Navigation and Obstacle Avoidance Help (NOAH) for Older Adults with Cognitive Impairment: A Pilot Study

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ABSTRACT
Many older adults with cognitive impairment are excluded from powered wheelchair use because of safety concerns. This leads to reduced mobility, and in turn, higher dependence on caregivers. In this paper, we describe an intelligent wheelchair that uses computer vision and machine learning methods to provide adaptive navigation assistance to users with cognitive impairment. We demonstrate the performance of the system in a user study with the target population. We show that the collision avoidance module of the system successfully decreases the number of collisions for all participants. We also show that the wayfinding module assists users with memory and vision impairments. We share feedback from the users on various aspects of the intelligent wheelchair system. In addition, we provide our own observations and insights on the target population and their use of intelligent wheelchairs. Finally, we suggest directions for future work.

Categories and Subject Descriptors
K.4.2 [Computers and Society]: Social Issues–Assistive technologies for persons with disabilities

General Terms
Design, Human Factors.

Keywords
Intelligent wheelchair, dementia, collision avoidance, navigation assistance.

1. INTRODUCTION
It is estimated that 60-80% of the residents in long-term care facilities have dementia [1]. These residents often experience limited mobility due to the lack of strength to walk and/or propel themselves in a manual wheelchair. Use of powered wheelchairs would help restore their mobility and independence, however safe operation of these wheelchairs requires significant cognitive capacity, thus excluding drivers with cognitive impairments and making them highly dependent on caregivers to porter them around. In order to address this issue, we propose an intelligent powered wheelchair that can ensure safe and effective navigation, thus increasing independence in older adults with cognitive impairment and reducing caregiver burden.

This paper describes quantitative and qualitative results obtained from a user study of a novel vision-based collision avoidance and wayfinding system for powered wheelchair users with cognitive impairment. We target older adults who have limited mobility due to lack of strength to operate manual wheelchairs, and face difficulties in safe and independent navigation due to cognitive impairment. The results from this study highlight the benefits that intelligent wheelchairs can provide to the target population. It also provides valuable insights gained from the users and suggests areas for future development and testing.

2. RELATED WORK
Although several intelligent wheelchairs have been developed recently [2-5], these wheelchairs navigate autonomously, thus taking control away from the user. On the other hand, wheelchairs that leave planning and navigation to the user and only provide collision avoidance support are not appropriate for users with cognitive impairment since they often lack planning abilities. We suggest a control strategy that provides supportive, passive navigation assistance that increases independence, while ensuring safety. In addition, we seek to build a system that is portable, cost-effective, and performs reliably in real-world settings. Existing intelligent wheelchairs have used various active sensors (acoustic, sonar, infrared, laser, etc.) that are often large, expensive, power-hungry, unsafe, and prone to cross-talk issues [6]. In this paper, we describe a system that relies on a stereo-vision camera due to its low power consumption, ability to perform in natural environments, and relatively low cost. In addition, cameras capture and provide a richer dataset than can be used for high-level scene understanding to build maps and determine what type of room the wheelchair is in (e.g., kitchen).

Other assistive technologies for older adults include Nursebot [7], a robot that guides the elderly in assisted living homes and

Figure 1. NOAH wheelchair system (commercially available wheelchair equipped with stereo-vision camera and laptop)

the Assisted Cognition project [8], which focuses on learning user models in order to predict when the user needs help. The prototype in [9] is a system that demonstrates the use of machine learning methods to assist users with cognitive impairment in outdoor wayfinding. Most outdoor wayfinding systems rely on GPS, which is unreliable in indoor settings, while indoor wayfinding systems typically use beacon and RFID technology, which require modifications to the environment. By using vision-based methods we achieve accurate localization, while reducing or eliminating the need for environment modifications. COACH [10] is an example of a vision-based adaptive prompting system that assists users with dementia in the task of handwashing. We apply similar techniques to the problem of navigation by combining adaptive prompts with collision avoidance to allow wheelchair users to reach their destination in a safe and timely manner. The study reported in this paper advances other studies with older adults with dementia driving anti-collision wheelchairs [11] [12] by adding a wayfinding component.

