Collaboratively Controlled Intelligent Robotic Wheelchairs: Capabilities and User Interfaces

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Why Smart Wheelchairs?

• 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 eg: dementia
  – 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)
Workshop Outline

• Introduction to Supporters & Participants
• Concepts, Goals and Approaches
• Example Projects and Outcomes
• Further Discussion

ASK QUESTIONS ANYTIME!
• Interdisciplinary team of 14+ researchers (mostly mobility specialists) at 6+ universities across Canada

• Created by Emerging Team Grant (2009–2015) from the Institute of Aging of the Canadian Institutes of Health Research (CIHR)

• Team seeks to address three basic questions:
  – How are power wheelchairs used now?
  – How can power wheelchairs be used better?
  – How can power wheelchairs be better?
Workshop Participants

• Ian M. Mitchell
  – Associate professor of Computer Science (UBC)
  – Engineering, computer science, robotics and math training

• Pooja Viswanathan
  – Postdoctoral researcher in Intelligent Assistive Technology and Systems Lab, Dept. Occupational Science & Occupational Therapy (Toronto) and Toronto Rehab Institute
  – Computer science training

• Rosalie Wang
  – Postdoctoral researcher in Intelligent Assistive Technology and Systems Lab, Dept. Occupational Science & Occupational Therapy (Toronto) and Toronto Rehab Institute
  – Occupational therapy training

• Who are you?
Intelligent / Smart Wheelchairs (WCs)

• Assistive technology for users with mobility plus motor control, sensory, or cognitive issues

• 50+ intelligent wheelchairs all over the world
  – PLAYBOT, NavChair, Wheelesley, Maid, OMNI, PALMA , ...
  – Simpson 2005 review

• Various sensors, assistive functionality and control strategies used
Concepts – Definitions & Examples

• Collision / Obstacle Avoidance

• Wayfinding

• Sensors

• User Interfaces

• Control Strategies
Collision / Obstacle Avoidance

- Keep the WC from approaching / touching / damaging nearby objects
  - Local environment includes moving obstacles

- Most common goal for intelligent WCs
  - For example, bumper skirt (Wang et al. PALMA 2011), SmartWheeler platform (Honoré et al. RESNA 2010), and many others (Simpson, JRRD 2005)
  - Limited specialization to individual needs is required(?)

- Also a common goal for mobile robots
  - For example, dynamic window approach (Fox, Burgard and Thrun, 1997), nearness diagram situated activity design methodology (Minguez and Montano, 2004), ...
Wayfinding

• Guide the WC to desired location
  – Locations are typically statically defined

• Common goal for intelligent WCs
  – For example: Autominder system (Pollack et al., 2002), Nursebot (Pineau et al., 2003), Assisted Cognition (Kautz et al., 2002), Wayfinding system (Liu et al., 2006)
  – Common in other AT and more generally: Guido walker (Rentschler et al., JRRD 2008), Google maps
  – Approach typically specialized to type of impairment

• Also a common goal in robotics ("path planning")
  – For example, LaValle 2006 (or any other robotics textbook)
An Intelligent Wheelchair

- User Command or Intent
- Stored Information
- Local Environment
- Computation
- Feedback to the User
- Wheelchair Motion
Sensors

• Device that provides information about the (local) environment

• Obstacle / collision avoidance: need to know location of obstacles relative to the WC

• Wayfinding: need to know location of WC relative to stored map information
Collision Avoidance Sensors

• Bumper skirts / whiskers: contact indicates obstacle
  – Cons: bulky, ugly, contact-based, easily fooled

• Sonar / infrared: Time of flight of reflected beam measures distance to obstacle
  – pros: small, cheap, low power
  – cons: active (eg: interfering), very narrow field of view, inaccurate, noisy, easily fooled

Paralax Ping))) ultrasonic rangefinder
Laser-based Rangefinders

• Time of flight of reflected laser beam measures distance to obstacles
  – Pros: long range, high accuracy, wide field of view, robust measurements
  – Cons: Expensive ($5000-$10000), not small, active (eg: interfering), high data rate, narrow beam width (although 3D models exist for $$$)

• Most common sensor solution for autonomous mobile robots
Stereo Vision-based RGB-D Cameras

• Location of features in images taken by carefully aligned cameras is compared to determine depth (works through parallax)
  – Pros: passive, produces 3D depth map
  – Cons: limited range, high data rate, heavy computational load, noisy, not small, expensive ($2000)

Point Grey Research Bumblebee
Patterned Light RGB-D Cameras

• Carefully chosen patterns are projected on the scene (in infrared); distortion and parallax in the pattern image determines depth
  – Most common example: Xbox Kinect
  – Pros: Cheap ($100), produces 3D depth map
  – Cons: limited range, noisy, active (e.g.: interfering), high data rate, narrow field of view, easily fooled
Wayfinding using Local Obstacle Map

