# On the Use of Modular Software and Hardware for Designing Wheelchair Robots

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## Abstract

This short paper describes experiences in the development of several smart power wheelchair platforms across three different sites. In the course of the project, we have re-used several of the components (both hardware and software) despite differences in the base platform of the robots. We describe the different platforms, and discuss some of the challenges and results of our work.

## Introduction

It is reported that among power wheelchair (PWC) users, about 40% have difficulty with daily maneuvering (Fehr, Langbein, and Skaar 2000). Given that over 4.3 million people in the US are wheelchair users (Simpson, LoPresti, and Cooper 2008) and that the number is only going to increase as the population ages, it makes sense to incorporate smart features into PWCs that will automate challenging tasks. Such "smart" wheelchairs aim to allow more people to be able to safely and effectively use a PWC, by reducing the physical and cognitive load required for operation. A remarkable number of smart wheelchairs have been developed over the years, many of them taking the approach of enhancing commercially available PWC models with a variety of sensors, processors, and custom software. Yet it seems like each new project must "reinvent the wheel" and invest a lot of time and effort in order to develop software/hardware that other groups may have already developed.

This position paper reports on the collaborative design of smart wheelchair platforms at three sites: McGill University, the University of British Columbia and the University of Toronto. An unprecedented sequence of cross-Canada team grants—initially the CanWheel emerging team, then the Canadian Field Robotics Network, and now the AGE-WELL Network of Centres of Excellence—has allowed us over the last five years to jointly develop and share hardware and software components, expertise and personnel while

Figure 1: The previous UBC chair.

pursuing parallel avenues of investigation in this challenging research space. The results of this collaboration are a collection of wheelchair platforms that share some core components while still providing a diversity of points in the design space to better explore tradeoffs between functionality, flexibility, usability, testability, commercializability and other design dimensions.

## Challenges in the Development and Testing of Smart Power Wheelchairs

The team at the University of British Columbia (UBC) began the collaboration using a Quickie Rhythm PWC modified by AT Sciences to include their DriveSafe collision avoidance system (Simpson et al. 2004), custom magnetic rotary encoders for odometry, and a framework of metal tubing around the back and sides of the chair which held a laptop and has supported a variety of sensors including the original DriveSafe sonar and infrared (IR) rangefinders, a bumper skirt, a Bumblebee stereo camera, Hokuyo planar LRFs, Asus Xtion RGB-D cameras, and accelerometers;

figure 1 shows a configuration with the first three mounted. In 2013 UBC and the University of Toronto jointly conducted a user study with 10 long-term care residents with mild-to-moderate cognitive impairment in the Greater Vancouver Area (Mitchell et al. 2014; Viswanathan et al. 2014). We learned a number of important lessons while conducting this study on (a considerably simplified configuration of) the AT Sciences PWC. First and foremost, the seating component is a critical aspect of testing with the target population. The bare-bones seat supplied with the chair was fine for (skinny) grad students, but we were as likely to get a mobility impaired older adult into that chair as onto a unicycle. We were fortunate to get a salvaged power tilt unit and wider seat through contacts with a local vendor, which facilitated ceiling-lift transfers of participants into the chair. While only minor further modifications were required for each study participant (for example, shifting the joystick to match the participant's dominant hand, moving one participant's backrest from her own chair to the study chair), even this seating configuration could not accommodate users with more complex needs. Additionally, the availability of a single study chair meant that only one participant could test the system at a time, adding further scheduling constraints and increasing the overall time required to complete the user study. Finally, mounting and wiring sensors was a challenge: sturdy locations with good fields of view inevitably block access to the seat and are an aesthetic nightmare; for example, consider that the configuration shown in figure 1 has 360° sonar, IR and bumper skirt coverage, an excellent forward stereo vision view and an easily accessed control laptop, but in order to sit down a user must thread their legs carefully between the sensor pods and then is at constant risk of bumping them or the laptop while operating the chair. When performing user studies it may be hard to distinguish between opinions driven by core performance and those driven by inconvenient or ugly appearance.

Although the user study was successfully completed with this platform, it required some rather obscure CanBUS drivers; by late 2014 we were limping along with a two year old disk image and could not get the hardware operational with newer versions of Ubuntu and ROS. When some electronics in the PWC base and the AT Science custom controller failed, we were unable to source replacements for either due to the age of the system. It thus became imperative to develop a new modular system that would be compatible with available and future commercial PWCs.