3. SYSTEM OVERVIEW

The intelligent wheelchair system consists of a Pride Mobility wheelchair, a 4mm Bumblebee® 3D stereo-vision camera mounted on the front of the wheelchair, and a laptop computer placed at the bottom of the wheelchair (see Figure 1). The wheelchair includes a Quantum Logic Controller, which sends signals from the laptop to the wheelchair, enabling/disabling motion of the wheelchair in specific directions. The main modules in this system are the Collision Detector, the Route Planner, and the Prompter (see Figure 2). We discuss each module in subsequent sections.

The modules are integrated using the Robot Operating System (ROS) framework (www.ros.org), which allows us to run multiple processes in a distributed fashion. The images collected by the camera are grabbed at 640 X 480 resolution. In order for the system to determine the wheelchair's position at any time, a map is first created of the test environment. This only needs to be done once for every new environment that the wheelchair has to navigate in. For this study, we constructed the map using a Pioneer robot equipped with a SICK laser using methods in [13] as seen in Figure 3. This allowed us to create an accurate and dense map that can be used by the Route Planner module. The map is loaded into a graphic interface in a visualization module provided by ROS called Rviz, where start and goal locations can be specified by clicking on appropriate regions.

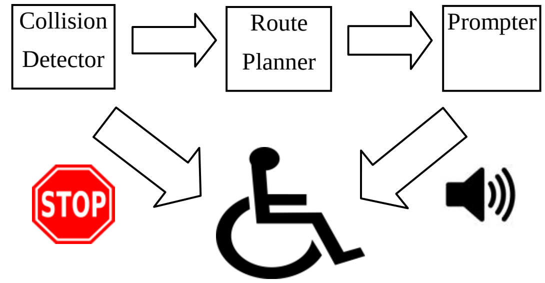

Figure 2. System Diagram of NOAH containing three main modules that aid in collision avoidance and wayfinding.

3.1 Collision Detector

In order to detect collisions with obstacles, we generate *depth maps* from stereo images that contain the distances from the wheelchair to visible objects in the environment. When an obstacle is detected within a pre-specified distance threshold, the wheelchair is stopped to avoid a collision. In addition, movement of the wheelchair towards the object is prevented to encourage the user to navigate around the obstacle. An earlier prototype also provided audio prompts suggesting an immediate direction for the user to drive in to avoid the obstacle, however these prompts were disabled in this study (only long-term navigation audio prompts were provided). Further details on this module can be found in [14]. While the Route Planner module only observes the position of the wheelchair at a pre-specified time interval, the Collision Detector module is on at all times to ensure safety.

3.2 Route Planner

After specifying the starting and goal locations on the map of the test environment, we use existing localization [15] and path planning techniques [16] to determine the position and orientation of the wheelchair at any specified time, as well as the optimal route to the goal. We compute whether the user is on-route, off-route, or stopped using the wheelchair's position and orientation. We also analyze the route for upcoming turns. This module is tested in [17] and is extended by incorporating information from the Collision Detector in order to ensure that the user is not guided towards an obstacle. The Prompter module is then used to issue an audio prompt.

3.3 Prompter

We use a decision-theoretic method called a Partially Observable Markov Decision Process (POMDP) to model the user's behavior and cognitive state (similar to [10]), as well as the wheelchair's status along the route, using noisy visual observations received from the Route Planner. The Prompter tries to estimate whether the user needs help, and then issues an appropriate prompt. For example, if the user is not *aware*, he/she is likely to perform an incorrect behavior (e.g. make a detour or stop before reaching the goal). If the user is *responsive*, he/she is likely to perform the correct behavior when an audio prompt is issued. Probabilities for the different user behaviors are specified using domain knowledge. Possible system actions are *do nothing*, *prompt*, or *call caregiver*. Possible prompts are "off route – turn right/left/around" if the user is off route, "move slightly to the left/right" if a minor correction is required or an upcoming turn is detected, and "move forward" if the user is stopped or moving backwards. Since we wanted to encourage the users to follow

