Personal Adaptive Mobility Aid (PAM-AID) for the Infirm and Elderly Blind

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Abstract

People with both visual and mobility impairments have great difficulty using conventional mobility aids for the blind. As a consequence they have little opportunity to take exercise without assistance from a carer. The combination of visual and mobility impairments occurs most often among the elderly. In this paper we examine the issues related to mobility for the blind and pay particular attention to the needs of the elderly or frail. We overview current mobility aids and detail some of the research in this area. We then describe a robot mobility aid "PAM-AID" that aims to provide both physical support during walking and obstacle avoidance. We examine the factors relevant to the operation of PAM-AID and give an overview of its design. Finally we describe the current status of the project and indicate its future direction.

1 Introduction

The opportunity for independent mobility is a major factor affecting the quality of life of all people. Frailty when combined with a visual impairment has a devastating effect on the ability of the elderly to move around independently. This often results in their becoming bed-ridden "for their own safety". There is therefore a real and present need for a device to improve the independent mobility of the frail visually impaired. The elderly and infirm blind are excluded, by virtue of their frailty, from using the conventional mobility aids such as long canes and guide dogs. Consequently the elderly visual impaired are heavily dependent on carers for personal mobility. This level of carer involvement is often beyond the resources of a family or residential care facility and the person is forced into a sedentary lifestyle. A sedentary lifestyle accelerates the degeneration of the cardio-pulmonary system and in addition the increased isolation and dependence can lead to severe psychological problems. In Europe over 65% of all blind people are over 70 years of age therefore this represents a serious issue.

The PAM-AID project aims to build a mobility aid for the infirm blind which will provide both a physical support for walking and navigational intelligence. The objective is to allow users to retain their personal autonomy and take independent exercise. In this research we have attempted to examine the needs of potential users and we have been aided in this by the staff of the National Council for the Blind of Ireland (NCBI). Initially we examine the issues involved in mobility for the visually impaired and look at the state of the art in mobility aids for the blind. We then examine the unique

mobility and navigational needs of the elderly and infirm and identify how these affect the technical issues associated with constructing a mobility aid. We then detail the design of the PAM-AID robot and report on the progress in developing the prototype system.

2 Mobility and Navigation for the Visually Impaired

Blind and visually impaired people experience difficulties in moving around dynamic environments. Two general classes of problems occur, mobility problems and navigational problems. Mobility is the ability to avoid obstacles and move through a known space with confidence while navigation is knowing where you are, where you are going and how to get there. There is a certain degree of overlap between these two functions, however they represent two different ways of thinking about the space through which the person is moving. In mobility it is not strictly necessary to recognize the various objects which are being avoided, their size and position is all that is required. To navigate on the other hand it is necessary to identify a sequence of landmarks to allow the person to recognize their route.

Mobility aids, advance route planning using tactile maps and occasional assistance from sighted people afford the able-bodied blind person a great deal of personal freedom. We will examine the currently available mobility aids and identify how they work in general. We will also try to identify their limitations particularly in the case of the elderly and infirm.

2.1 The Long Cane

By far the most common mobility aid for the visually impaired is the long cane. Techniques for the use of the long cane were developed by the Veteran's Administration in the US during the 1960's (Welsh & Blasch 1987). At its most simplistic the cane is swept from left to right synchronized to the stride of the user. The synchronization is such that the cane sweeps the space in front of next stride. The length of the cane is the distance from the base of the sternum to the ground, thus the blind person is given approximately one stride preview of the terrain directly ahead. If an obstacle is detected the cane user must be able to react quickly to avoid a collision.

The limitations of the long cane are that the entire space through which the body moves is not scanned. Of particular importance is the fact that overhanging obstacles such as the rear of parked trucks and holes in the ground cannot be detected reliably. Sophisticated use of the long cane is possible by using the sound of echoes from the tapping of the cane or by following walls, kerbs and other environmental features. However it can be very difficult for users to detect slowly curving paths and thus orientation can be lost. Noises and smells from the environment also play a part in helping the visually impaired cane user move around an environment. There can however be a high degree of stress associated with cane use due to the limited preview of the terrain and the limited amount of information it provides.