• Match local obstacles to obstacles in a known map to determine position
  – Simultaneous Mapping And Localization (SLAM) seeks to build map at the same time
  – Pros: no need for additional sensors, good tracking performance
  – Cons: noisy (due to moving obstacles), heavy computational load, can get confused

• Commonly used by mobile robots
Position Localization Sensors

- **GPS**: Timing information from satellites
  - Pros: cheap, small, low power, not easily fooled
  - Cons: outdoors only, inaccurate, can lose signal

- **Wifi**: Signal strength from wifi access points
  - Pros: cheap, small, low power
  - Cons: inaccurate, noisy, requires learning phase
Position Localization / Tracking Sensors

• Beacons, RFIDs, QR codes: uniquely identifiable markers are placed in the environment
  – Pros: cheap, small, low power, accurate
  – Cons: requires environmental modification, limited range

• Odometry: counting wheel rotations
  – Pros: cheap, small, low power
  – Cons: highly inaccurate except over short distances, difficult to retrofit
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  – Wayfinding
  – Sensors
  – User Interfaces
  – Control Strategies

• Example Projects and Outcomes

• Further Discussion
User Interfaces

• Head-controlled (Jia et al. 2007)
  https://www.youtube.com/watch?v=ZOhNfgnmWwY

• Face and gaze (Matsumoto et al. 2001)

  https://www.youtube.com/watch?v=77KsE--Adp8
  (University of Zaragoza)
User Interfaces

• Speech recognition (Honore et al. 2010)
  – McGill voice activated videos
    • Unfortunately, these videos cannot be published because of participant privacy restrictions
Control Strategies

• Safe-guarded operation – user maintains control, wheelchair occasionally takes over to avoid imminent damage

• Autonomous control – wheelchair navigates on its own
  https://www.youtube.com/watch?v=FUgHMReg4xM

• Shared control – control switches between user and wheelchair
  – But who decides when this happens and how?
Shared Control

• MAID, NavChair, TinMan, Smartchair, Wheelesley, VAHM, etc.
  – users choose destination – wheelchair navigates autonomously
  – System might prompt user to make decisions to ensure plan is appropriate

• Thus, EITHER user in control OR wheelchair – decision triggered by EITHER user OR wheelchair

• Can user and wheelchair contribute to control simultaneously in a more collaborative way?
Collaborative Control Wheelchairs

- Intent recognition and safe mini-trajectories (Carlson and Demiris, 2008, 2012)

**Figure 6:** The steering signals sent to the motor unit are modified by the computer between 16 and 30 seconds to prevent the wheelchair from crashing into the doorframe.

**Figure 11:** The average joystick jerk of all the trials when driving through doors 1, 2 and 3. The jerk is measured as the average physical rate of change of acceleration of the joystick during the manoeuvre, in terms of a percentage of its maximum deflection range per second-cubed.
Collaborative Control Wheelchairs


Note: no collision avoidance
Collaborative Control Wheelchairs

• Efficiency-weighted strategy for continuous cooperation (Urdiales et al. 2008)

http://www.youtube.com/watch?v=04XdSZnZIqA
Learn early!

- Understand **user population** and **contexts** and understand what they may need from **wheelchair technology** before going too far in deciding specific solutions.
- Iterative design and evaluation is continuous – evaluate early prototypes.
- Cost of re-design gets exponentially larger as process goes on.
What does involving users look like?

- Designers learn from users about their needs and preferences
- Designers provide information to users about technical capabilities and what is possible
- Users provide feedback and keep designers on track
- Users and designers evaluate designs and prototypes together
# User-Centred Design (UCD)

<table>
<thead>
<tr>
<th>Data Gathering Techniques</th>
<th>Example Purposes</th>
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| Surveys, Questionnaires, Interviews, Focus groups | • Collect data related to needs and expectations of user  
• Evaluate designs and alternatives  
• Collect data related to user satisfaction and usability |
| Direct observation, Participant observation | • Collect data related to how product is used  
• Collect data on contexts in which product will be used |
| Role playing, Think aloud, Walkthroughs, Simulations, Wizard-of-oz | • Gain additional information about users’ needs and expectations  
• Evaluate prototypes  
• Evaluate alternative designs |
Preferred Approach: User-centred Design (UCD)

- Focuses on designing to meet users’ needs and involves users in design process
- Adapts design process to learn about and incorporate users in design
- Recognizes that we are NOT able to design for everyone in all cases
- May be better in some cases to design for specific subset of population
Approaches to Testing