## Modular Design of Smart Power Wheelchairs

There are many different brands and models of PWCs on the market that can be equipped with a variety of interfaces, seating, drive configurations and other customizations, so it is important to be able to abstract away as many of the hardware differences as possible, and develop add-on modules that are independent of the type of wheelchair used. One major challenge we have encountered (across all platforms) is the interface between our added on-board computer and the original motor controller of each PWC. Somewhat fortunately several brands of PWC use the same kind of motor controller (originally developed by PG Drives and now part

of Curtiss-Wright) which allows an external joystick to be connected via an interface variously called the Omni+, R-Net Omni or R-Net Input/Output module. Even with this commonality, the motor controller's interface remains proprietary and a reverse engineered joystick emulation is our only means of motion control.

The board that we built to interact with the motor controller incorporates a standard off the shelf Arduino with a custom designed shield. The Arduino's standard USB interface is used to communicate through ROS to a laptop, while the shield has ports for the Curtiss-Wright module and a PWC joystick. This combination allows us to take input from the user, route it through ROS nodes on the laptop to record and potentially modify that input, and then deliver it to the motor controller. Because there is no mechanism for feedback from the PWC base, the shield also provides a port to capture odometry data from custom designed and mounted wheel encoders. Unfortunately, joystick commands do not map well (or even consistently) to the linear and angular velocity commands generated by standard ROS libraries. Where available, feedback from the odometry has enabled design of a PID feedback loop that considerably improves linear and angular velocity control; however, such odometry is not always available and even with it control is imperfect due to the black box nature of the proprietary motor controller into which the joystick signals are fed.

Nevertheless, this board has been successfully incorporated onto six PWCs in the three groups, with only minor tweaks of parameters to account for different electrical and mechanical profiles among the four different commercial models represented. Currently we are working on algorithms that will further refine the joystick control signal with a goal of achieving consistent motion behaviour among the various models of PWCs.

## Modular Software Development

With the emergence of ROS the development of modular code that can be ported from one system to another has become significantly easier. There exist drivers and ROS interfaces for the majority of important robotics sensors—such as laser range scanners, 3D cameras, IMUs—that publish standard messages for use in other packages. External libraries like OpenCV and PCL can also be used seamlessly. This effectively allows for building software that is abstracted from the specific hardware, and is only dependent on whether the correct message type is available.

In the course of this project, we have developed several modules that can be used across platforms.

- Module for people detection and tracking from planar laser scans
- Module for detection of tables and ideal docking locations
- Remote control module
- Parallel parking module
- Back-in parking module
- Wall following module
- Module for basic navigational commands with obstacle avoidance (forward/backward motion and turning)

Figure 2: The Quickie Freestyle Smart Wheelchair



Figure 3: The Quickie S646 Smart Wheelchair

- GUI module for utilizing the common user commands
- Module for merging input from multiple laser scanners into a single message that can be easily used for mapping and navigation

ROS makes the creation and sharing of modules easy. Each module in ROS is a package that can contain multiple executables, custom libraries that can be reused in other packages, and a plug-in system is available for convenience. ROS follows the publish/subscribe design pattern which allows modules to subscribe to topics that they are interested in, and to publish messages to topics which in turn can be useful for other modules. This loose coupling lends itself very well to mix and match designs.

## Our Smart Wheelchairs
### The McGill SmartWheeler platforms
The team at McGill University in Montreal has built two different smart wheelchairs – a Sunrise Quickie Freestyle (Figure 2) and a Sunrise Quickie S646 (Figure 3). Both models are equipped with laser range-scanners, an Asus Xtion RGB-D Camera, custom magnetic wheel-encoders, IMU, GPS, touch screen, remote control joystick, and WiFi connectivity. The Freestyle model has two SICK LMS100 planar laser range-scanners (one facing forward and one facing backward), while the S646 Model has three Hokuyo UHG planar laser range-scanners (one in the back and two on the sides) as well as multiple sonars (to detect transparent surfaces like glass that are common in malls). Both wheelchairs use the custom Arduino controller board with an Omni+ module in order to send control commands from ROS.