2.2 Guide Dogs

The other most common mobility aid is the guide dog. Dogs have been used as a guide for the blind since at least Roman times. However systematic training of guide dogs did not begin until the 18th century. Guide dogs became wide spread after the first world war when the German army began training German Shepherd dogs to guide war veterans (Welsh & Blasch 1987). The typical guide dog begins training at 2 years of age and has a working life of roughly nine years. Guide dogs cost approximately $16,000 to train and about $30 per month to maintain. Guide dogs are not suitable as a mobility aid for all blind people.

The blind person's visual impairment must be severe so as to prevent the anticipation of stops or turns before receiving this information from the dog. If the guide dog user could anticipate such events the dog would not have the opportunity to put its training into practice and without sufficient reinforcement the guide dog may no longer function effectively.

The training process is physically strenuous and the users must have good coordination and balance. A typical guide dog walking speed is 5 to 6 kilometers per hour therefore the user must have an active lifestyle to provide the dog with sufficient exercise and reinforcement. The dog must be given constant correction if it disobeys a command or does not perform correctly except in the case of intelligent disobedience. This is where the dog disobeys the command if it would cause danger to the person and is particularly important for crossing roads.

2.3 Walking Aids

There are a variety of mobility aids for those with a balance or weight bearing problem. Although there are many different models of walking frames they fall into three distinct categories, conventional walking frames, reciprocal walking frames and rollators. Conventional walking frames, often called "Zimmer" frames, are designed to provide a larger base of support to a person with lower limb weakness. Most are adjustable in height and some models can be folded away. The frame is used by lifting, placing it forwards, bearing weight through the grips and taking two strides to the center of the frame. Particular attention must be paid to the height of the frame to ensure good posture during walking.

Reciprocal Frames are similar to the standard "Zimmer" 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.

Rollators are walking frames with wheels attached, there are many different configurations of the base available. 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. Rollators are often attached with brakes to prevent "run away", baskets for carrying shopping and seats in case of tiredness. A great deal of attention is paid to the cosmetic design of Rollators as they are often used out of doors.

2.4 Electronic Mobility Aids

Even though the long cane is a very cheap and reliable mobility aid it does have the drawback that all the space through which the body travels is not scanned. This leaves the upper body particularly vulnerable to collisions with overhanging obstacles or with other people. This deficit of the long cane has prompted much research into electronic mobility aids. Several reviews have been done such as (Nye & Bliss 1970), (Boyce 1991) which contains a good overview and (Welsh & Blasch 1987) which reviews mobility devices in depth.

Personal electronic mobility aids are not used by the majority of blind users, primarily due to the excessive cost, poor user interfaces and poor cosmetic design. If a mobility aid is to be successful the device must provide the user with a great deal more information about the environment than the long cane. It must also present this information in a manner that does not occlude the remaining senses. For example requiring the user to wear a pair of headphones would exclude noises from the environment. The device must be affordable, robust and not draw undue attention to the user's blindness. This is a difficult specification to achieve as emphasized by the continued preference for long canes and guide dogs by the majority of blind people. Many interfaces to mobility devices have been proposed including stereo headphones, vibrating pads on the forehead, chest or back, however none have been very popular. A mobility device currently under development in the European Project "Autonomous System for Mobility, Orientation, Navigation and Communication (ASMONC)" proposes to use an instrumented handle to give the user directional information. The ASMONC system is primarily designed for use in outdoor urban environments.

3 Related Work in Assistive Technology

There are a wide range of projects aimed at improving the mobility of persons using wheelchairs. European projects such as OMNI

(Hoyer et al. 1995), SCENARIO (Katevas et al. 1995.) and MANUS (Kwee et al.1988) focus on improving the operation of conventional electric wheelchairs or extending their functionality. OMNI is building a very high maneuverability wheelchair for confined domestic and office environments. SCENARIO is improving on conventional wheelchairs by the introduction of navigational intelligence, the user is able to choose manual control or fully autonomous navigation. MANUS is a wheelchair fitted with a robot arm to the wheelchair to facilitate manipulation of objects by persons with quadriplegia. US projects such as NavChair and DeVAR have also investigated the integration of navigational intelligence onto wheelchairs.