Lab $\leftrightarrow$ Natural setting

Obstacle course $\leftrightarrow$ Real objects/environments

Surrogate users $\leftrightarrow$ Target users

One-off testing $\leftrightarrow$ Long term use

No user training $\leftrightarrow$ “Usual” training

Simulation (W-o-O) $\leftrightarrow$ Functional prototype
CanWheel Research

• Limitations of Previous Work
• Our Systems and Studies - Development and evaluation
• Recommendations for Future Work
• Ongoing Work
• Challenges
Related Work

• Several intelligent wheelchairs have been developed – e.g. PLAYBOT, Wheelesley, NavChair, MAid, OMNI, PALMA (Simpson 2005)

• Some use brain-controlled and voice recognition interfaces (Jia et al. 2007, Honore et al. 2010)

• Developed for users with various disabilities, vary in design goals and implementation approaches
Limitations of Related Work

• Many systems use autonomous **control strategies** - might confuse/frustrate users

• Small number of systems **tested** with cognitively-impaired users

• Performance and usability issues faced by our target population - poorly understood and documented
Our Research

• Target population: mild-to-moderate cognitive impairment, long-term care
• Semi-autonomous control strategy to keep user in control, while ensuring safety
• All systems have been tested with target population
• Researchers at University of British Columbia and University of Toronto, McGill University
Proposed Solution

Intelligent/modified powered wheelchair for cognitively-impaired older adults in long-term care that:

1. Improves safety (reduce collisions)
2. Ensures timely and effective navigation (e.g. audio prompts)
3. Automatically determines timing and type of prompts (by estimating user’s cognitive state)
Multi-Modal Feedback

Users:
• N=5
• Mild-to-moderate cognitive impairment

(Wang et al. 2011)
Power Wheelchairs for Older Adult Long-Term Care Residents with Cognitive Impairments

What can we learn from our users?

Technology Team, Toronto Rehab and University of Toronto
Power Wheelchairs for Older Adult Long-Term Care Residents with Cognitive Impairments

What can we learn from our users?

Technology Team, Toronto Rehab and University of Toronto
Studies with Long-Term Care Home Residents with Cognitive Impairments using Anti-Collision Wheelchairs

- Environmental coverage and reliability of sensors to ensure safety
- Capability to drive outdoors, uneven surfaces
- Effort-reducing driving and assisted use modes
- Appropriate driving speed
- “Acceptable” appearance, form and size
- Design for perception of safety
- Multi-modal feedback user interface characteristics


Intelligent Wheelchair System (IWS)

Stereovision Camera
Senses environment in front of wheelchair

Joystick
User shares control of wheelchair with onboard computing unit

Audio Speaker
Prompts user with navigation cues

Onboard Computing Unit
Analyzes camera data and determines system action (e.g. stop chair, prompt)

(How et al. 2013)
IWS: Collision Detection

Stereovision camera used to create depth map of environment in front of wheelchair; brighter objects are closer to camera.

Powered wheelchair is stopped and prevented from driving towards obstacle(s) within threshold distance.
IWS: User Study

• N = 2 (mild-to-moderate cognitive impairment) completed study

• Single-Subject Research Design

• A = baseline phase (without system)
  B = intervention phase (with system)

• Task: manoeuvre around foam boards in an obstacle course
One participant’s ability to complete right turn without collision showed significant improvement when driving with anti-collision system (5 runs per phase).
IWS: Prompting Adherence Results

- Large differences between individuals (older adults with dementia).

- Low adherence due to:
  - low overall prompting accuracy (63%)
  - prompting modality (i.e., only audio).
Navigation and Obstacle Avoidance Help (NOAH)

The system consists of:

- Powered Wheelchair (Pride)
- Bumblebee Stereovision Camera from Point Grey Research
- Laptop (under seat)

(Viswanathan et al. 2011, 2012)
NOAH: System Architecture

Detect obstacles within distance threshold

Mapping, path planning, trajectory analysis

Probabilistic user model to estimate responsiveness and awareness

Collision Detector → Route Planner → Prompter

Stop and block motion towards obstacle

“Off-route – turn left!”, “move forward”, etc.
NOAH: User Study

• N = 6 (mild-to-moderate cognitive impairment), 4 female, 66-97 yrs old

• Single-Subject Research Design

• Random half completed A-B ordering, remaining completed B-A.

