# NOAH for Wheelchair Users with Cognitive Impairment: Navigation and Obstacle Avoidance Help

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### Abstract

Cognitive impairments prevent older adults from using powered wheelchairs due to safety concerns, thus reducing their mobility and resulting in increased dependence on caregivers. An intelligent powered wheelchair is proposed to help restore mobility, while ensuring safety. Machine vision and learning techniques are described to help prevent collisions with obstacles, and provide reminders and navigation assistance through adaptive prompts.

## Introduction

As the number and proportion of older adults increase, there is a greater need for technology that is accessible and adaptive to user needs, and ensures continued mobility and independence. Older adults commonly use powered wheelchairs for enhanced mobility, however operation of these devices requires significant cognitive capacity. Of the 1.5 million nursing home residents, 60-80% have dementia, primarily Alzheimer's disease (Payne et al. 2002). These residents lack the cognitive abilities to safely maneuver powered wheelchairs, and are thus not permitted to use them. This leads to reduced mobility, and, in turn, depression, social isolation, and an increased dependence on caregivers.

We propose intelligent wheelchairs to enhance mobility and help improve the quality of life of older adults with cognitive impairment, while simultaneously reducing the burden on caregivers. Audio prompting is an effective technique in assisting cognitively-impaired adults with activities of daily living (e.g. Hoey et al. 2007). A study of users with cognitive impairment reports that speech-based prompts are more effective than image-based and text prompts in route finding, and are also preferred by users. (Sohlberg et al. 2007). Thus, audio prompts that suit the user's needs and capabilities (estimated by a user model) will be provided to the user to promote social interaction and exploration of his/her environment in a safe and timely fashion. For example, the wheelchair can inform the user about a social event being held at the nursing home, and assist in navigating to the destination while accounting for his/her needs, preferences, and scheduling constraints.

## Related Work

Several intelligent wheelchairs have been previously developed to assist users with limited ability to operate a wheelchair (Gomi and Griffith 1998; Yanco 1998; Levine et al. 1999; Gulati and Kuipers 2008). However, most of these wheelchairs are either always autonomous, or require the user to select the mode of assistance. We propose a mixed-initiative control strategy, where the wheelchair learns the user's needs and preferences to determine what action should be taken and when.

Other assistive systems designed for older adults include the Nursebot Project (Pineau et al. 2003), the Assisted Cognition Project (Kautz et al. 2002), and an indoor wayfinding system (Liu et al. 2008). Although these systems use AI techniques for planning and/or reminding, they do not incorporate user attitude modeling. A system for assisting persons with dementia during the handwashing task is described in (Hoey et al. 2007). This system contains a user model that can be modified and incorporated into the intelligent wheelchair's planning and prompting modules.

## Research Plan

The proposed wheelchair will have three main capabilities:

1) Collision avoidance
2) Infer the user's goal location/activity and provide automated reminders
3) Provide navigation assistance using prompts

The system must be able to estimate and adapt to the cognitive state of the user, and determine an appropriate prompting strategy. An optimal strategy will fulfill the following (possibly conflicting) goals according to their order of priority:

1) Ensure safety (through navigation assistance, medication reminders, etc.)
2) Assist in the effective completion of daily activities

3) Minimize user frustration (minimize incorrect and excessive prompting)
4) Maximize user independence (minimize caregiver intervention)
5) Maximize user awareness (issue appropriate level of prompts with justification)

Human factors experts will also be consulted during the design stage. The system will first be tested in simulation to verify its safety. Clinical trials will then be run with users with mild to moderate cognitive impairment, as well as caregivers, to ensure that the wheelchair's design and operation are effective and appropriate for all users. Future work will involve a greater extent of autonomous control for users with severe cognitive impairment.

## Collision Avoidance

Safety is of highest priority in the design of an intelligent wheelchair due to the vulnerability of the target user population. Various active sensors (laser, acoustic, sonar, etc.) have been used in the existing intelligent wheelchairs mentioned above. However, these sensors are often large, expensive, power-hungry, unsafe, and prone to cross-talk issues. We have therefore created an anti-collision system that uses a stereovision camera to sense obstacles and stops the wheelchair if the user gets too close. The system then issues an appropriate audio prompt (e.g. “try turning left”) to help the user navigate around the obstacle. Results achieved by the vision-based sensor are compared to those obtained using an infrared sensor in (Viswanathan et al. 2008). The stereovision camera enables effective collision avoidance in indoor settings. It also shows promising results in outdoor/natural lighting conditions that produce false alarms when infrared sensors are used. Additionally, vision-based sensors allow more comprehensive navigation assistance by capturing visual features/landmarks in the environment that can be used for mapping and recognition. A prototype of the NOAH wheelchair system is seen in Figure 1. A bumper skirt (Wang, Holliday and Fernie 2007) will also be integrated with the anti-collision system as a failsafe backup mechanism.

## Goal Locations and Activities

The user's goal location at any specific time is inferred from his/her daily schedule (provided by the caregiver). It can also be inferred from past behaviors as in (Liao, Fox and Kautz 2004), where previous routes and locations that the user stays at for long periods of time are learned. Activity recognition might be an important component of learning user goals, since some activities might not be location-specific (e.g. eating snacks). Another effective strategy to learn about user goal locations and activities is to engage in spoken dialogue with the user. An example of a dialogue system that handles noisy and ambiguous speech is described in (Williams and Young 2006). Once the desired destination is determined, reminders and further assistance will be provided to the user.

Figure 1: NOAH wheelchair system prototype (a commercially available powered wheelchair equipped with a stereovision camera and a laptop placed under the seat).

## Navigation Assistance

In order to guide users to their desired destinations, the wheelchair first needs to learn a global map of its environment, its current location, and the location of the user's destination on the map. The global map and, subsequently, the current location of the wheelchair with respect to the global map can be determined using σSLAM (Elinas, Sim and Little 2006). The map must then be annotated using labels to indicate regions of interest, such as “lounge” or “bathroom”. Such topological maps can be built automatically, as described in (Ranganathan and Dellaert 2007), or manually.

An optimal path can easily be constructed between the current location and the user's goal location using the global map. However, this path needs to be updated based on dynamic objects that appear as the wheelchair moves through the environment. Thus, the anti-collision system described previously will be integrated into a hierarchical path planning approach described in (Yang and Mackworth 2007). This will lead to the construction of a high-level route based on the global map, which is then refined as local information is received through the sensor.

The user must then be prompted in a manner that accounts for his/her cognitive state upon failure to move or significant deviation from the path. Information about the user’s awareness will be acquired from the caregiver initially. This information will then be updated based on recently inferred user behaviours, since the capabilities of persons with Alzheimer's disease can change frequently. The user's responsiveness can also change based on the number and type of prompts received. The user's state will thus be estimated using a Partially Observable Markov Decision Process (a decision-theoretic model) as in (Hoey et al. 2007) in order to determine the optimal prompting strategy. Examples of some POMDP states are: *awareness*, *responsiveness*, *goalLocation,* and *distanceFromGoal.* Possible actions are: *prompt*, *callCaregiver*, or *doNothing*. A user with high awareness might only need a simple activity reminder, while one with low awareness might require detailed prompts that assist in navigation as well.

## Conclusions

The intelligent wheelchair described above has the potential to restore mobility in older adults who are currently not allowed to operate powered wheelchairs. The safety feature would reduce the number of wheelchair accidents and related injuries. The adaptive prompts would ensure successful completion of daily activities and effective wheelchair navigation. This innovative technology is expected to enhance the health care system, reduce the burden on care-giving staff, and improve the quality of life of older adults with cognitive disabilities.

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