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

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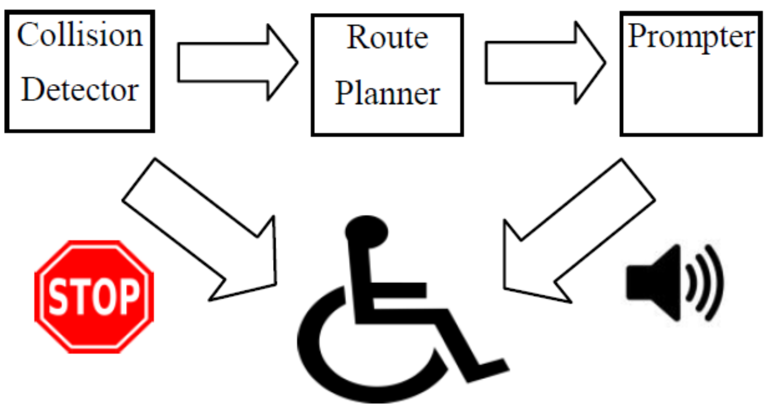
CANWHEEL

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



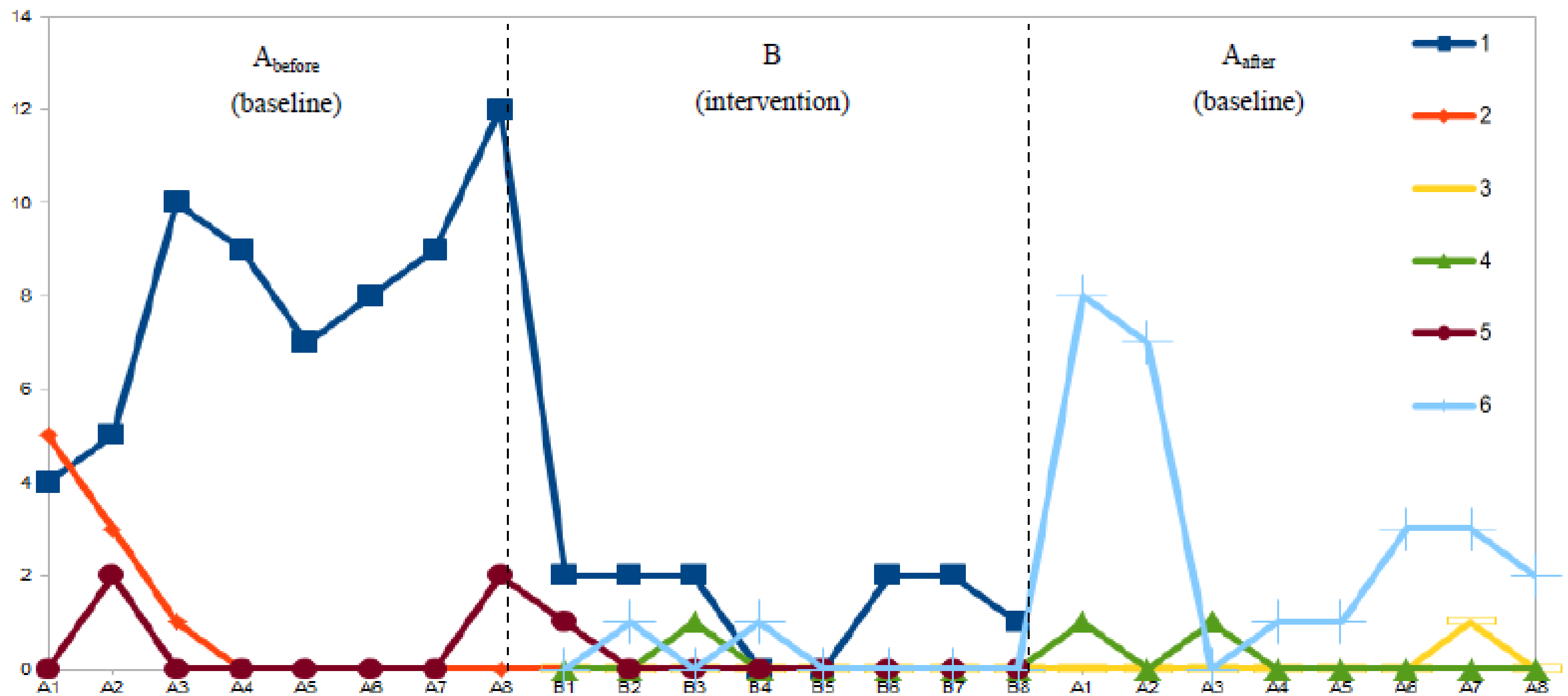
NOAH Efficacy Study

- 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]

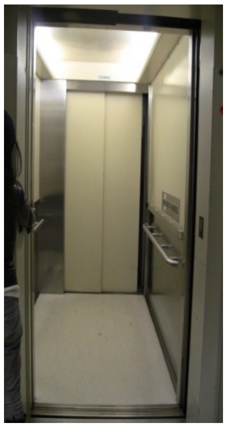
Wizard of Oz

- 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

The Wizard [Baum, 1900]

