BUILDING A SMART WHEELCHAIR ON A FLEXIBLE SOFTWARE PLATFORM

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INTRODUCTION

For people with significant movement disorders (from stroke, Parkinson's disease, cerebral palsy, etc.) manually operated wheelchairs can be extremely difficult, if not impossible, to use. Smart wheelchairs have the potential to improve mobility and independence for tens of thousands of Canadians [1],[2],[3], particularly amongst older adults with severe physical or cognitive disabilities. However, for the approximately 200,000 seniors with disabilities who reside in long-term care facilities [4], powered wheelchairs are often not prescribed because of the danger that these large, powerful machines pose to the operator, other residents, staff, and the facility itself.

Driving conditions are a significant factor in many accidents involving powered wheelchairs [5]. Powered mobility users must navigate precisely around fixed obstacles (e.g., carts, custodial equipment) in narrow hallways, through narrow doorways, and around tight corners. In addition, powered mobility users face moving obstacles traveling at a wide range of speeds that include other wheelchair users and walkers. Smart wheelchairs that can reduce or even eliminate collisions or near-collisions with fixed and mobile obstacles in the environment have the potential to reduce the liability associated with powered wheelchairs in residential care facilities. As part of CanWheel — a newly formed, cross-Canada collaboration focused on current and future power wheelchair use among older adults (http://www.canwheel.ca) — our group is studying the design, implementation, and basic user testing of a modular, robust, and safe smart wheelchair.

A number of smart wheelchairs have been designed, built, and tested since the early 1990s [6]. Collision prevention schemes [7],[8] have been developed to stop the chair upon detection of a collision via bumper skirt [9] or via laser range finders or stereovision cameras that detect an obstacle within a certain distance of the chair [10]. Some chairs provide vocal prompts to the user [7],[11] after the stop, or attempt to guide the user to another heading or path [12],[13]. The SmartWheeler chair interprets voice commands from the user [14] for mapping, obstacle detection, and navigation. A major technological challenge for any automated system is its ability to work seamlessly with the user in uncertain environments; such collaborative capability is one of the long-term goals of our work.

The smart wheelchair we describe in this paper incorporates an open-source robotic operating system (ROS) [14] to enable modular, reconfigurable, and hence more robust operation. Originally designed and instrumented by AT Sciences LLC [15], the wheelchair is built on a Quickie Rhythm base, with a bumperskirt, customized sensor pods with integrated infrared and sonar rangefinders, and Controller Area Network (CANBus) communication framework. Our contribution is the implementation of ROS onboard the instrumented wheelchair, and design and experimental validation of controllers for autonomous wall following around a corner. ROS provides inherent modularity since its processes are designed to perform computations independently and exchange information through a publish / subscribe model. Hence swapping out a sensor, a controller, or other system element, can be achieved in a straightforward manner. This is a distinct advantage for real-world systems with inevitable component failures, and for the high degree of customization required for heterogeneous user populations.

To the best of our knowledge, this is the first ROS implementation of a smart wheelchair. This paper describes the system architecture and operating characteristics of a prototype smart wheelchair that will be a testbed for collaborative control. We demonstrate an autonomous system wall following around a corner, a moderately difficult task from the Powered Wheelchair Skills Test [16]. Although designed for human operators of powered wheelchairs, the Powered Wheelchair Skills Test provides a good benchmark for performance of autonomous wheelchairs [14], as it represents a set of skills necessary for safe navigation through real-world hazards.

Figure 1: Quickie Rhythm with wheel encoders, bumper skirt, stereovision camera, and five sensor pods containing infrared and sonar rangefinders.

SYSTEM ARCHITECTURE

A Quickie Rhythm wheelchair has been modified with the addition of specially designed sensor pods [8] (AT Sciences, Inc), at the front right, the front left, the right side, the left side, and the rear of the chair, as shown in Figure 1. Each sensor pod contains 3-5 infrared sensors, and 5-7 sonar sensors. In addition, both wheels contain high-accuracy encoders, and the base of the chair is surrounded by a touch-sensitive bumper skirt along the front and sides. Multiple sensors provide redundant information to counter the high levels of noise possible with IR and sonar.