### The UBC platform
The UBC platforms consist of a pair of Permobil M300 bases with power tilt seats and width adjustable cushions. We have discarded the IR, sonar and bump sensors from the older platform, and are currently using Asus Xtion Pro RGB-D cameras (instead of stereo) and/or Hokuyo LRFs.

The only minor issue getting the McGill Arduino controller board operational with the Rnet Omni controller modules was the manual retuning of a few parameters, although it is not yet clear whether that was necessary due to fundamental differences in the PWC models or manufacturing variance in the joysticks and/or drive electronics. Thanks to the new board, we were quickly able to port and then update our core control software to modern versions of ROS. The chairs can be remotely controlled, but are not yet autonomously operational as we are currently designing an aesthetically minimalist mounting frame for the sensors and are awaiting an opportunity to install odometers to improve the accuracy of autonomous velocity control.

### The University of Toronto platform
The team at the University of Toronto had an old, donated Quickie P200 and a newer Pride Quantum 6000z. We stripped these wheelchairs of their controllers and installed new Rnet controllers instead, along with Rnet Input/Output modules. Sensors include Microsoft XBOX Kinect and Asus Xtion RGB-D cameras, ZX distance and gesture sensors by XYZ Interactive, and an IMU. Since our wheelchairs do not have built-in encoders, we will likely use custom magnetic wheel-encoders, similar to those built at other sites. After slight tuning of a parameter due to differences in our joysticks, we were able to use the McGill Arduino controller board as is, along with the Rnet I/O module, to send drive commands to the wheelchair. We also added on a bluetooth module for remote wheelchair control. Integration of the modular hardware and software components with our ROS modules is currently underway.

## Evaluation of Smart PWCs
With the modular hardware and software components we have developed, we are now able to not only reduce the time it takes to develop new algorithms and functionality by re-using ROS modules, but also replicate our systems across multiple wheelchair bases fast and easily, allowing us to

conduct user trials across sites and at a larger scale. In addition, the compatibility of our hardware components with Curtiss-Wright controllers, which are currently used by several wheelchair bases, opens up the possibility to simply add on our systems to study participants own power wheelchairs that are often customized for them, thus overcoming seating issues. This could potentially reduce the number of PWC bases that would need to be purchased to run larger-scale trials, a savings of $3000 - $30,000 per chair.

However, before we are able to conduct more user testing with the target population, we must overcome several obstacles. First, our interface to the chair electronics emulates a joystick. Consequently, we cannot get any feedback from the black-box controllers (such as a direct measure of odometry, speed profiles, tilt, etc), cannot send any data to the heads-up display, and we do not have a simple mapping from input signals to motion. Third, these off-the-shelf chairs have no mounting points for sensors, so in adding support structures to the system we must balance carefully between the flexibility and convenience desired for engineering prototyping and the aesthetics desired for user studies.

Seating is still an issue with some of the wheelchairs. In the McGill group, the Quickie Freestyle is primarily used by students for internal testing of the algorithms since its seat does not lend itself well to the big modifications that may be needed to accommodate people with disabilities. The Quickie S646 is used for user studies with wheelchair users since it has a more adjustable seat, but still may not be appropriate for users with more complex seating needs.

Despite differences in sensor configurations between PWCs, the data collected by the different teams can be very useful in order to create benchmark datasets for scene and object recognition, and real users' PWC driving data which is currently difficult to obtain/access. User studies are time-consuming and challenging to run (recruitment, etc.), so sharing existing study data can expedite development, although privacy and ethics issues need to be addressed.

## Conclusion

Our experience so far suggests that it is feasible and productive to develop diverse robot platforms across sites while making use of modular software and hardware architectures to share successful component designs.

Nonetheless, it is worth noting that different users may have difficulty with different tasks and may require only certain "smart" features. This situation further emphasizes the desirability of developing modules that can be added or removed as needed, similar to how car manufacturers offer different options, such as adaptive cruise control, backing cameras, pedestrian detection, etc. In the case of our projects, the availability of several distinct platforms at the different sites has allowed us to investigate different configurations without overwhelming development effort, while still pushing us to develop portable solutions which can be shared when appropriate.

The modular systems we have implemented and ongoing efforts to increase compatibility with commercial wheelchairs can thus speed up development efforts and facilitate larger scale trials with our target users in order to validate system usability and effectiveness, which will be an essential step in the eventual commercialization of smart wheelchair technologies.

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