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A Smart Walker for the Frail Visually Impaired

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Abstract

This paper describes the design of a smart mobility aid for frail, visually impaired people. The device is based on the concept of a walker or rollator - a walking frame with wheels. This work is motivated by the fact the frail visually impaired have extreme difficulty using conventional mobility aids such as guide dogs or long canes. The device, which is called PAM-AID (Personal Adaptive Mobility Aid) has two modes of operation – manual and assistive. In manual mode the device behaves very much like a normal walker and, in addition, provides the user with information on the environment via a speech interface. In assistive mode, the PAM-AID assumes control of the steering and navigates safely around obstacles. The PAM-AID was evaluated in residential homes for the elderly.

1 Introduction

Comprehensive statistics on dual disabilities are rare. Some studies do provide compelling evidence that there is a substantial group of elderly people with both a visual impairment and mobility difficulties. Ficke[4] estimated that of the 1.5 million people in nursing homes in the United States around 23% have some sort of visual impairment and 71% required some form of mobility assistance. Both visual impairments and mobility impairments increase substantially with age. Rubin and Salive[11] have shown that a strong correlation exists between sensory impairment and physical disabilities.

People who have a visual impairment and are also frail have difficulty using conventional navigational aids in conjunction with standard mobility aids. Their lifestyle can thus be severely curtailed because of their heavy dependence on carers. Increased mobility would lead to more independence and a more active, healthier lifestyle.

A variety of electronic travel aids for the visually impaired already exist. Farmer [3] provides a comprehensive overview. A small number of devices have reached the stage of extensive user trials, notably the Laser Cane[1], the Pathsounder[12] and the Sonicguide[6]. More recently, the GuideCane[2] has received a lot of attention. None of these devices provide any physical support for the user however.

A previous version of PAM–AID is described in [9]. The navigation and feature detection modules have since been completely revised and sonar has been replaced by laser as the primary sensor. Also, the user interface has been substantially simplified while still maintaining its functionality.

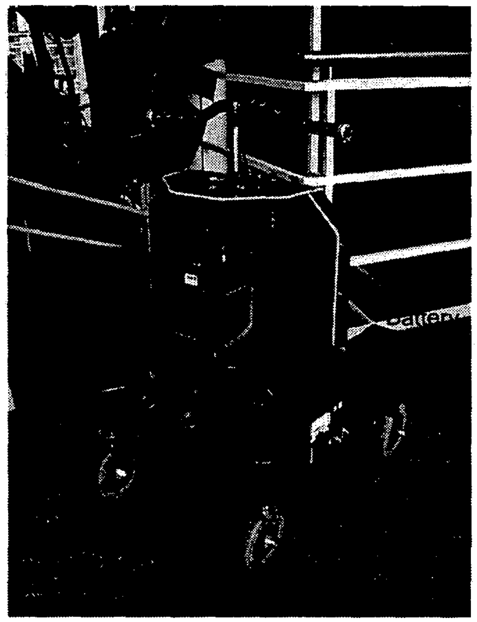

Fig 1. **PAM-AID Smart Walker**

2 Design

The goal of this project was to design an aid that would increase the independent mobility of people with both a visual impairment and a mobility impairment. Particular emphasis was placed on a number of areas of the design - It is important that the users always feel in control when using the device. For this reason, it was decided that the device should not have motorised locomotion, only the steering is motor controlled. The user interface must be extremely simple and intuitive. Switches must be kept to a minimum and placed strategically for minimum confusion. Path trajectories calculated by the obstacle avoidance routines must be smooth. Sudden changes of direction should be avoided. If the device behaves in an erratic fashion the user can easily be confused and disorientated. These design issues are discussed in greater depth in the following paragraphs.

2.1 Mechanical

The mechanical design of the device is very similar to that of a conventional walker with a few important distinctions. The two castor wheels at the front of the walker have been replaced by two wheels with zero off-set and are controlled independently by two separate motors. The motors are solely for adjusting the steering angle of the device, they do not in any way propel the device. The device thus has kinematic constraints similar to those of an automobile. Because the wheels are not coupled by a mechanical linkage, much smaller turn radii can be achieved. Also, the wheels can be positioned such that the device can be rotated about the user. See Fig 2. This is important for visually impaired people as they are not encouraged to walk backwards.