Sensor readings are transmitted onto the CANBus as shown in Figure 2. The CANBus communication framework we have implemented in ROS consists of Talker, Listener, and Sender "nodes" (e.g., computational processes) that process "messages" (e.g., data structures) read from or published to a "topic" (a message bus). A single Talker node reads all raw messages from the CANBus and breaks them into separate topics for each sensor. Listener nodes read raw messages from a particular sensor's topic and publish an appropriately processed sensor reading onto another topic. One or more controller nodes can then use the sensor readings and internal data to decide on a course of action, which is published onto one or more other topics. Sender nodes read a message from a topic and send the message back to the CANBus, decoupling any controller nodes from the end devices. Some end devices (such as the joystick) will then read messages from the CANBus. All messages are logged by ROS and can be replayed for diagnostic and simulation purposes.

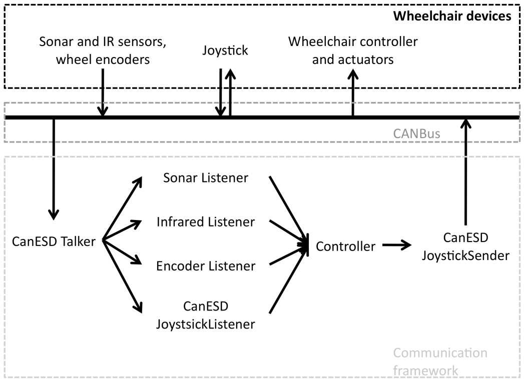

Figure 2: CANBus communication framework.

At present, we have listener nodes to process readings from the sonars, the IRs, the encoders, and the joystick (e.g., a measure of how the user has deflected the joystick). In the example below, only the IR and encoder listeners are used.

The only sender node ("JoystickSender") communicates through the CANBus with the wheelchair motor controllers by emulating a joystick. In manual operation mode, this sender node merely passes along the message received from the joystick listener node. In the example below, a wall-following and cornering controller node (which maintains an internal model of the wheelchair's state with respect to the wall and corner using sensor readings) provides messages to the sender.

The ROS platform easily accommodates new sensor, interaction, or actuation hardware, or new software features, through the addition of new nodes and message topics.

SENSOR CHARACTERISTICS

For the wall-following task, we use only the infrared sensor mounted on the side of the wheelchair. (We do not consider the sonar sensors due to their orientation in the sensor pods.) The GDP2D12 Sharp Infrared sensor is triangulation-based, hence less sensitive to ambient light and surface reflectance properties than reflected light intensity infrared sensors. The sensor has a range between 10 and 80 cm, and is insensitive to the color of the surface. It returns a 0 reading for distances outside of the maximum range.

To obtain an estimate of the variation in the readings, 1000 measurements were taken at a distance of 70cm. Figure 3 shows a near-normal distribution (p = 0.0109, Jarque-Bera test [17]). The skew means that the sensor is likely to underestimate the distance, an important factor to consider in designing automation for precise maneuvering. Furthermore, we showed that the variance in measurements is a function of the actual distance to an object. As shown in Figure 4, the standard deviation of measurements for a white surface increases nonlinearly as the distance to the object increases. At distances <40cm, the standard deviation is less than the sensor resolution, while at 80cm, the standard deviation reaches a peak of almost 5cm.

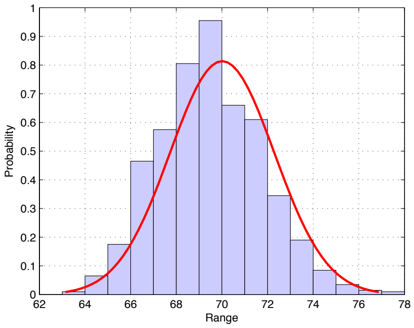

Figure 3: Distribution of measurements for a true distance of 70 cm from a white surface.

