "dead-man switch", i.e. it had to be kept pressed at all times to allow the robot to move. The second switch was used by the user to invoke wall following behaviour.

3.3. Hardware architecture

The central controller for the robot was implemented in C++ on a PC running Windows 95. The PC communicated with the slave devices (motor controller, sonar controller and digital I/O interface) via RS232. The overall hardware architecture is shown in Fig. 3. Three safety systems are built into the robot, bumpers to the front and sides of the robot, user operated brakes and a standard emergency stop button which can be operated by a person standing near the robot. In addition to being connected to the central controller these systems are also directly connected to the motion controller providing real time performance. Information about sudden motion changes is used to provide a voice message to the user.

3.4. Software architecture

In this application it is difficult to separate the user interface from the control system as the speed and manner of mode/direction switching determines a great deal about the user's experience of the robot. The control system used reactive processes as in [6] however the execution of these was controlled by a supervisor process as in [9].

The architecture shown in Fig. 4 was chosen to take advantage of the performance benefits of reactive behaviours while at the same time preventing some of the associated problems such as oscillations between behaviours and restricted scalability. In this architecture the Arbitration System dynamically decides which sets of behaviours are allowed to access the output devices in the system. This decision is based on the information coming from the sensors and the current state of the system. In this model the user interface is regarded as a sensor.

Crowley [9] defines a *virtual sensor* which is a digitised time sampled function, computed using sensor data and intermediate representations. We also adopt this model by employing sets of feature detectors as inputs to our control system. Currently a simple description of the features is used, i.e. they are classified as being present or absent, no measurement error or certainty measure is used. These features correspond to the observed events within the Supervisory Control Theory of Ramadge and Wonham [17] as used to control mobile robots by Košecká and Bajcsy [13]. The Arbitration System models the environment as a finite state machine in which state transitions occur due to combinations of observed events. In addition to controlling the execution of the behaviours the Arbitration System also monitors the commands for the motion control system. If a sudden change in direction and speed are detected, it interpolates between current and new values to prevent sudden moves which would throw the user off balance.

4. Evaluation of PAM-AID prototypes

The first prototype was evaluated in the laboratory by representatives from the National Council for the Blind of Ireland, the Sensory Disabilities Research Unit, University of Hertfordshire, UK and the Dept. of Consumer Technology, Chalmers University of Technology. Concerns over the safety of the device were expressed by both carers and users. The most important factor was the detection of descending stairs. In the words of one mobility expert "If the device fails to detect descending stairs it will be useless". In addition the evaluators and users were concerned that the device must be extremely responsive to user input i.e. not drag the users after it or exert any force on them which might upset their balance.

A great deal of attention was paid to the user interface of the device. Many of the preferences expressed by different users were contradictory confirming the requirement for customisation of the user interface. A typical example was the preference by some people for voice control of the robot while others prefer switch based input. Cultural and personal differences also produced a wide spectrum of responses to the whole concept of a robot mobility aid. Some users were delighted at the prospect of regaining their independence while others would "prefer to crawl" rather than use a walking frame.

The process of introducing a robot aid into the lives of potential users requires flexibility on the part of the user interface and control system. Initially the users would prefer to have only limited control over such parameters as speed, acceleration, and user interface configuration, however as they become more familiar with the device they would like to have increasing control over the various parameters of the robot. A typical example would be the disabling of voice feedback in a church or changing the robot speed on command.

The second prototype was evaluated by field trials in two residential homes for the visually impaired in the UK. Eight subjects used the device, five women and three men, the maximum age was 90 and the minimum age was 76. Five of the subjects were blind, while the remaining three were visually impaired. The task used in the assessment was the navigation of a corridor which was well known to the users. The finger switches and the instrumented handles were used by alternate users, as was tonal and speech feedback.