Other projects are attempting to replace functionality lost to people who are bed ridden. The MOVAID-URMAD project (Guglielmelli et al.1994) and WALKY (Neveryd & Blomsjo 1995) are projects that aim to assist the bedridden person be as independent as possible by performing common daily tasks remotely from their bed by means of a mobile robot fitted with an arm.

4 Related Work in Robotics

Mobile robotics and signal processing research is undergoing a period of rapid advancement due to a number of factors, not least due to the availability of cheap, portable and powerful computing. This has brought the possibility of viable applications for mobile robot technology ever closer. In (Horswill 1993) it was shown that a reliable robot guide could be constructed using only visually sensed data. This robot guided people around the floor of a building giving a running commentary on the surroundings. He also noted that when moved to a new environment the robot detected false obstacles due to shadows and color changes. In (Garibotto, Ilic & Masciangelo 1994) a robot guide for public spaces such as theaters and museums is described. The authors reported that the robot guide required human intervention approximately every 10 minutes. While these applications have experienced some minor difficulties they show the potential for harnessing this technology.

Signal processing techniques have been developed to use cheap sensors for mobile robot navigation. Leonard in (Leonard & Durrant-Whyte 1993) showed that sonar, despite having some limitations, can be used to reliably detect features such a corners and walls etc. using a-priori feature maps. This allows the robot to successfully navigate around a complex environment.

The control of mobile robots has undergone the most radical change in the recent past. Systems with multiple competing behaviors have proven to be successful in dynamic environments (Brooks 1986). The inter-relationship of these behaviors can perform tasks such as hall following etc. However in some cases several contradictory behaviors may be invoked simultaneously and arbitration is required. The arbitration can be a fixed hierarchy as in (Brooks 1986) or by inter-behavioral bidding as in (Sahota 1994) or by a variety of other schemes. A fixed hierarchy can be quite brittle especially when the robot is tested in an environment different to the one in which it was developed.

Of particular relevance to our work are techniques for shared control between robot and user. This research is common in tele-operated robots which are used for bomb disposal or other hazardous environments. Borenstein in (Borenstein & Koren 1990) describes a system of tele-autonomous guidance which allows for the gradual sharing of control between the user and the robot for obstacle avoidance.

5 The Visually Impaired Elderly

Vision loss in later life can be crippling particularly for those in long term care. Psychological problems associated with lack of motivation and lessened expectations make mobility training difficult (Welsh & Blasch 1987). This difficulty is compounded by memory loss, the need for a support during walking and an increased fear of falling. If the long cane is used both for support and mobility it can be quite heavy and lead to rapid fatigue. Using a long cane and a walking aid in tandem would result in both hands being occupied and thus an increased fear of falling. In long term care

facilities practical concerns discourage independent mobility for the aged visually impaired as long canes pose a risk of tripping the other residents.

The difficulties involved in providing the elderly visually impaired with independent locomotion results in their being confined to their beds or to chairs for their own safety. In this sedentary state a rapid deterioration in the cardio-pulmonary systems occurs. The link between inactivity and the deterioration of health in older persons has been noted in various studies (Bonner 1969),(Brunner 1970). The psychological effect of increased dependence also has an adverse effect on the persons quality of life. Even limited independent mobility can greatly increase the quality of life of the elderly person. 5.1 User Profile The target user group for PAM-AID is the visually impaired who also require physical support while walking. A British survey (Richards 1993) of blind library users showed that 63% of blind persons are aged over 70. The ratio of females to males among the blind was 2:1 and the ratio of blind to partially sighted was also 2:1. Also notable from the survey was a preference for spoken rather than Braille material particularly in the 70+ age group.

A 1986 survey of the 1.5 million residents of US residential care facilities (Ficke 1991) showed that 70.7% of persons over 65 years had a mobility impairment and 22.7% had a visual impairment. Among those aged 85 and older the proportion of visually impaired increased to 30%.

According to the European Blind Union there are 4 million people in the EU who can be described as being visually impaired (persons with residual vision below 6/18). Many population projections say that, if current population trends continue, as many as 25% of Europeans will be aged 65+ by the year 2020, the biggest increase will be in those aged 75+. This increase will be most notable in the Netherlands, Germany and Denmark where it is projected that by 2040, the number of over 65's will be approaching 45% of the number of 15-64 year olds in society.