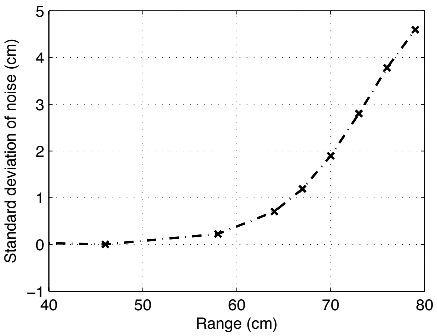

Figure 4: Standard deviation of range as a function of distance from a white surface.

MODELING AND CONTROL

Using a standard kinematic model [18] for the wheelchair dynamics, we design feedback linearizing controllers [19] for a) wall following, and b) constant radius turning. While wall following, only infrared sensors provide external information; the wheel encoders are used in an extended Kalman filter as inertial (onboard) sensors to provide estimates of the current state. While turning, the infrared sensors cannot provide useful information about either the wall or the corner, so the controller only uses the wheel encoders. Details are described in [20].

EXPERIMENTAL RESULTS

The wheelchair was initialized close to a wall, oriented nearly parallel to the wall. All ROS and CANBus communications are logged, providing a history of sensor data and control actions over the duration of the run. In addition, an external Metris iGPS indoor metrology system was used to track the position of the wheelchair, thereby providing sub-millimeter accuracy of the wheelchair's actual trajectory for analysis purposes.

Autonomous navigation is shown in Figure 5, starting from the lower left corner. The wheelchair successfully tracks a fixed distance from the wall using the encoders and infrared sensors. It executes a fixed radius turn upon reaching the corner, using only the encoders, then resumes tracking a fixed distance from the next wall, using both encoders and IR. While the distance to the corner was pre-programmed for simplicity, in general the discontinuity in range measurements that occurs when the sensor passes the corner could be used to trigger a constant radius turn.

By using ROS, we can achieve the modularity and flexibility that is so important for physical systems expected to operate reliably under variable conditions. For example, in the system described above, the talker and sender nodes handle all of the CANBus-related details, and the IR listener node handles the nonlinearity and inaccuracies of this particular sensor; consequently the controller node is independent of the underlying hardware, and could be used on any other platform that provides suitable sensor readings.

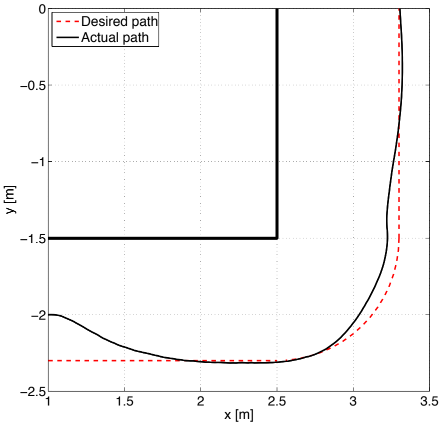

Figure 5: Autonomous wall following around a corner, with desired path (dashed), and actual path (solid) from metrology data.

ACKNOWLEDGEMENTS

We thank student volunteers Richard Yu, Timothy Tang, Amy Leson, and Sean Ding for their assistance.

REFERENCES

[1] Cooper, R., *Quality-of-life technology.* IEEE Engineering in Medicine and Biology, 2008. **27**(2): p. 10-11.

[2] Ding, D. and R. Cooper, *Electric-powered wheelchairs: A review of current technology and insight into future directions.* IEEE Control Systems Magazine, 2005. **25**(2): p. 22-34.

[3] Viswanathan, P., J. Boger, J. Hoey, P. Elinas, and A. Mihailidis, *The future of wheelchairs: Intelligent collision avoidance and navigation assistance.* Geriatrics and Aging, 2007. **10**(4): p. 253-256.