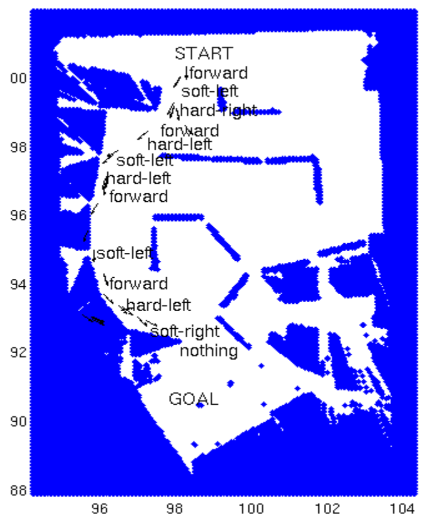

Figure 3. Laser map of the facility with examples of system prompts for participant 5 in a run during phase B.

directional prompts in this study, the cost of the *call caregiver* action was set to be very high to assign this action low preference. In a realistic setting, this action could alert caregivers in the event that the user is wandering and unresponsive to prompts. Refer to Figure 3 for an example of system prompts issued to participant 5 during a run of phase B.

4. EVALUATION

4.1 Study Design

The study consisted of two phases A and B. In phase A, the automated collision avoidance and wayfinding system was deactivated (baseline), while phase B was conducted with the system in use (intervention). We used a within-subjects, counterbalanced study design where we randomly chose half of the participants for A-B phase ordering, and assigned the other half B-A ordering. Each phase consisted of one training session and eight driving sessions (runs). All participants (n=6) completed a total of sixteen runs.

The study was conducted in a dedicated research room (approximately 50 metres x 50 metres in size) of the long-term care facility. A video camera was mounted above the wheelchair to capture joystick motion while the user was driving, and an additional camera was used by the research assistant to capture the scene view. All participants provided consent to videotape their sessions and to log any verbal feedback or observations during the period of the study. During the trials, the researcher followed each participant closely in order to provide assistance in case the participant was confused or anxious, or to stop the wheelchair in the case of an emergency.

4.2 Task

Prior to each phase, a training session was conducted for each participant, where he/she was taught how to operate the powered wheelchair (with or without the anti-collision and wayfinding system depending on the phase being conducted) in an open area. They were taught how to navigate around sample obstacles. In phase B, the researcher explained the stopping mechanism of the collision avoidance and taught the participant to use enabled joystick motions as well as to move backwards (to create more free space) and then move around the obstacle. Additionally, the

Figure 4. Scene view of the maze. Participants were required to navigate around wall and maneuverability foam obstacles.

various audio prompts delivered by the system were played to the participant in phase B training to ensure that they were able to follow the prompts. The training session in both phases was concluded by escorting the participants in their manual wheelchair along the optimal route to a specified goal (a stop sign) at the end of the maze.

The maze was assembled out of Styrofoam boards (see Figure 5). The use of Styrofoam for obstacles ensured that collisions did not harm the participants. The course included 5 types of movements: 90° right turn, 90° left turn, entering a narrow straight line path, weaving motion (around maneuverability obstacles along the route) and stopping. These movements were based on existing tests used to assess powered wheelchair mobility [18] [19]. The maximum speed of the wheelchair was set to 0.25 m/s to ensure safety. In order to reduce learning effects, we alternated between two different layouts of maneuverability obstacles, so that subsequent runs contained slightly different positions of obstacles. In addition, we constructed a random ordering of five different starting orientations, such that the participant started every run facing in a different direction than the previous run. This ordering was repeated in both phases.

At the beginning of each run, the user was asked to report on whether they were confident in navigating along the specified route using learning transference acquired from the training period and/or previous runs. The participant was then asked to find the stop sign by following the route specified during the training session and performing the movement tasks described above. During each run, the researcher recorded the number of collision events that occurred, the time taken to reach the goal, as well as the length of the route navigated by the participant (measured with a distance measuring wheel). At the end of each run, the participant answered questions for perceived ease of use of the powered wheelchair, using the standardized NASA-TLX questionnaire [20]. At the end of each phase, the researcher administered a QUEST 2.0 (Quebec User Evaluation of Satisfaction with Assistive Technology) questionnaire [21] regarding the participant's perceived satisfaction, as well as a custom questionnaire to solicit general feedback from the user regarding the device and their mobility needs.