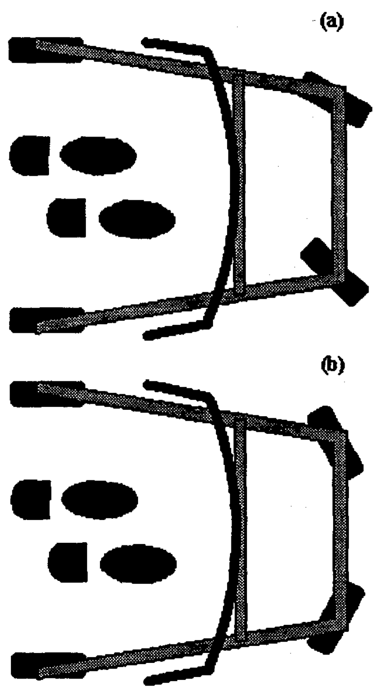

Fig 2. Walker Kinematics (a) Normal ackermann steering (b) Turn-on-the-spot

The device has two modes of operation – manual and assistive. In manual mode, the user has complete control of the steering. The device will issue the user with voice messages giving the user information regarding the state of the environment but will not assume control of the device from the user. In assistive mode, the device controls the steering and will servo around obstacles while attempting to maintain the user's goal direction. Again, voice messages are given to the user with information pertaining to the immediate environment. If their exists a number of possible directions to take, the user can signal the direction in which he intends to travel (left, right, straight-ahead) by turning the handlebar in the appropriate direction.

2.2 User Interface

The user interface had to be conceptually very simple. Elderly people are easily confused by a complicated interface. A deliberate attempt was made to make the control of the device as intuitive as possible, hence a bicycle handlebar analogy was chosen.

The handlebar can rotate through approximately +/- 15 degrees. The angle of rotation is measured by a linear hall-effect sensor positioned between 2 magnets. The hall-effect sensor is mounted on the handlebar while the magnets are stationary on the device frame. The handlebar is spring loaded. Thus, when no torque is applied it will return to its zero position. A transfer function converts the handlebar deviation to an actual steering angle. A momentary switch is mounted on the side of the handlebar. Its function is to flip the wheels so that rotation-on-the-spot is possible. By rotation-on-the-spot we mean that the user is at the centre of rotation of the device. This is illustrated in Fig 2b.

The user is constantly updated as to the current state of the environment. The information is conveyed to the user in the form of voice messages. Two types of messages exist – feature messages and obstacle messages. Examples of feature messages are *Left Junction*, *T Junction* etc. Obstacle messages would be typified by expressions such as *Object Ahead*, *Object Above* etc. The messages are prioritized so that important messages such as *Object Ahead* are never blocked by, for instance, feature messages. Also, the time between messages and the repetition of messages is constrained. A user who is bombarded by messages tends to get confused and frustrated with the system. Previous work [8] has demonstrated that the user group found recorded voice messages easier to understand than tones or other audio signals. The audio server is responsible for the scheduling and prioritizing of messages.

2.3 Software Architecture

The system runs Linux with the Task Control Architecture (TCA) [14]. Currently, there are eight TCA servers running on the device - motion control, sonar, laser, feature extraction, audio output, navigation, a supervisor and the TCA central server. See Fig 3. All servers run on the same processor. The complete control loop is executed in approximately 0.25 seconds, the main bottleneck lies in is the acquisition of laser ranging data via a serial interface.

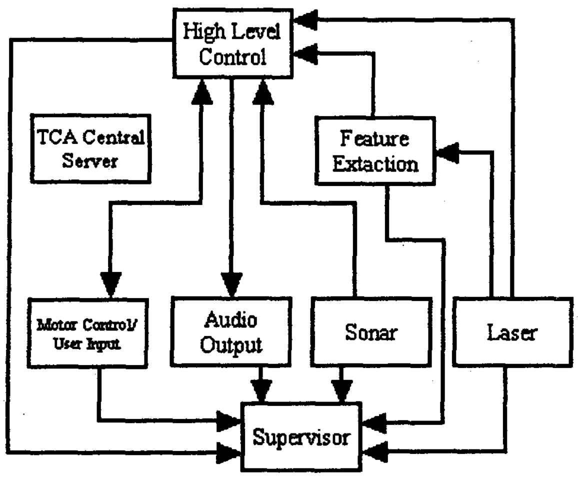

Fig 3 Software Architecture

2.4 Sensor Configuration

Both laser and sonar were used for navigation. The laser (Sick LMS200) was used as the primary sensor while the sonar ring was used for situations where the laser was unreliable e.g. environments where there was an abundance of glass or for detecting features like table-tops. The laser data was generally much more accurate and reliable than the sonar data. Specularities didn't pose such a problem.

