ADAPTIVE CONTROL OF A MOBILE ROBOT FOR THE FRAIL VISUALLY IMPAIRED

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ABSTRACT

This paper describes the development and evaluation of a novel robot mobility aid for frail Visually Impaired People (VIPs). Frailty makes the use of conventional mobility aids for the blind difficult or impossible and consequently VIPs are heavily dependent on carers for their personal mobility. In the context of a rapidly increasing proportion of elderly in the population this level of support may not always be available in the future. The aim of this research is to develop a robot that will increase the independence of frail VIPs. This paper will describe the walking aid and its overall control system. The controller adapts its operating mode to satisfy the constraints imposed by both the environment and the user using a probabilistic reasoning system. The reasoning system and the software architecture of the robot will be described in detail as will the evaluation of the robot in a residential home for visually impaired men.

BACKGROUND

Dual disability can severely limit the range of mobility aids a person may use. This is particularly true of the frail VIPs. 75% of VIPs are aged 65+ and frailty is also common among this age group. An estimate of the number of people can be achieved by analysing the survey data produced by Ficke [1]. His study of nursing home residents in the USA showed that of the 1.5 million residents, 22% were visually impaired and 70% had mobility impairments. His survey did not directly measure the incidence of dual disability however Rubin and Salive [2] have noted the correlation between visual impairment and frailty.

Mobile robot technology has been applied in assistive technology to develop smart wheelchairs [6] [7] [8]. The mobility aid described in this paper, the Personal Adaptive Mobility AID (PAM-AID), aims to improve the independent mobility by assisting a frail VIP to take moderate exercise within the confines of a rest home or hospital. This is achieved by providing the physical support similar a walker or rollator and navigational help similar to that provided by a carer or guide dog.

ROBOT DESIGN

The application of robotics to the mobility of the elderly blind is a significant challenge given their unfamiliarity information technology, their poor short-term memory and motivational problems in dealing with new things. The underlying design principal of the PAM-AID project was that of *Interactive Evaluation* as described by Engelhardt and Edwards in [3]. This involved regular contact with the users through interviews and regular field trials of prototypes and sub-systems.

The design process was iterative, involving the construction and evaluation of three prototypes and several user interfaces. The central concept was that of a walker or rollator with the ability to avoid obstacles and inform the user about the environmental conditions. Figure 1 shows the progression from Concept Prototype to the final Active Demonstrator system over the course of the PAM-Aid project. The main design challenges were the development of an acceptable user interface and the development of a adaptive control system.

The Active Demonstrator consisted of a custom-built mobile robot chassis, fitted with sonar sensors and a laser range finder. The main controller was a PC however many of the real time tasks were devolved to MC68332 and MC68HC11 based micro-controllers. The controller was implemented in C++, using WIN32 threads.

Figure 1: Concept Prototype, Rapid Prototype and Active Demonstrator

The user interface was a critical component of the system. User input was by means of a set of direction switches or an optional voice input system. User feedback was provided via proprioception and voice feedback. The voice feedback enabled the robot to provide information to the user regarding the nature of the environment, such as presence of junctions, doors, etc. as well as warnings about the presence and location of obstacles.

Related work by some of the authors has developed a passive version of PAM-AID [4], which the user pushes. However, the active approach, which provides its own traction, allows for the autonomous operation of the robot within a hospital or nursing home. For example an active PAM-AID could be shared between several users in a residential home as it has the ability to travel independently to each user on request. This functionality is foreseen within Smart Healthcare Environments as outlined in [5].

CONTROLLER DESIGN

The device operated in two modes, manual and automatic. Selection between the modes was by means of a switch. In manual mode the user determined the direction by means of input switches or voice commands. The robot followed these commands except if a potential collision was detected. In this case the robot stopped and provided information to the user. Control is then returned to the user to facilitate manual obstacle avoidance.

