Shared Control Policies for Safe Wheelchair Navigation of Elderly Adults with Cognitive and Mobility Impairment

Designing a Wizard of Oz Study

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Why A Smart Wheelchair?

• Aging population
• Quality of life depends on mobility (Bourret et al. 2002)
• Older adults often lack strength for manual wheelchair (WC) use
• Mobility impairments in older adults often accompanied by co-morbidities (dementia, blindness, ...)
  – There were about 35.6 million people in the world living with dementia in 2010 - approximately 65.7 million by 2030 (World Alzheimer Report, 2009)
  – Of 1.5 million nursing homes residents, 60-80% have dementia (Marcantonio 2000)
  – Prohibited from using powered wheelchairs due to safety concerns (Hardy 2004)
  – Reduced mobility leads to social isolation, depression and increased dependence on caregivers (Iezzoni et al. 2001)
Why Now?

• Many intelligent wheelchair projects in the past
  – For example, PLAYBOT, Wheelesley, NavChair, MAid, OMNI, PALMA
  – Many target populations
  – Excellent review article [Simpson, JRRD 2005]

• Improvements in sensor systems
  – Lower cost, better accuracy, lower power, smaller size
• Improvement in computing power
• Improvements in robotic autonomy
• The right team
  – Access to experts in robotics and wheeled mobility research
  – Trainees willing to bridge the gap
The CanWheel Team

- Founded under six year emerging team grant from CIHR
  - 15+ researchers from 6+ universities across Canada
- Guiding Questions:
  - How are power wheelchairs used now?
  - How can power wheelchairs be used better?
  - How can power wheelchairs be better?
- Five core projects:
  - Evaluating needs & experiences
  - Measurement of mobility outcomes
  - Wheelchair innovation
  - Data logging
  - Wheelchair skills program for powered mobility

www.canwheel.ca
Our Goals

• Cognitively (and mobility) impaired older adults in long term care (LTC) facilities
  – Heterogenous population
  – Constrained but navigable environment

• Shared control
  – Autonomous navigation (with supervisory control) can cause confusion or agitation in this population

• Assistance with multiple objectives
  – Short term: Collision avoidance
  – Medium term: Wayfinding

• Low cost sensors

• User trials with target population

• Reproducible research
Motivation & Key Informant: NOAH

• Navigation & Obstacle Avoidance Help
• Slightly modified PWC
  – Motion can be disabled in three forward directions
• Bumblebee stereo vision camera plus laptop (under the seat)
• Collision avoidance: stop if an obstacle is detected in that direction
• Wayfinding: POMDP driven audio prompts based on heading relative to optimal path to goal
NOAH Efficacy Study

- Styrofoam maze created in basement of LTC facility

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

- Six adults 66–97 years old in LTC with mild to moderate cognitive impairment and not allowed to use PWC
  - Single subject design, half with A-B and half with B-A ordering, eight trials each
  - System reduces frontal collisions for all participants
- More data and analysis in [Viswanathan, 2012]
NOAH Conclusions

• Stopping motion was frustrating for the users
  – Feedback only through audio instructions
  – Motion was blocked conservatively
  – Increased task completion time for participants who were already good at collision avoidance

• Missed collisions
  – Narrow field of view leads to incomplete sensor coverage
  – Styrofoam obstacles reduced fear of collision

• Effective wayfinding assistance is challenging
  – Requires accurate localization and user state estimation

• Counter-intuitive(?) participant desires
  – Participants with higher levels of anxiety and/or confusion wanted to maintain more direct control of motion

• Also [Viswanathan et al & Wang et al, RESNA 2013]
Wizard of Oz

• Earlier prototypes not tested until fully functional
  – Users had no opportunity to provide early feedback
• Earlier semi-structured interviews lacked context
  – Participants (and even interviewers) lacked common vocabulary for and understanding of technology
• Wizard of Oz study allows testing of the user interface without fully developed system
  – Hidden researcher controls the wheelchair to simulate an intelligent wheelchair in varying modes
  – Collect qualitative and quantitative data to obtain user feedback and inform continuing design work
  – Release anonymized sensor data so the rest of the community can see a robot's view of LTC facilities and elderly adult drivers
Driving Assessments

• Subset of Power-mobility Indoor Driving Assessment

Elevator

Docking under Table

Back-in Parking

Manoeuverability

Hallway
Our PWC

• Modified Quickie base
  – AT Sciences provided a CANBus interface to intercept the joystick signals and read odometry
  – Power tilt and adjustable width seat added in-house
  – Seating adjustments for every participant