• A = baseline phase (without system)
  B = intervention phase (with system)

• Task: find stop sign at the end of a maze (shortest route shown during training phases)
NOAH: Data Collection & Analysis

• Quantitative data: frontal collisions, distance traveled, completion time, user confidence regarding route, QUEST 2.0, NASA-TLX

• Qualitative data: custom survey, visual and audio observations from recordings

• Visual analysis and C-statistic for quantitative data

• Thematic analysis of qualitative data
NOAH: Anti-Collision Results

Participants 1, 2 and 5 have A-B phase ordering, while participants 3, 4 and 6 have B-A ordering.
Participants 1, 2 and 5 have A-B phase ordering, while participants 3, 4 and 6 have B-A ordering.
NOAH: Prompting Adherence Results

• Prompting adherence to correct prompts was high for all users (89% - 99%)

• Users who were less confident about the route (four out of six users) tended to rely on the system more - adhered to 25% - 60% of incorrect prompts

• Confident users (two out of six) correctly disobeyed more than 93% of incorrect prompts

• High prompting accuracy across all users and trials (87%)
NOAH: Usability Results

- 5/6 users said they would use the system, but had different preferences for wheelchair speed
- Stopping behavior of system caused frustration for users with high baseline collision avoidance skills (when prevented from making safe maneuvers)
- Completion times higher with the system for some users due to stopping mechanism
- One participant with limited self-mobility in her manual wheelchair said:
  
  “[With this powered wheelchair], I would go to all the places I can’t currently go to” (Viswanathan et al. 2011)
IWS & NOAH: Limitations

• Foam obstacles in study – possibly reduced anxiety and fear of collisions

• Validity of self-reports by cognitively-impaired users

• Generalizability of results (small n, variability)
Power mobility with collision avoidance for older adults: User, caregiver and therapist perspectives

- Only study that explores views of users, caregivers and therapists on novel collision avoidance technology
- Interviews: 20/29 of users, 5/5 caregivers and 8/10 therapists felt collision avoidance would be useful
- Collision avoidance might benefit CURRENT users and potential users with visual impairments
- Reservations expressed for potential users with significant cognitive impairments
- Design issues to be addressed: context awareness, reliability, user interface specifications, collaborative control

Recommendations

• Better sensor coverage & mapping of the environment
Maintaining Local Map Information

• Pouria Talebifard, Ian Mitchell
• Takes into account movements using odometry data. (low-cost optical odometer, IMU, visual odometry etc)
• Handles dynamic (moving) obstacles
• Allows for development of new wayfinding algorithms and obstacle avoidance policies centered around (collaborative) human controlled robots.
Recommendations

• Wheelchair’s interaction with the environment
Object Classification

• Paul Oramasionwu, Alex Mihailidis
• Improve user interaction with the environment and with the wheelchair itself by classifying obstacles
  – Facilitate docking at a table
  – Facilitate transfer to a bed or chair
  – Alert user of hazards and fragile objects
Risk and Uncertainty

- Junaed Sattar, James Little
- Accounting for risk in man-machine dialog
  - Uncertainty and errors in communication
  - Commanded task could too risky (i.e., dangerous, costly)
- Identify (use multiple sensors to calculate risk) and clarify reasons behind high-risk evaluation
- Confirm before executing costly task
- Application to intelligent wheelchair – unsafe wheelchair commands sent by user (e.g., collision with object to save collision with person)
Socially Adaptive Navigation

Approach:

- Extract information about dynamic obstacles from RBG-D camera.

- Acquire training data containing trajectories of driving in crowds from a human expert.

- Apply machine learning methods on the training data to learn a policy that matches dynamic features to control actions.

[Kim and Pineau., RSS 2013.]
Recommendations

- Alternate control strategies (e.g., speed and/or steering correction approaches)?
Wizard-Of-Oz and Mixed-Methods Study

Limitations of previous CanWheel studies:

• Waited until intelligent system was ready for testing – missed out on early feedback from users
  – however, rich qualitative data was obtained during the studies

• Many users in semi-structured interviews did not know what the technology looked like (e.g. collision avoidance, wayfinding, etc.)
  – working with a real device would allow for more useful feedback
How will it work?

– Hidden researcher controls the wheelchair to simulate an intelligent wheelchair - Wizard

– 3 modes used in completing realistic tasks:
  1) speed control to prevent collisions
  2) heading correction to avoid obstacles + direction
  3) autonomous driving

– Other researcher stays with participant to collect data eg: surveys (quantitative), co-operative evaluation (qualitative)

– Pre- and post-driving interviews for subset of users

– Sensor data collected by system (joystick movements, obstacles, eye-tracking, physiological data, motion data)
Challenges

• Recruitment challenges (consent)
• Manufacturer’s liability, reimbursement, technical support
• Acceptance by clinicians (safety, reliability, perceived benefits of technology)
• Abandonment (stigmatization, usability issues, etc.)
• Knowledge Translation + Commercialization!!
Workshop: June 26, 13:45 – 18:15

Evaluation of Intelligent Powered Wheelchairs

Speakers: P. Viswanathan, R. Wang, C. Urdiales, C. Mandel, F. Routhier, S. Arthanat, K. Moffatt
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For more information, please visit us at www.canwheel.ca!