4.3 Outcome Measures

The primary outcome measures in the study were:

1. The number of frontal collisions encountered with obstacles by the participant;

2. The amount of time taken to reach the goal;
3. The length of the route navigated by the participant.

The secondary outcome measures for the study were:
1. Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0);
2. NASA-TLX (Task Load Index) scores;
3. User's rating of self-confidence in following the route specified during training;
4. General feedback regarding the device obtained using the custom questionnaire;
5. Verbal comments and visual observations relating to user interactions with the device.

4.4 Participants

A purposive sampling method was used. Six participants from the long-term care facility were recruited for this study. Since it was a pilot study, a larger sample size was not needed. Also, a minimum of four single subjects is suggested to give preliminary evidence that the initial findings did not occur by chance [22].

To be included in the study, participants had to:
- be over the age of 65;
- have a mild-to-moderate cognitive impairment (assessed by the Mini Mental State Exam (MMSE) or equivalent);
- provide written consent from his/her substitute decision maker;
- be able to sit in a powered wheelchair for an hour per day;
- be able to follow prompts and have basic communication skills;
- be able to operate a joystick and identify directions.

Preference was given to individuals who met the criteria above and had difficulties with staying oriented and/or experienced short-term memory loss (as determined by MMSE or equivalent test results) and/or had visual impairments. Participants were excluded if they had a history of aggression or significant prior experience with a powered wheelchair due to potential historical effects on the validity of the outcome measures.

Table 1. Participant Information

ID	Age	Gender	Impairment Level (MMSE Score)
1	97	Female	Moderate (15)
2	71	Male	Mild (19)
3	66	Male	Moderate (15)
4	86	Female	Moderate (15)
5	91	Female	Mild/Intact (25)
6	80	Female	Mild (19)

Three of the selected participants had short-term memory deficits (participants 1, 3 and 5), and participant 1 also had a severe visual impairment (according to their quarterly assessments). Participant 1 could not understand some of the audio prompts, so the recordings were slightly simplified and modified to include one of her native languages. She had severe mood swings, as indicated in her assessment, and thus her participation in the trials was highly inconsistent. She was able to propel herself in her manual wheelchair. None of the participants had significant experience driving powered wheelchairs, however participants 2 and 3 had used a similar wheelchair in a few previous studies, and used manual wheelchairs on a regular basis, with participant 2 mainly propelling himself backwards. Participant 4 was unable to propel herself in her manual wheelchair and required total assistance to complete activities of daily living according to her assessment. Participant 5 used a walker and was highly mobile, but tended to wander because of the memory deficits and high disorientation found in her cognitive assessment. She completed all sixteen runs with the same starting orientation (facing the entrance of the maze), since any other orientation was found to increase her anxiety. Participant 6 used a walker and was able to navigate around the facility independently. She had left-right confusion, and was thus provided with markers on her hands to help her in identifying directions. Refer to Table 1 for information on each participant's age, gender and level of cognitive impairment.

5. RESULTS

In this paper, we report on the primary outcomes: number of frontal collisions and length of the route traveled. Although we do not report on the time taken here, we summarize related observations in the discussion.

5.1 Collision Avoidance

Figure 5 shows the number of collisions for all participants. Regardless of ordering, we can see that the total number of collisions for all participants is lower with the system (phase B). Participants 1 and 6 benefited the most from the collision avoidance system. While most participants did not show any learning trends, participant 2 demonstrated learning effects, as seen in Figure 5. The overall performance of each participant per phase can be summarized by the mean number of collisions as shown in Table 2. The mean number of collisions is lower with the system for all participants.

Table 2. Collision Avoidance Performance

ID	Mean Number of Collisions	
	Phase A (8 runs)	Phase B (8 runs)
1	8	1.38
2	1.13	0
3	0.13	0
4	0.25	0.13
5	0.5	0.13
6	3.13	0.25

Table 3. Wayfinding Performance

ID	Mean Length of Route Taken (in metres)	
	Phase A (8 runs)	Phase B (8 runs)
1	18.21	11.31
2	11.31	11.31
3	13.92	11.31
4	11.68	11.31
5	18.91	11.94
6	11.31	11.31