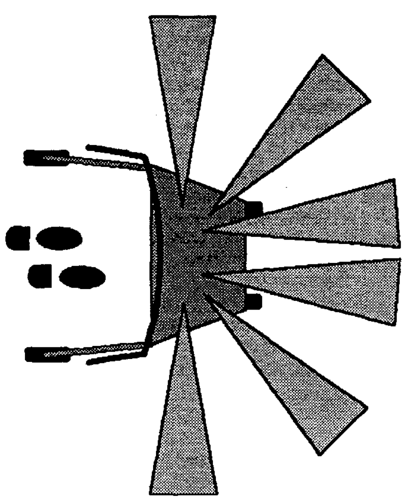

Fig 4. Sonar Configuration

The laser returned range readings every degree over a 180 degree sweep in front of the robot. Six sonar transducers overlapped this region as well. Two sonars pointed upwards and were used for detecting tabletops and other overhangs. Where a laser reading corresponded to a sonar reading, the two readings were compared and the shortest value was used for the potential field. This generally worked well as a specular reflection (or the case of the laser going straight through glass) caused an increase in the range reading, not a decrease.

Reliable range data was important for planning smooth trajectories for the elderly. Any sudden changes in direction makes them very uneasy and will impede their use of the device. A schematic of the sensor configuration is shown in Fig 4. Incremental encoders are mounted on the two fixed rear wheels to obtain odometric data.

2.5 Environment Description

The users of PAM-AID were given voice feedback describing their environment. Unlike other research performing feature and place recognition in mobile robotics, no map of the environment was used. This allowed the robot to function effectively in any environment without the need for any set-up phase. This approach was adopted to allow maximum operational flexibility for PAM-AID. The descriptions of the environment provided to the user were the types of corridor currently around the robot. Six corridor types were chosen as shown in Fig 5. These particular corridor types were chosen as they represent important navigational landmarks in indoor environments.

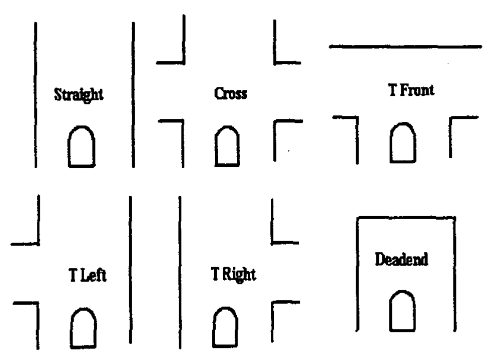

Fig 5. Corridor types classifiable by the Feature Recognition System

The corridor types were recognized from the laser data. The straight line features were extracted from the range scan using the Range Weighted Hough Transform[5]. The position, length and angle of the features were input into a Bayesian Network[10] in order to classify the types of corridors present. The structure of the network is shown in Fig 6.

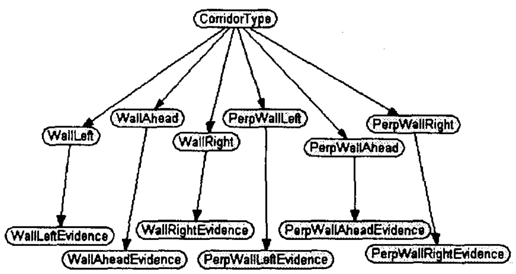

Fig 6. Bayesian network structure

The network contained three layers of nodes. The lowest layer represented the raw feature evidence. Feature strength was proportional to feature length and scaled as being one of the set {weak, medium, strong, certain}. This classification represented the size and type of line features around the robot. The middle layer of nodes represented the likelihood of each feature given the uncertain sensor input and as such represented the error in the sensor/feature detection system. The top-most layer of the network classified the features into one of the six corridor types.

The prior probabilities in the Bayesian Network were trained using example laser scans and a learning algorithm. The laser scans were taken from a variety of different positions to ensure robustness and generalization. The learning algorithm incremented a feature's causal probability when it supported the corridor classification and reduced it otherwise. After training, the bias in the training data was apparent due to the lack of symmetry in the network and the over-sensitivity of some corridor classifications. Shannon's measure of Mutual Information[13] and entropy reduction were used to identify the nodes contributing to this over sensitivity and guided the tuning of the network.

The corridor classification was passed to the user interface system where a recorded voice message would provide the user with a description of the environment.