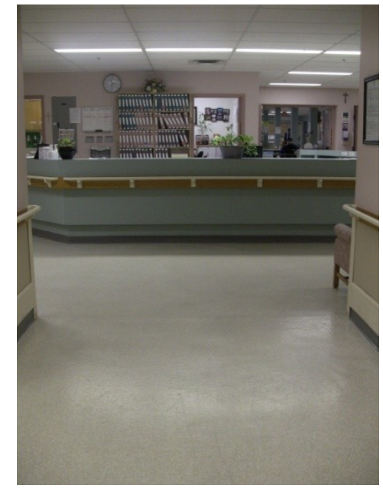
Driving Assessments

- Subset of Power-mobility Indoor Driving Assessment



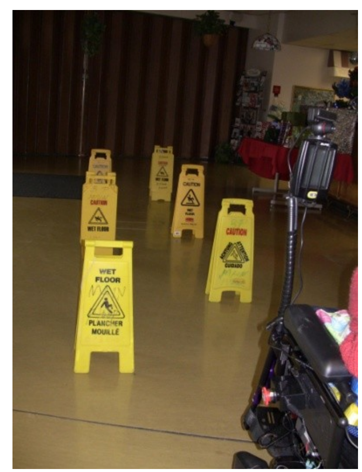
Elevator

Docking under Table



Hallway

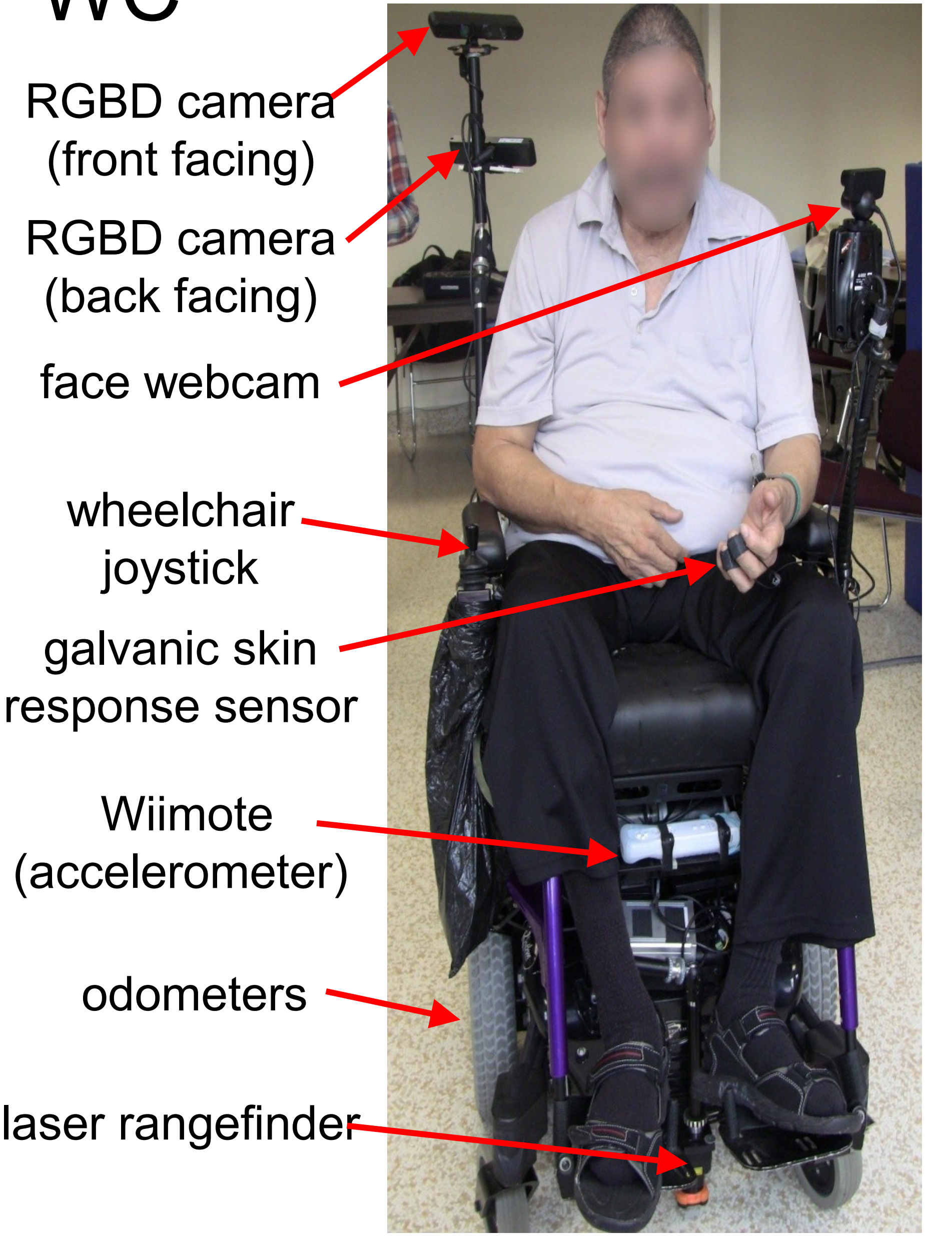
Back-in Parking



Manoeuverability

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