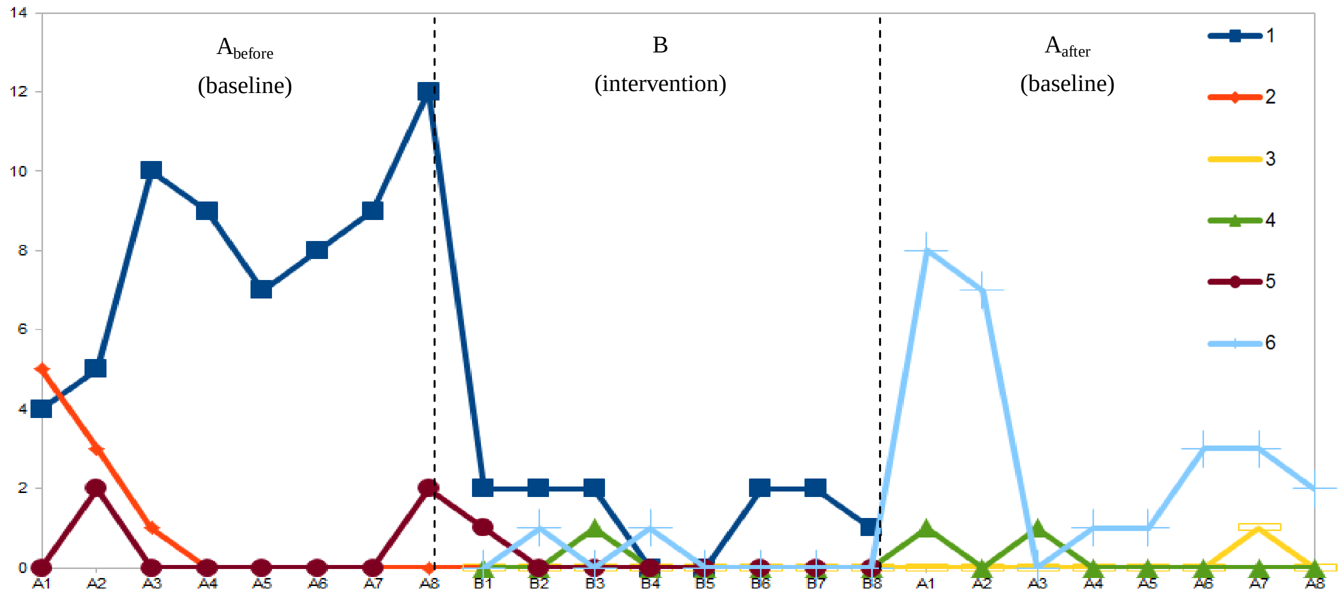

Figure 5. Number of collisions for each participant. Note that participants 1, 2 and 5 have A-B (A_{before} and B) phase ordering, while participants 3, 4 and 6 have B-A (B and A_{after}) ordering, where A is the baseline phase and B is with the system activated.