• ROS-based control system
  – Blends wheelchair's joystick and wizard's PS3 controller signal

• Lots of sensors recorded into ROS bags
  – Data not used during trials

RGBD camera (front facing)
RGBD camera (back facing)
face webcam
wheelchair joystick
galvanic skin response sensor
Wiimote (accelerometer)
odometers
laser rangefinder
Shared Control Modes

• Speed control:
  – Ideally: stretch time to collision
  – WoZ: slow if obstacle less than 2 feet away, stop if less than 1 foot, but resume at very slow ("docking") speed
  – Vibration in joystick if user signal is being clipped

• Heading (plus speed) control:
  – Ideally: bring PWC back onto desired path if it gets too close to a (stationary) obstacle
  – WoZ: assume full control if obstacle is less than 1 foot away and maintain control until obstacle is roughly 2 feet away
  – Vibration if the wizard has assumed control
  – Wizard generated audio prompting to get back on path

• Fully autonomous control:
  – Ideally and WoZ: PWC drives itself to accomplish the PIDA task (participant may deflect joystick to stop motion)
Example

- Lab data using young, healthy participant
- Task: parking at a table
- Occupancy grid used only for visualizing path
  - Wizard provides obstacle detection
  - Path estimated by dead reckoning based on odometry
Policy 1: Speed Control

- Speed limit in effect for time intervals [27, 46] and [52, 70]
Policy 2: Heading & Speed Control

- Wizard intervenes during time intervals [16, 21] and [32, 39]
- Also speed limit in effect throughout

Polar Joystick Coordinates

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Ian Mitchell (UBC Computer Science)
Teleoperator's Interface

- semi-autonomous back-in parking video
The Study

• 10 Participants at 3 LTC facilities in Vancouver
• About 14 hours / participant spread over two weeks
  – Pre-study assessments and data collection (2 hours)
  – Pre- and post-driving semi-structured interviews (3 hours)
  – 5+ driving sessions (9 hours) comprising three repetitions of each policy in each task (45 trials) + interviews
  – Months of prep, three months of trials and ongoing analysis

• Preliminary Findings
  – Control policy preference varies across participants & tasks
  – Participants prefer autonomous mode for back-in parking
  – Resumption of participant control is challenging
  – Issues and conflict around trust and control

• Sensor data post-processing for public release is underway!
Related Work: Controls

• Highly trained operators and/or high degrees of freedom
  – Autopilot modes [eg: Matni & Oishi, ACC 2008]

• Driver assistance systems
  – Haptic feedback vs "drive by wire" experiments [Katzourakis et al, IEEE TSMC 2013]
  – Steering control replacement determined from hybrid automaton & composite quadratic Lyapunov function [Enache et al, IEEE ITS 2010]
  – Steering & braking control addition determined from MPC [Gray et al, IEEE ITS 2013]

• Humans-in-the-loop sessions I & II, ACC 2013
Related Work: Smart WCs

• Survey article [Simpson, JRRD 2005]
  – Few systems tested on target populations

• Supervisory / switched control
  – Children: [Ceres et al, IEEE EMBM 2005; McGarry et al, Disability & Rehab: AT 2012]

• Shared control: various ways of blending continuous control signals
  – Mobility: [Carlson & Demiris, IEEE TSMC 2012]
  – Older adult mobility: [Li et al, ICRA 2011]
  – Mobility + CP or TBI: [Zeng et al, IEEE TNRE 2008]
  – Older adult mobility + dementia: [Urdiales et al, Autonomous Robots, 2011]
What to Call It?

• We wish to combine real-time and typically continuous signals from multiple agents
  – For smart WC, agents are the driver and the automation
• Not supervisory control
  – Where one agent provides high-level and typically discrete guidance to a second agent
• Not switched control
  – Where multiple agents take turns generating a control signal
• Not collaborative or cooperative control
  – Most commonly used for coordinated control of multiple physical entities each with its own agent
• Human in the loop?
  – Is the human part of the controller or the plant?
Conclusions

• Smart PWCs for cognitively impaired older adults in LTC
  – Fully autonomous motion is not the problem
• Shared control is desirable
  – Desired degree of assistance depends on driver, task and environment
• User trials with target population are critical
  – They are a lot of effort
• Full sensor coverage is challenging
  – Aesthetics, robustness and cost are significant factors
• Risk assessment formulas are unclear
  – Need a formula compatible with human intuition

• Plan to release your code and data
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