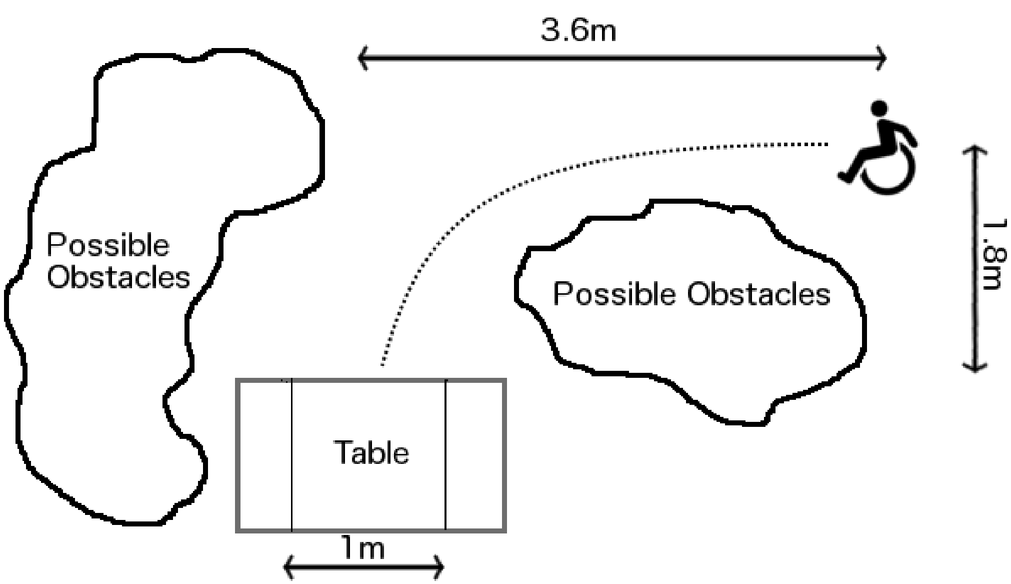


Shared Control Modes

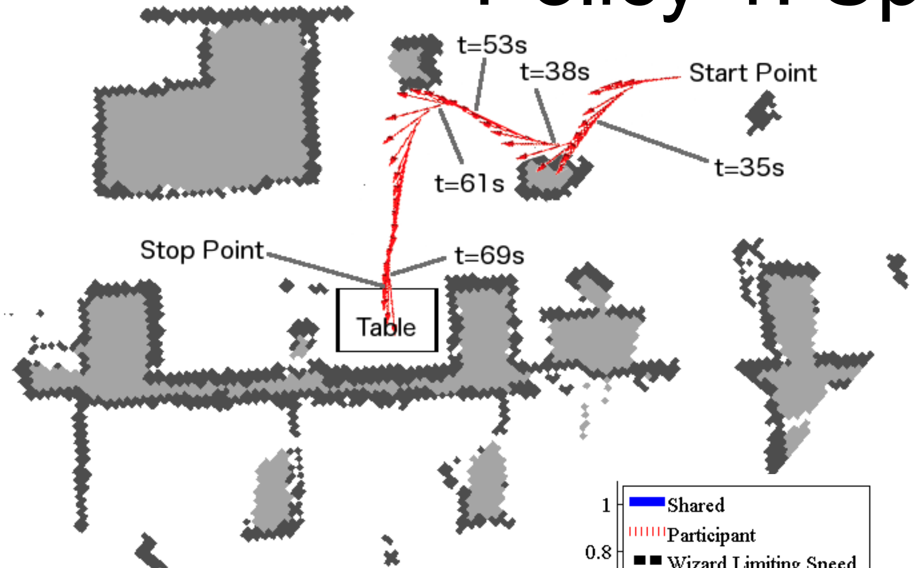
- Speed control:
  - Ideally: stretch time to collision
  - WoZ: slow if obstacle less than 2 feet away, stop if less than 1 foot, but resume at very slow ("docking") speed
  - Vibration in joystick if user signal is being clipped
- Heading (plus speed) control:
