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Adaptive Navigation Assistance for Visually-Impaired Wheelchair Users

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INTRODUCTION

It is estimated that approximately 10% of people who are legally blind require wheelchairs [1]. Wheelchair users with visual impairments face difficulties in avoiding obstacles as well as identifying visual cues in the environment, thus making independent navigation challenging, and in some cases, impossible. The authors in [1] suggest that intelligent wheelchairs capable of collision avoidance and path planning would greatly benefit wheelchair users with visual impairment. Although several intelligent wheelchairs have been developed recently [2-4], these wheelchairs navigate autonomously, thus taking control away from the user. On the other hand, wheelchairs that only provide collision avoidance support [5] are not appropriate for drivers who are unable to determine their location and want to navigate to a specific location. We thus present a novel, real-time, vision-based intelligent wheelchair system that avoids collisions and provides adaptive audio prompts to help blindfolded users navigate to specified destinations. Existing intelligent wheelchairs have used various active sensors (acoustic, sonar, infrared, laser, etc.) [6]. We rely solely on a stereovision camera due to its low power consumption, ability to perform in natural environments, and relatively low cost. 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 techniques we can achieve accurate localization, while reducing/eliminating the need for environment modifications. 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.

MATERIALS AND METHODS

The intelligent wheelchair system consists of a Nimble Rocket™ wheelchair, a 4mm Bumblebee® 3D stereovision camera, and a laptop computer placed under the wheelchair seat. The wheelchair consists of a customized controller, which sends signals from the laptop to the wheelchair, enabling/disabling motion of the wheelchair in specific directions. The modules below are integrated using the Robot Operating System provided by Willow Garage (http://www.willowgarage.com), which allows us to run multiple processes in a distributed fashion:

- *Collision Detector* - detects frontal collisions and stops the wheelchair if an object is detected within a distance of approximately 1 meter, preventing motion in the direction of the obstacle through the controller. Implementation details of this module can be found in [5].
- *Path Planner* – given a global map of the environment and an initial position estimate, visual odometry is used to estimate the current position of the wheelchair using [7]. Techniques in [8] are used to produce the optimal route to the specified goal location. The trajectory is analyzed to determine deviations from the optimal route as well as upcoming turns.
- *Prompter* – uses a Partially Observable Markov Decision Process (POMDP) to determine the optimal prompting strategy, similar to [9]. Specifically, this module estimates the users' levels of awareness (their ability to navigate to the goal independently) based on past errors, and responsiveness to prompts in order to select appropriate audio prompts to assist the users in navigation.

In order to test the system, we recruited four able-bodied participants with no previous wheelchair driving experience. They were shown a route in a realistic environment and required to navigate a powered wheelchair to the destination while blindfolded. The experiment consisted of two distinct phases, A and B. Phase A was conducted without the collision avoidance and navigation system (baseline), while the system was activated in Phase B. In order to ensure a balanced study, half (two) of the participants were randomly selected for A-B, and the remaining participants were assigned B-A ordering. The primary outcomes measured were number of frontal collisions, number of turns successfully completed (the route consisted of three turns in total), and maximum progress made towards the goal (determined by measuring the shortest distance to the farthest point along the optimal route reached by the user, and expressing it as a percentage of the total (shortest) distance to the goal).

RESULTS AND DISCUSSION

Table 1 shows the results of the primary outcomes measured for each participant. Participants 1 and 3 completed B-A ordering, while participants 2 and 4 completed A-B ordering.

Table 1. Primary outcomes for each participant

Participant ID	Phase A (baseline)			Phase B (intervention)		
	Collisions	Turns	Progress	Collisions	Turns	Progress
1	3	2	44.0%	0	3	100.0%
2	3	0	15.4%	0	3	100.0%
3	2	3	100.0%	0	3	100.0%
4	2	2	48.3%	0	3	100.0%

As seen above, the number of frontal collisions is lower when the system is activated, regardless of the phase ordering. In addition, the number of turns completed and progress made towards the goal is greater with the navigation system in most cases. Participants 1, 2 and 4 were unable to reach the destination without the system and stopped driving due to high levels of anxiety and confusion in the baseline Phase A. All participants completed the navigation task during the intervention Phase B and expressed a strong preference for the system due to higher safety and lower mental demand/stress.

Only a few false positive collisions were detected during the experiments due to glare from one of the windows in the test environment, suggesting the need for window detection in future prototypes.
We acknowledge that users with real vision impairments might perform differently from blindfolded users. However, we anticipate that our system can still benefit newly-impaired users. Preliminary trials of the system with users with dementia show that the system described in this paper is able to benefit cognitively-impaired drivers as well [10].

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