5.2 Quality of Life of the Elderly

In (Rowe et al. 1991) Chon and Sugar conducted a survey of the perceptions of residents and carers as to the determinants of quality of life. The residents chose morale and social-emotional environment as the key determinants of quality of life. The carers generally chose the quality of care and the morale as the key determinants of quality of life. The conclusion drawn was that a tension existed between the needs of the residents and the limitations of the institution and an expansion of resident choice in as many areas as practicable was recommended. Quality of life is a very difficult thing to measure. Measures that are currently used often only relate to the medical condition of the person. Quality of life can be seen to be a complex relationship of physical activity and social contacts as well as a purely medical definition.

5.3 Technology and the Elderly

Firnie (Rowe et al. 1991) reviews assistive devices for the elderly and their affect on their quality of life. He focuses attention on the need to retain the ability of the individual to make choices and on the need to pursue the real problems as he describes them of falls, incontinence and cognitive dysfunction. In the design of technology for the elderly Nicolle et. al. (Poulson, Nicolle & Richardson 1995) advise a broadly based approach to the specification of new technology involving carers, observation of potential users as well as user interviews.

Wellford in (Birren, J. 1959) reports that the speed and accuracy of elderly people for simple motor tasks is quite good but this deteriorates rapidly as the complexity increases. This is particularly true if there is a extended time between the stimulus and the taking of the responding action. This result is attributed to a poor short term memory. In general where possible the elderly shift concentration from speed to accuracy in an attempt to maximize the use of limited physical resources. This can often result in lower error rates than younger people for simple motor tasks.

Kay in (Birren, J. 1959) examines learning and the effects of aging. Short term memory is very

dependent on the speed of perception and thus deterioration in perception skills 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.

The major factor in learning is motivation. In the elderly motivation for learning is much reduced as the acquisition of a new skill may not seen to be worth the effort given the limited life expectancy. Karlsson in (Karlsson 1995) notes that usability or "perceived ease of use" is not the limiting factor in the adoption of new technology by elderly people. She shows that "perceived usefulness" is the prime factor in the adoption of a new technology as it is directly related to the users motivation. Perceived usefulness is influenced by information and is sustained by the evaluation of "service quality" parameters. Perceived ease of use on the other hand influences the adoption of new sub-systems technology and is in turn influenced by hardware and software design, user experiences and by training and support. Introducing new technology into the domestic area affects that environment and this must be considered when assessing the design of the system.

6 Personal Adaptive Mobility Aid (PAM-AID)

We aim to develop an robot mobility aid which will be a primary mobility aid to the aged or infirm visually impaired for use in the home or in a residential care facility. The robot guide at its most simplistic will provide obstacle avoidance to a visually impaired person. This will be achieved by a combination of warning messages and direction control provided by PAM-AID. The control strategy aims to combine the control input of the user with the sensor information to provide a safe path.

We aim to keep the technologies as simple and modular as possible to maintain a low overall cost and to allow for tailoring the system to meet individuals needs. For example PAM-AID could be fitted with a module to allow it navigate from point to point in the building, in a nursing home it could lead the person from their bedroom to the dining room. Other enhancements proposed include a wide variety of user interface configurations tailored to suit the individual needs and preferences of the user. In particular adaptations to cope with hearing impairment and arthritic complaints will be considered.

The safety of the device is of major concern to both the carers and the users themselves. The most important factor in the design is the detection of descending stairs. In the words of one mobility expert "If the device fails to detect descending stairs it will be useless". PAM-AID 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.

6.1 PAM-AID Rapid Prototype

Our work to date has been concerned with the construction of the mobile robot base which is currently being used as the prototype for PAM-AID. Three types of sensor are used to provide information on the environment : sonar, infra-red proximity sensors and bumpers switches. The data gathered is sufficient for obstacle avoidance and is simple enough to allow rapid processing. This fast reaction time ensures reliable obstacle avoidance.