  - Ideally: bring PWC back onto desired 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

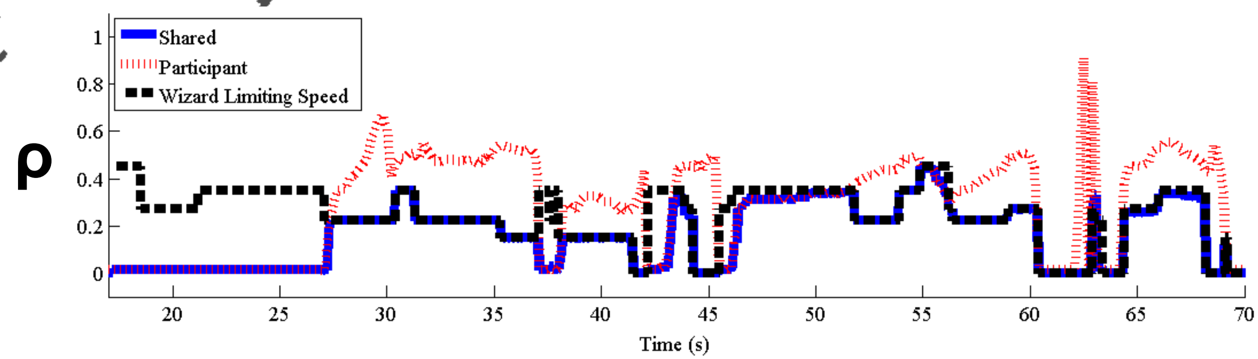
- Lab data using young, healthy participant
- Task: parking at a table
- Occupancy grid used only for visualizing path
  - Wizard provides obstacle detection
  - Path estimated by dead reckoning based on odometry