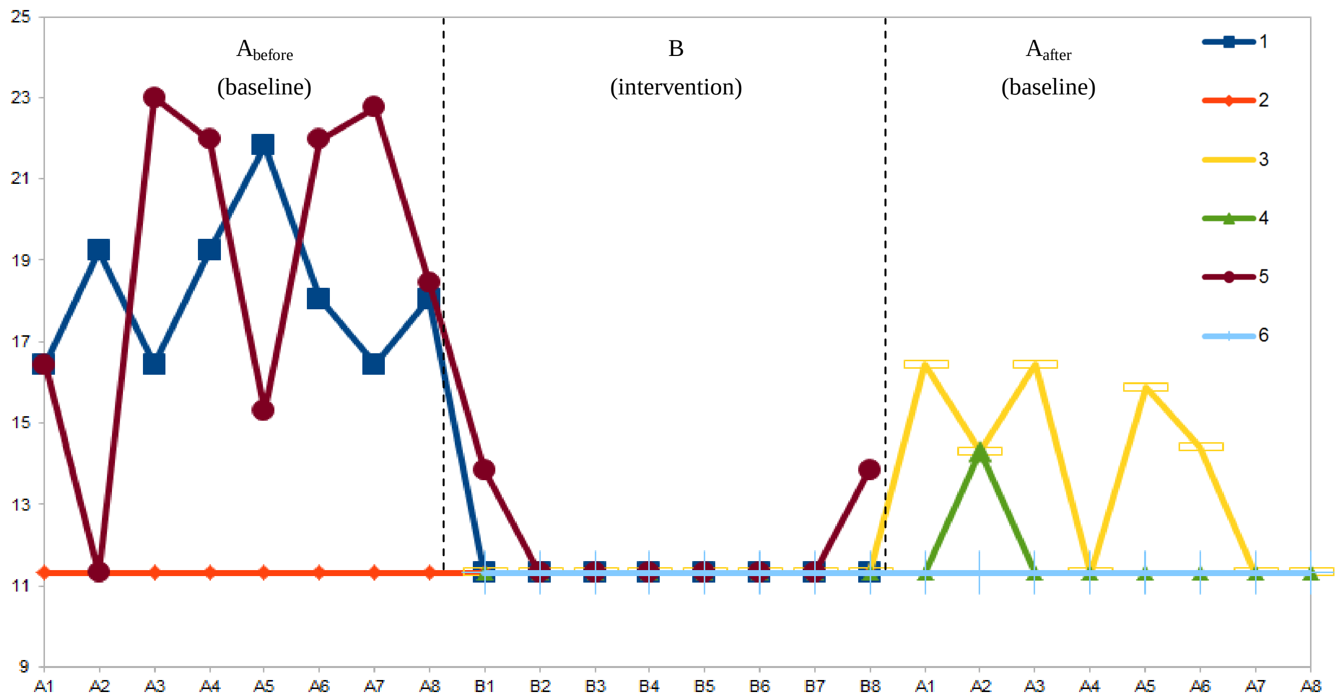

Figure 6. Length of route taken (in metres) for each participant. Note that participants 1, 2 and 5 have A-B (A_{before} and B) phase ordering, while participants 3, 4 and 6 have B-A (B and A_{after}) ordering, where A is the baseline phase and B is with the system activated (intervention phase).

5.2 Wayfinding Assistance

Figure 6 shows the length of the route traveled by all participants. Participants 1 and 3 traveled along the optimal route when the system was engaged, but often traveled longer distances without the system since they had short-term memory impairments that prevented them from learning the shortest route. Participant 5 also traveled along the optimal route more often in the intervention phase, however she traveled slightly longer distances in her first and last run during the intervention phases due to a delayed prompt, which resulted in a missed turn. The system was able to redirect her to the destination subsequently. While the other participants did not benefit greatly from this module, the system did not hurt their performance either. Participants 2 and 6 followed the optimal route in every run in both phases. Participant 4 deviated from the optimal route in one of her baseline runs due to temporary disorientation, thus traveling a longer distance. Table 3 shows the mean distances of the routes traveled by all participants.

5.3 User Surveys

We collected qualitative feedback using the NASA-TLX, the QUEST 2.0, and a custom questionnaire regarding the device and task loads. These surveys included simple Likert-scale questions, which have been used successfully with older adults with cognitive impairments in order to provide useful and valid self-reported information, such as level of pain [23] and quality of life [24-27]. Because of space constraints, we focus here on four main areas: collision avoidance, concerns with powered wheelchair use, overall satisfaction with the system, and attitudes towards autonomy.

5.3.1 Collision Avoidance

Participants 3, 4 and 5 did not feel that they required a collision avoidance system. This could be due to the fact that they had high baseline driving abilities. In addition, the test environment was static and was free of safety hazards (such as sharp and hard objects), thus possibly reducing anxiety and fear of collisions. Participant 2, on the other hand, felt that he really needed a collision avoidance system and did not trust himself to drive without colliding into obstacles. Due to his tendency to push himself backwards in his manual wheelchair, he often had minor collisions in the long-term care facility, thus possibly making him more concerned about safety. Participant 6 also shared a high level of anxiety regarding collisions, and wanted a collision avoidance system. Although participant 1 could not answer any of the custom survey questions, she expressed a fear of collisions. She slowly overcame this fear during the baseline phase through repeated trials, however, she reported lower levels of anxiety and higher levels of performance in the NASA-TLX survey when the system was in use.