2.6 Navigation

For navigation, a variation of the VFH+ algorithm [15] was used. It was attempted to use the VFH+ algorithm with a standard ring of sonars alone but persistent specularities in the sonar returns resulted in undesirable robot behaviour. This was understandably not welcomed by the elderly users. When using the VFH+ with the laser scanner, it was not necessary to build a polar histogram as the range data from the laser was sufficiently accurate to work on a single shot basis. The raw laser range data was converted into C* space as shown in Fig 7. The circle radius in the diagram equals the robot radius plus the minimum acceptable distance to an object. The robot is thus treated as a point object. The C* space representation of the local environment is subsequently converted into an obstacle density map using a potential field type equation [7]:

$$PF[i] = \frac{A}{B \times LaserData[i]^2 + 1} \qquad (1)$$

where $PF[i]$ is the i^{th} potential field element, $LaserData[i]$ is the i^{th} laser reading, A and B are sizing parameters. For the current implementation, A has a value of 2000 and B has a value of 0.000001. Low values of the potential field indicate low obstacle density in that particular direction. The potential field is thresholded to separate out gaps that are too narrow for the walker to negotiate successfully. Gaps are further characterised as narrow or wide. For narrow gaps, the heading of the walker must approximately correspond with the centre of the gap. For wide gaps, the heading of the robot can be any value between the gap walls. Once the gaps have been located and characterised, a particular gap must be chosen to follow.

The feature extraction module informs the user of any features in the environment which require a decision to be made on the part of the user. Typical features that would require user input would include any sort of junction that would require a choice of direction. Once the user has been queried on a preferred direction, he can indicate his preference via the user interface. While the device is in assistive mode, the user preference is broken up into three regions - left, straight ahead and right. This user input is used to influence the choice of direction.

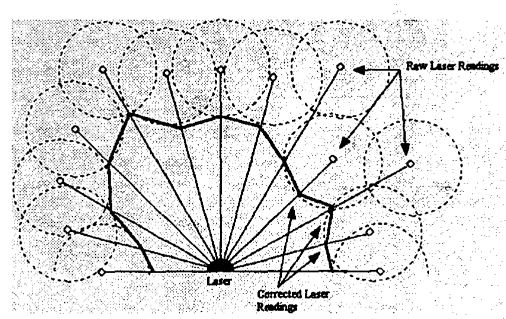

Fig 7. Conversion of raw laser range data to C* space (obstacle space).

The gaps which result from thresholding the potential field are ranked according to proximity to the *desired heading*. For wide gaps, each side of the gap is treated separately as a contender for being closest to the *desired heading*. This facilitates, for instance, wall following where only one wall exists in the local environment. The walker will travel as close to that wall as is safe. If the current heading of the walker is within the boundaries of a wide gap and the user's desired direction is straight ahead then no direction alteration needs to be made. For narrow gaps, the midpoint of the gap is chosen as a possible contender for the goal heading. Once an optimal turn radius has been chosen for following a particular gap in the potential field, the trajectory is examined for possible collisions as is detailed in VFH+ algorithm.

3 Evaluation

The PAMAID was evaluated on-site on twelve people (all female), all registered as visually impaired. The average age of the test participants was 79 years. They were all resident in a home for visually impaired persons. They suffered from a variety of other physical problems - 5 had painful arthritis, particularly of the knees, hips, ankles and hands, 3 were very frail and 2 had balance problems. After testing the device, the users were questioned on its performance. The results are summarised in the table below. The results were compiled using a 5 point Likert scale.

Fig 8. PAM-AID field trials

User's sense of safety while using device	4.4 / 5
Ease of use	3.5 / 5
Overall Usefulness	3.8 / 5
Maneuverability	3.8 / 5
Usefulness of spoken messages	4.4 / 5

Table 1. User Feedback on device performance

4 Conclusions and Further Work

A smart walker for frail visually impaired people was constructed and evaluated in formal field trials. The mobility aid is capable of navigating safely within a typical residential care setting while giving the user voice feedback on specific features in the local environment. A prime concern during development was that very smooth trajectories were obtained. This necessitated the use of a laser range finder as the primary sensor. A ring of sonars was maintained on the walker for sensor redundancy. A user interface was developed which was both simple and intuitive to use. It allowed the users to maneuver out of difficult situations in manual mode and was very robust to error in assistive mode where the user would use the interface to indicate intended direction.

Currently work is focused on integrating the PAM-AID within a smart building. The goal of this work is to have the device communicate with the building in order to carry out more complex tasks. We are also looking into the design of more reliable drop-off sensors for detecting stairwells etc. Although the user interface works well, we still see a lot of scope for further development. A wealth of information is conveyed by the user through the handlebars – this information can be processed more extensively and used for a more reliable interpretation of user's intent. Coupling this with a more sophisticated speech interface will improve further the ease of use of the device.

Acknowledgements

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