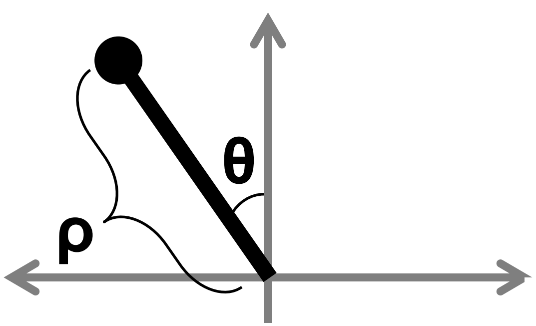


Policy 1: Speed Control

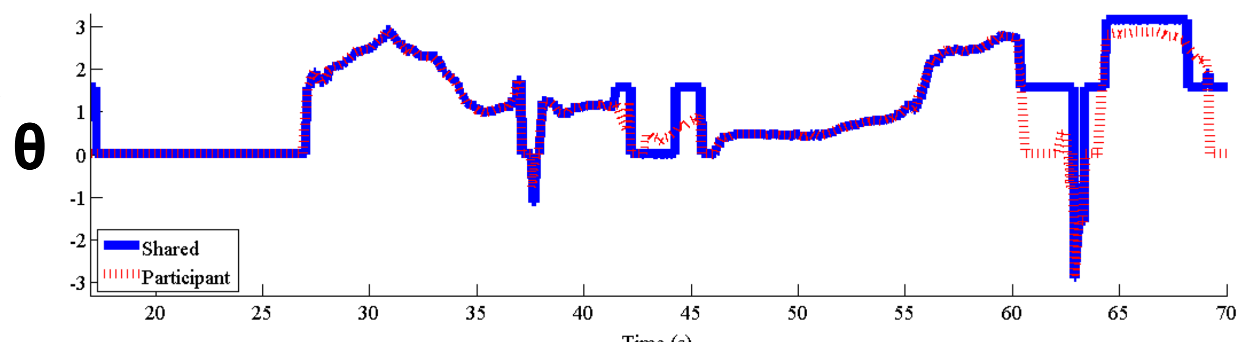


- Speed limit in effect for time intervals [27, 46] and [52, 70]