5.3.2 Concerns with Powered Wheelchair Use

When asked about what the participants liked least about the wheelchair system, most responses were found to be hardware-related (relating to the commercial wheelchair) rather than software-related. Some participants expressed that they did not like the need to charge batteries. While participants 2 and 3 wanted to be able to drive faster, participants 1, 4 and 5 were satisfied with the speed, and participant 6 wanted the chair to be slowed down. Participants 2 and 4 found the chair to be bulky and preferred a smaller and lower chair, while participant 3 preferred a bigger chair.

5.3.3 Overall Satisfaction

When asked about the effectiveness of the collision avoidance and wayfinding system, most participants were quite satisfied, with participants 2 and 4 stating, "it seems to be doing what it's supposed to be doing". Participant 3 liked the just-in-time method of prompting, and said that he was happy to receive directions and assistance as long as it was not excessive and distracting. When asked whether they would use the wheelchair if it was available to them, participants 2 and 4 said they definitely would. Participant 4 was the most interested in the wheelchair since she felt "[she] would go to all the places [she] couldn't currently go to" on her own. Participants 3 and 5 felt that they did not need a powered wheelchair since they felt they were able to fulfill their mobility needs with their own mobility devices. Participant 3 did, however, mention that he would be interested in a powered wheelchair if it gave him the ability to navigate significantly faster. Although participant 6 was found to be quite mobile with her walker, she said she would like to be able to use the wheelchair when she was too tired to walk. Participant 1 could not communicate her responses, however we noticed high levels of enthusiasm (due to increased performance and shorter driving times leading to lower fatigue) when the system was activated. Without the system, the participant traveled longer distances for greater amounts of time, and often needed to be motivated to complete the task. With the system, she was able to independently follow prompts, and often asked for "more!" when she reached her destination, suggesting greater satisfaction.

5.3.4 Autonomy

We solicited feedback to gain insight on participants' reactions to a completely autonomous wheelchair that would take them to their desired locations. Participant 5 emphatically stated, "I want to be in control!". Due to her high levels of anxiety, it is highly likely that an autonomous system would frustrate her. However, her willingness to follow instructions suggests that a prompting system that allows her to make her own decisions (such as the system described in this paper) is well-suited to her needs and cognitive abilities. Participants 2, 4 and 6 said they would like to use an autonomous chair as long as it functioned correctly, thus suggesting that high system reliability is a crucial requirement of an autonomous wheelchair. Participant 3 was open to using an autonomous wheelchair, but preferred to be in control, only receiving assistance when required. We could not gain any feedback from participant 1 on this topic. It is interesting to note that participants with higher levels of confusion due to memory impairment (3 and 5) expressed a higher need to be in control, while participants who were not confused were more willing to give up control. Further studies with the target population would help us determine whether these observations generalize to other older adults with cognitive impairment.

6. DISCUSSION

The results in this study indicate that users with dementia have varying functional abilities. Users with short-term memory deficits but high (observed) visuo-spatial awareness often possessed sufficient planning abilities to be able to maneuver around obstacles; however they could not remember the optimal route to the goal. Participant 3 learnt, over time, what he was looking for (the stop sign) and was able to reach the destination on his own by exploring the maze, although the system helped him navigate along the shortest path more often. Participants 1 and 5, on the other hand, needed constant reminders about the purpose of the task and often retraced their paths in the same run. Interestingly, when the system was not used, participant 5 viewed the task as simply a driving task with no time constraint. She often asked questions such as "Where am I going?". However, interview responses indicated that when the system was in use, she viewed the task as "trying to get from one room to another". She did not seem to benefit from the collision avoidance module since her baseline driving ability was quite high. Participant 1 also did not show any signs of learning the optimal route because of her memory and visual impairments. Since she could not see obstacles clearly, she benefited from both the collision avoidance and wayfinding modules. Participant 4 usually had excellent memory and high maneuverability skills. However, on rare occasions, she was found to experience temporary disorientation and deviate from the optimal route.

Participants 2 and 6 were found to have excellent memory, but had more collisions than most of the other participants. It is unclear whether this was due to low visuo-spatial awareness, delayed reaction times, or impatience. It is important to consider that the foam obstacles might not have been perceived as dangerous by the participants, possibly making the participants more likely to drive through them. However, it is difficult to conduct a study with real obstacles because of safety concerns.