The users preferred the instrumented handles while in the direct human control mode but found them confusing while in the automatic wall following mode. This reaction was due to the fact that while in the *automatic* mode it was still possible to move the handles and users felt that the handles should not move while the robot made decisions regarding direction. To reinforce this point users felt that the finger switches were easier to use during the *automatic* mode as the handles did not move. The users made many suggestions regarding the design of the instrumented handles and shape and texture of the buttons which will be incorporated into future designs.

All of the users preferred voice feedback over tonal information. However the timing and content of the voice messages did cause some confusion. When the users heard the command confirmation messages they thought that they were receiving instructions from the robot about which direction to take and thus found them confusing. This is likely to be due to the fact that instructions of this type are given to the users by nurses and occupational Therapists when helping them move around. The warning messages were said to be useful most of the time to explain the motion of the robot, however the users indicated that they would like to have the ability to turn them off occasionally.

5. Further work

We are currently expanding the sensor suite of the PAM-AID robot to include a laser range finder and IR down-drop sensors. With these additional sensors we aim to improve the users safety particularly from descending stairs. We will also be investigating the recognition of features such as doorways, corridor junctions, etc. and relaying this information to the user.

We are developing a Shared Control System as an alternative to the current control options of either direct human control or automatic control. In the immediate future we intend to replace the finite state machine based Arbitration System with a Bayesian

Network [16] and investigate its potential for sensor fusion and shared control.

Due to the variety of user interface options requested by the users we intend to expand the modes of human–robot interaction. Currently we are integrating a speaker dependent voice recognition system and will be field testing it in late 1997. In addition in an attempt to develop an interface for arthritic users we are developing force sensing handles which will provide an intuitive interface without requiring fine manipulation of switches or a joystick. In addition to the technical adaptations we intend to perform explicit user modelling as in [14] and [1] to aid the development of a formal specification for the user interface.

6. Conclusions

This work is a part of an effort to apply Artificial Intelligence and Robot Technology to the needs of the wider community. We have chosen a well-focused robot application such as PAM-AID as it represents both a concrete need and a significant challenge. The needs of the infirm blind and visually impaired are quite different from those of the able-bodied blind. This manifests itself in the need to combine both a walking support and a mobility device. We are developing a modular robot design in which complex tasks and user interfaces can be customised to meet the needs of each individual user.

By placing a human being at the centre of the design of the device we have had to consider several interesting research issues. The primary issue is the user's relationship with the device. The short term memory problems of the elderly and the likelihood of cognitive dysfunction constrain it to be as simple and intuitive as possible. The provision of feedback about objects in the environment must be based on the needs of the user (reassurance, information) and the needs of the robot (user safety). The modalities of this feedback must be flexible to cope with a wide range of user preferences. It is hoped that the lessons learned in developing applications for the disabled will contribute to other domains such as service robotics, tele-operation, sensing, planning and control.

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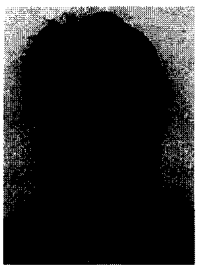
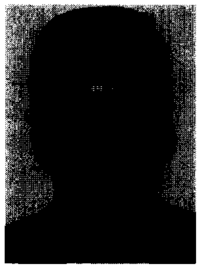


Gerard Lacey was born in Yorkshire, UK, on August 23, 1968. He received a BAI degree in Computer Engineering from Trinity College, Dublin in 1991. He is currently completing his Ph.D. at the Department of Computer Science, Trinity College, Dublin. Since 1991 he has been a research assistant and lecturer in the Department of Computer Science, Trinity College. He is currently Principal Investigator of several EU and Irish research projects in the areas of automated visual inspection and mobile service robotics.



Kenneth M. Dawson-Howe, M.A. (1987), Ph.D. (1991), has been a lecture in the Department of Computer Science, Trinity College, Dublin, Ireland since 1991. His research has focused on a wide range of applications in Computer Vision and Robotics including 3D object recognition, camera calibration, diagnostic ultrasound imaging, industrial inspection, advanced HCI, robotics for the disabled and most recently landmine detection.