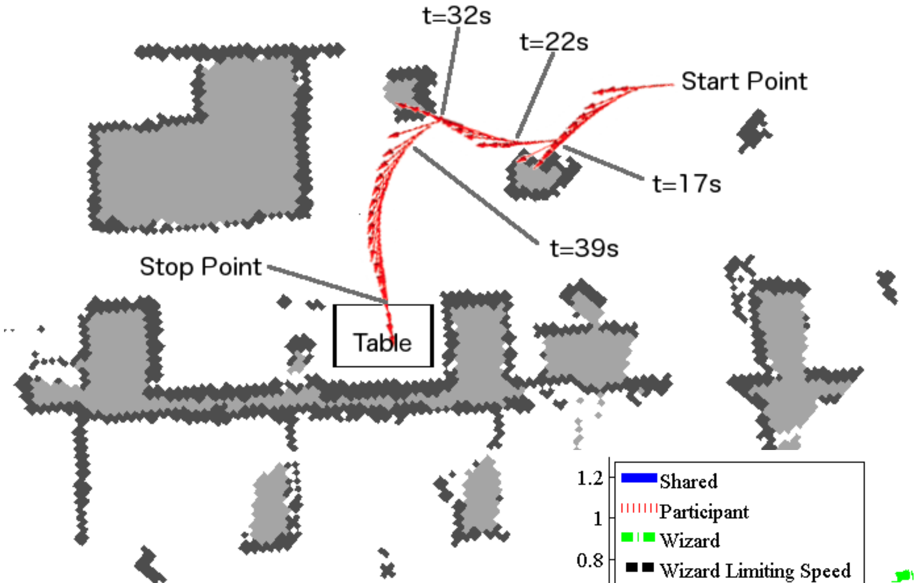




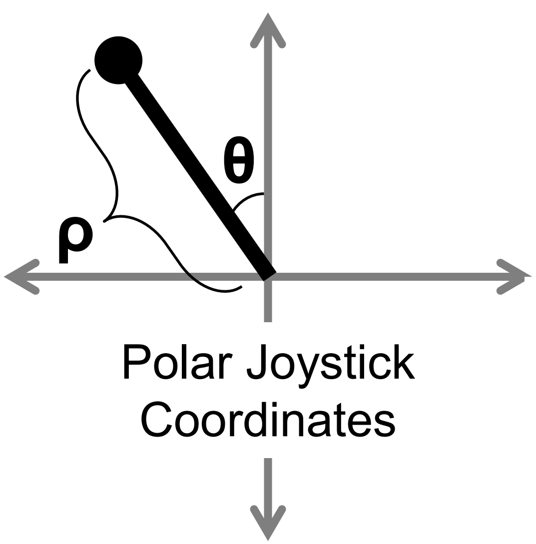
Polar Joystick Coordinates



Policy 2: Heading & Speed Control



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



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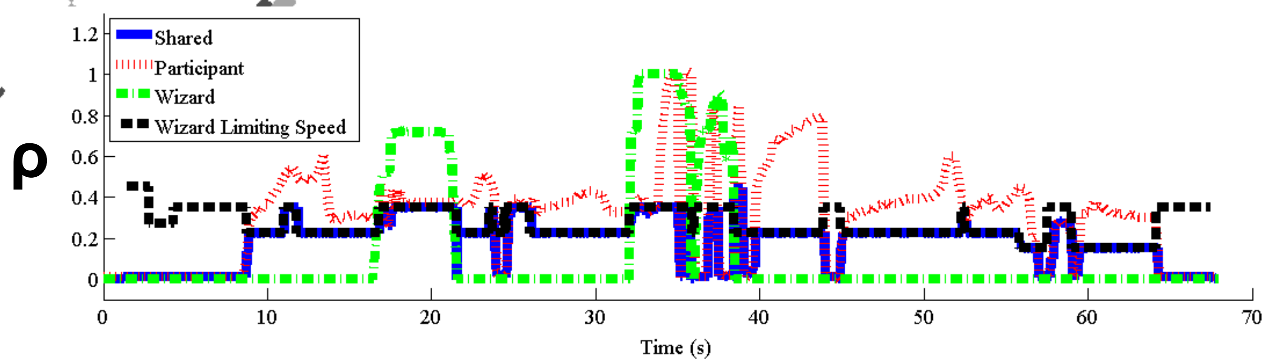
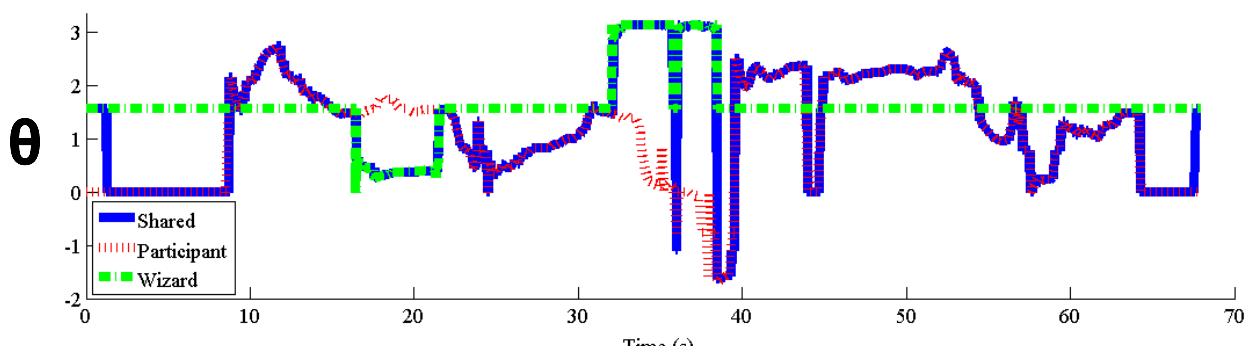
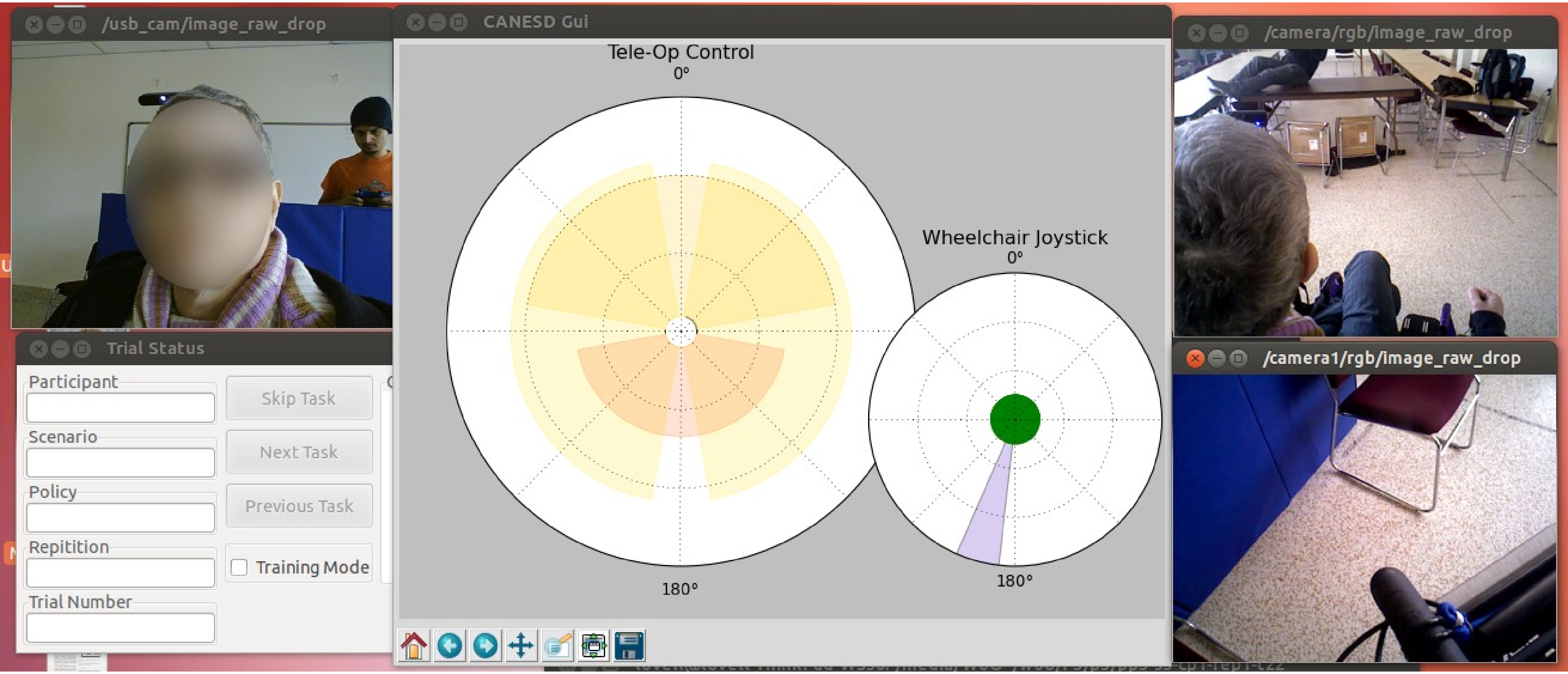




Teleoperator's Interface

- 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
  - Surgical virtual fixtures [eg: Yamamoto et al, Int. J. Medical Robotics & Computer Assisted Surgery, 2012]
  - 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]
  - Vibration alerts [de Groot et al, Human Factors 2011; Chun et al, Int. J. Industrial Ergonomics 2012]
- 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
  - Dementia: [Wang et al, AT 2011; How et al, JNR 2013]
  - 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

Acknowledgements

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  - Pouria TalebiFard for help with WC, ROS and testing
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