[4] *Advancing the inclusion of people with disabilities*. 2005, Government of Canada: Canada.

[5] Mortenson, W., W. Miller, J. Boily, B. Steele, E. Crawford, and G. Desharnais, *Overarching principles and salient findings for including in guidelines for power mobility use within residential care facilities.* Journal of Rehabilitation Research and Development, 2006. **43**(2): p. 199-208.

[6] Simpson, R., *Smart wheelchairs: A literature review.* Journal of Rehabilitation Research and Development, 2005. **42**(4): p. 423-436.

[7] Mihailidis, A., P. Elinas, J. Boger, and J. Hoey, *An intelligent powered wheelchair to enable mobility of cognitively impaired older adults: An anticollision system.* IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2007. **15**(1): p. 136-143.

[8] Simpson, R., E. LoPresti, S. Hayashi, S. Guo, D. Ding, W. Ammer, V. Sharma, and R. Cooper, *A prototype power assist wheelchair that provides for obstacle detection and avoidance for those with visual impairments.* Journal of NeuroEngineering and Rehabilitation, 2005. **2**(1): p. 30.

[9] Wang, R.H., S.M. Gorski, P.J. Holliday, and G.R. Fernie, *Evaluation of a contact sensor skirt for an anti-collision power wheelchair for older adult nursing home residents with dementia: Safety and mobility.* Assistive Technology, 2010.

[10] Viswanathan, P., A. Mackworth, J.J. Little, J. Hoey, and A. Mihailidis, *Noah for wheelchair users with cognitive impairment: Navigation and obstacle avoidance help*, in *Proceedings of AAAI Fall Symposium on AI in Eldercare: New Solutions to Old Problems*. 2008: Washington, DC. p. 150-152.

[11] Simpson, R. and S. Levine, *Voice control of a powered wheelchair.* IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2002. **10**(2): p. 122-125.

[12] Parikh, S., V. Grassi, V. Kumar, and J. Okamoto, *Integrating human inputs with autonomous behaviors on an intelligent wheelchair platform.* IEEE Intelligent Systems, 2007. **22**(2): p. 33-41.

[13] Carlson, T. and Y. Demiris, *Human-wheelchair collaboration through prediction of intention and adaptive assistance*, in *Proceedings of the IEEE International Conference on Robotics and Automation*. 2008: Pasadena, CA. p. 3926-3931.

[14] Atrash, A., R. Kaplow, J. Villemure, R. West, H. Yamani, and J. Pineau, *Development and validation of a robust speech interface for improved human-robot interaction.* International Journal of Social Robotics, 2009. **1**(4): p. 345-356.

[15] Simpson, R., E. LoPresti, S. Hayashi, I. Nourbakhsh, and D. Miller, *The smart wheelchair component system.* Journal of Rehabilitation Research and Development, 2004. **41**(3B): p. 429-442.

[16] Smith, C. and R. Kirby, *Wheelchair skills test as a means of assessing power mobility*, in *Proceedings of the Canadian Seating and Mobility Conference*. 2001: Toronto, ON. p. 130.

[17] Jarque, C.M. and A.K. Bera, *A test for normality of observations and regression residuals.* Int'l Statistical Review, 1987. **55**(2): p. 163-172.

[18] Walsh, G., D. Tilbury, S. Sastry, R. Murray, and J.-P. Laumond, *Stabilization of trajectories for systems with nonholonomic constraints.* 1994. **39**(1): p. 216-222.

[19] Khalil, H., *Nonlinear systems*. 2002: Prentice Hall.

[20] Oishi, M., P. Taghipour Bibalan, A. Cheng, and I. Mitchell, *Modeling and control of a powered wheelchair: Wall-following around a corner with infrared*, in *Canadian Congress of Applied Mechanics*. 2011. In review.

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