Sensor data is processed to provide reactive obstacle avoidance. The reactive control system is based on a subsumption architecture (Brooks 1986). The robot base controller is connected to the master P.C. via a serial link. The PC contains a text-to-speech card and performs the sensor processing and control.

6.2 Current Status

As a primary mobility aid PAM-AID must address the needs of the users by providing both a support for walking and a mobility aid. To ensure user confidence in what is effectively "a rollator with a mind of its own" a fail safe strategy is incorporated into the operation of the base unit. If the robot gets "confused" by the sensor input or the user attempts to enter a

region deemed dangerous by the robot the robot stops.

6.2.1 User Interface

The feedback to the user comes in the form of proprioceptive feedback through the frame and speech feedback from the on-board computer. The joystick interface is limited in several respects due to the fact that it only indicates position, ideally the user could indicate both direction and speed via a force controlled input device. This type of user input device is currently under development.

6.2.2 Control System

The control system determines a great deal about the users experience of the robot and several options are under development. One option involves complete directional control by the user with the robot only providing direction assistance via speech feedback and stopping before dangerous situations occur. Control can be swapped between the user and the robot by allowing the robot to control the direction for fixed lengths of time. This "bang-bang" control is signaled by the user placing and holding the joystick in "reverse" during a dialogue with the robot.

The main issue in control is that unlike a conventional mobile robot or a robot wheel chair the user is a separate entity. This presents its own individual set of problems in that users actions must be sensed accurately. Currently this requires the users to indicate via the joystick their intended direction. The motion of the robot, particularly when moving from rest or initiating a turn affects user hand position relative to the robot. Thus an element of "debouncing' is required on the joystick input. The robot also must be prevented from reversing over the user or performing very tight turns.

In (Borenstein & Koren 1990) a system for shared control between user and robot in tele-operated robots is described. The user indicated direction via a joystick and speed via a foot pedal. Currently we are developing a force sensing handrail for the PAM-AID device which will allow us to sense both the direction and intensity of the forces applied by the users. It also has the added advantage of safety as it makes possible the detection of the user stumbling by attending to sudden increases in the downward force. The aim of the control systems research is a shared control in the manner of guide dog users where the user will be unaware of the scene complexity or of the subtle maneuvering of the robot. A guide dog user communicates with the dog via a series of simple spoken commands such as "forward", "right", "left" ,"stop", "steady" to slow the dog and "hup-hup" to speed up. When both dog and owner are used to an area more complex instructions can also be used such as heading to particular locations. Currently we are extracting these commands from a joystick input, soon this will be replaced by the force sensing interface and ultimately we hope to compliment this with a simple speech based interface.

7 Future work

To date the robot has been tested by graduate students as it is not sufficiently well developed for field trials. The descending stairs detection system is currently being developed and remains to be integrated, a force sensing handrail system is also under development. All of these subsystems will be integrated into the overall control strategy before the first field trials which are scheduled for early 1997.

8 Conclusions

This work is seen as part of a long term effort to apply Artificial Intelligence and Robot Technology to the needs of the wider community. We have chosen a well focused project 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 in the early stages of this work and are concentrating on developing the user interface and control systems required to provide a reliable mobility aid in a dynamic environment. We aim to develop a modular

robot design in which complex tasks and user interfaces can be customized to meet the needs of individual users.

By placing a human being at the center of the design of the device we have had to consider several interesting research issues. The primary one is the users relationship with the device. The short term memory problems of the elderly and the likelihood of their being some cognitive dysfunction constrain it to being as simple and intuitive as possible. The provision of feedback on the environment to the users 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 range of user preferences.

The research contributes to general research in AI in that it focuses attention on how humans represent and use environmental information. In a practical way it also concentrates the mind on the issue of reliability in robot applications. The lessons learned in developing applications for the disabled will contribute to other AI domains such as tele-operation, sensing, planning and control.

In this work we are trying to provide limited independent mobility to a group of people who would otherwise be bed-ridden. We are not attempting to build a robotic guide dog which will work in all environments and for all people. We try to support the users remaining abilities by increasing their confidence to take independent exercise. We do not aim to remove the necessary human contact involved in the care of the elderly however we hope to facilitate the greater independence of the person within a caring environment.

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