In automatic mode the robot implemented an adaptive shared control scheme based on Bayesian Networks [11]. Adaptation was achieved by balancing environment constraints with an estimate of the user's goals. The bayesian network calculated the user's goals by fusing a-priori probabilities with the current user input and sensor readings. The ultimate outcome of the adaptation scheme was the selection of the most appropriate operating mode for the

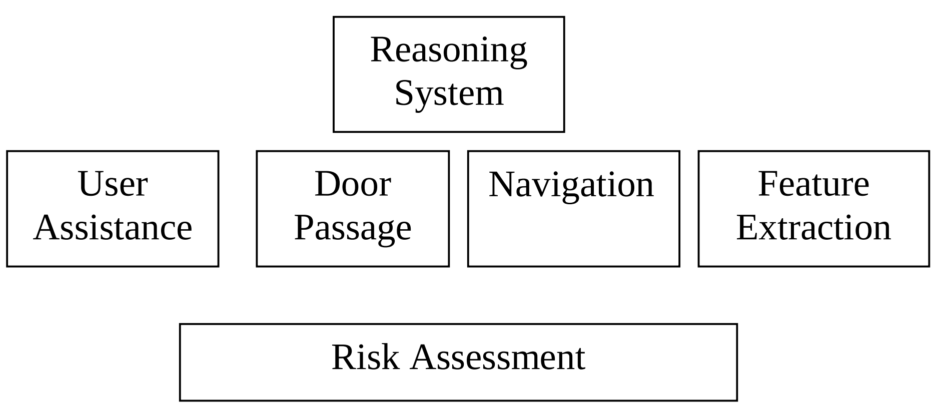

Figure 2 Schematic of Software Architecture

robot. Further details of the adaptive reasoning system can be found in [12].

SOFTWARE ARCHITECTURE

The adaptation scheme was encapsulated within the **Reasoning System** module shown in Figure 2. The software architecture is a three-layer system, similar to the 3T architecture of Bonasso et. al.[10].

The **Risk Assessment** module ran at highest priority and was responsible for detecting potential collisions and initiating the appropriate action on the part of the motion controller and user interface. It used the 0^o to 180^o laser scan and a set of sonar sensors to assess the risk of collision.

Sensor input was processed in the **Feature Extraction** module. The Range Weighted Hough Transform [9] was used to extract straight-line features from the range data. The lines were further processed to detect walls, doors and junctions. No a-priori map was used in this process thereby facilitating the immediate use of the device in new environments.

The feature data and user input was passed to the **Reasoning System** and was then used to select the operating mode for the robot. The possible operating modes were: **Door Passage**, **Navigation** and **User Assistance**.

Door Passage was an autonomous task that guided the robot through doors safely. The door passage routine identified the centre line of the door from the feature data and tracked it through the door.

Navigation was a shared control mode where the relative importance of robot control and user input was determined by the risk of collision as determined by the **Risk Assessment** module. The navigation system used the laser system that provided a 0^o to 180^o scan of the environment every 25^{th} of a second. The shared control method is based on the MVFH as described by Bell in [13]. However as the laser data is more accurate than sonar no occupancy grid was required. Multiple parabolic weighting functions were used to implement the sharing of control between the user and the robot. The parameters of the parabolic functions were selected on the basis of the measured risk of collision.

The **User Assistance** module was a dialogue-based module invoked when the robot did not have enough information to make a reliable mode selection. For example the user would be consulted when a dead-end was reached. Typically the user would initiate the manual mode in this situation.

RESULTS

During the development of PAM-AID three field trials were carried out, in seven locations, involving 30 participants, ranging in age from 55 to 94. During the trials a wide range of design ideas were evaluated and the users were encouraged to suggest alternatives and improvements. The main factors evaluated were the acceptability of the device to the target user group, the user's feeling of security while using the device and the performance of user interface.

Participant's responses were rated on a five-point scale ranging from 1 (Very Low) to 5 (Very High). Participants gave positive measures for the acceptability noting that the device was easy to use (3.5) and that they felt quite safe while using the device (3.2). When asked if the device would be useful, Participants gave they device a mean rating of (4.42).

CONCLUSION

This paper has described research to develop and evaluate a robot mobility aid for the frail visually impaired. It is motivated by the need to maintain the independent mobility of frail VIPs within a structured environment such as a nursing home or hospital.

The design of the Active demonstrator has been described and the operation of an adaptive controller has been outlined. The device has undergone regular evaluation during its development and some results from these evaluations have been provided.

This research has described a novel mobility aid that has been accepted by the user community however much research remains to be done. Our research goals include the expansion of the operating modes of the robot, the development of reliable down-drop sensors and the integration of PAM-AID within an intelligent building system [5]

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