The above discussion indicates that the abilities of collision avoidance and wayfinding might be independent. Main predictors of success in these two tasks might be short-term memory and visuo-spatial awareness. The POMDP could be extended to include these predictors as different variables that lead to distinct user behaviors. For example, the model could specify that users with low visuo-spatial awareness are more likely to collide with obstacles, thus needing additional prompts that identify free space and obstacles. Users with poor short-term memory are more likely to deviate from the optimal route and need directions, while those who are able to learn the route might simply require task reminders (e.g., “Find the stop sign”).

In addition, some participants required justification for the stopping action of the wheelchair and were frustrated by the blocked wheelchair motions. Participant 3 commented during a trial “it's not going where I'm telling it to go”. Participant 4 said the wheelchair was more “regulated” when the system was activated, and that, in contrast, the wheelchair was more “responsive” when the system was deactivated. Although she did not feel that the collision avoidance module harmed her, she did not perceive it as a necessity and appreciated being told why the wheelchair was being stopped. The stopping action was, in general, found to be confusing for some participants and was found to increase the time taken to complete the course in some cases.

We also found differing levels of responsiveness to prompts. Participant 5 constantly relied on instructions from caregivers to perform day-to-day tasks, and her compliance with the prompting system was found to be quite high. Participant 1 was mostly compliant with the system, and often responded “yeah” when she heard a prompt, as she tried to follow it. However, when the system seemed to guide her towards an obstacle hidden from the camera's view, she said “no sense!”, showing that she did not agree with the system, and correctly disobeyed. Participant 3 seemed to wait for and comply with the prompts when he was unsure of which direction to navigate in, but was found to correctly ignore incorrect prompts when he was confident of which direction the destination was in. Most errors in prompting occurred towards the end of the run, due to accumulated localization errors, thus suggesting the need for re-initialization of position estimates based on pre-registered landmarks. Alternatively, wheel encoders or inertial measurement units could be added to provide additional information on distance traveled and to increase localization accuracy. Although the isolated prompting errors did not seem to frustrate users during the study, we anticipate that reducing these errors will help increase user satisfaction.

Although we showed that the distances traveled were longer for some participants when the system was not used, it is important to note that the longer distances reported were specific to the maze constructed for this study in a limited amount of space. One can see that in a more realistic environment, even a single deviation from the optimal route can lead to arbitrarily longer routes depending on the floor layout. Thus, the effectiveness of the system in guiding the participants along the optimal route can lead to increased timeliness, and, more importantly, decreased fatigue, which is a major factor in wheelchair use.

7. FUTURE WORK

In the future, we hope to test alternative methods of collision avoidance such as automatic correction of wheelchair heading, moving the user away from the obstacle. This could help reduce stop times and thus ensure faster navigation to the goal. Another possible area of future work is haptic and/or visual feedback to provide more useful information on what the correct user behavior should be in a collision event. We will also investigate increasing computational speed of the collision avoidance and wayfinding modules in order to allow participants to navigate faster, while maintaining high system accuracy.

We plan on modifying/expanding the user model to incorporate the results found in this study. For example, the likelihood that a driver needs detailed collision avoidance prompts is higher if he/she has low visuo-spatial awareness. However, someone with poor memory and high visuo-spatial awareness might only require wayfinding assistance. Also, users with left-right confusion might require added visual prompts.

Finally, we would like to improve localization accuracy and test the system in a more realistic environment to help users navigate to real locations in the long-term care facility. Through this study, we hope to evaluate the effects of the system on their day-to-day mobility and social well-being.

8. CONCLUSIONS

Very few intelligent wheelchair studies have been conducted with older adults with cognitive impairment. We hope that this study provides key insights on the benefits of intelligent wheelchairs to the target population. We have shown quantitative evidence that such a wheelchair could allow safe and independent mobility for cognitively-impaired older adults. Our system is able to lower the total number of frontal collisions and help users in navigating along the shortest route to the specified goal. We found that users with short-term memory and/or vision impairments benefited most from the system. We hope that continued development and testing of the system will help refine user needs and allow us to create an intelligent wheelchair that truly improves quality of life of older adults with cognitive impairment.

9. ACKNOWLEDGMENTS

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