Comparison of Different Powered-wheelchair Control Modes for Individuals with Severe Motor Impairments

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Abstract: This paper presents the preliminary evaluation of different powered-wheelchair control modes for individuals with severe motor impediments. To this end, a C400 Permobil wheelchair has been updated with a control command communication interface and equipped with a scanning laser sensor to carry out the automation algorithms that are part of the robot operating system framework. A pilot test was performed with three different modalities; hand-joystick mode, tongue-joystick mode and autonomous mode. The results of the tests have proven the feasibility of using a power wheelchair either autonomously or controlled by users interchangeably in order to continue the development towards a better user/wheelchair shared-control paradigm.

1 INTRODUCTION

Electrically powered wheelchairs (PWC) are used to assist mobility of individuals with severe motor disabilities, such as those with tetraplegia. Users that still maintain some degree of motor control of arms or hands use a joystick in order to control the direction and speed of the PWC. In the other hand, users with more severe or total motor disabilities have to rely on alternative interfaces to control a PWC. To this end, research has been done to develop devices that can interface the remaining functional parts of such individuals. Such as interfaces based on detecting head movement (Christensen and Garcia, 2003), chin movement (Guo et al., 2002), the eyes (Agustin et al., 2009), the tongue (Huo and Ghovanloo, 2010; Lund et al., 2010) and even forehead muscular activity and brain waves (T. Felzer and R. Nordman, 2007).

However, most of these interfaces require high levels of concentration for navigating in environments with many obstacles. The eye-tracking system maybe tedious and tiresome when it is used constantly to maneuver a wheelchair. Furthermore, it can also affect the normal use of the user's vision, especially in cases where the user, either consciously or unconsciously, looks at a point in the surrounding environment rather than at the desired path. In which case the system may believe that the user wants to go to that position (Huo and Ghovanloo, 2009). Similar problems might occur with head tracking interfaces. In general, driving the wheelchair with a specific interface and doing an activity that require the use of the same part of body, e.g. the eyes, the head or speech at the same time, might not be efficient.

Brain-computer interfaces (BCI) often used electroencephalographs (EEG) to detect voltage fluctuations in the scalp. There are few limitations of using BCIs to control PWC. Due to a small signal amplitude in the brain waves, EEG signals need to be amplified by a factor on the order of 10^4, thus any noise contamination or whenever the subject blinks, swallows, laughs, talks etc. makes the corresponding EEG sample unusable (Huo and Ghovanloo, 2009; T. Felzer and R. Nordman, 2007). Moreover, the input rate is also quite slow for a real-time control, e.g. it is up to 25 bits per minute making less than 1 bit every 2 seconds, meaning that it will take more than 2 seconds to stop it with a command yes/no.

Using the tongue to control a PWC seems to be a promising alternative. The tongue is able to perform sophisticated motor control and manipulation tasks with many degrees of freedom. It is able to move rapidly and accurately and does not fatigue easily and can be controlled naturally without requiring too much concentration. Georgia Institute of Technology, has developed a tongue drive system (TDS) that consists of a headset and a magnetic tongue barbell, which is able to interpret tongue movement as commands (Huo et al., 2008). The user drives the PWC with the tongue using five different commands: forward (FD), backward (BD), turning right (TR), left (TL) and stopping (N) (Huo and Ghovanloo, 2010). A smartphone (iPhone), directly connected to the wheelchair, can serve as a bridge between the TDS and a PWC (Kim et al., 2012), eliminating the need of bulky computers or specialized hardware. Similarly, an inductive tongue control system (ITCS) has been designed at Aalborg University, which is an intra-oral dental retainer with 18 inductive sensors that can precisely detect the position of a metallic tongue barbell (Lotte and Andreasen, 2006). The ITCI can interpolate the sensors signals to emulate an intra-oral touchpad that can proportionally control the direction and speed of the PWC, just as if it was controlled by a standard joystick. Moreover, it can provide 10 different function commands with the remaining sensors (Caltenco et al., 2011).

In the previous approaches the system lacks of full autonomy, meaning that the user has to use the tongue all time to conduct the wheelchair to a desire goal location. A survey showed that $973,706$ to $1,700,107$ persons in the U.S. would benefit from an autonomous PWC (Richard et al., 2008). Especially patients with diagnoses of ALS, cerebral palsy (CP), cerebrovascular accident (CVA), multiple sclerosis (MS), multiple system atrophy (MSA), severe traumatic brain injury (TBI), among others. Moreover, $1,389,916$ to $2,133,280$ would benefit from a PWC that provides obstacle avoidance, duties of planning and navigating, but where the user still has control of high-level tasks, such as destination point selection, emergency stop and direction change. For instance users with Diagnoses of Alzheimer disease (AD), ALS, CP, CVA, blindness or low vision, MS, MSA, Parkinson disease (PD), spinal cord injury (SCI) at or above fourth cervical vertebra (C4), among others. There has been several advances in the development of fully auntonomous wheelchair navigation systems using laser range finders (Demeester et al., 2008), depth sensors/cameras (Theodoridis et al., 2013) and other combination of navigation sensors and equipment. An extensive review of several autonomous wheelchairs has been performed by Simpson (Simpson, 2004).

However a fully autonomous system is not desired, since users should be allowed as much control of the wheelchair as their capabilities and the degree of disability allows them to. There has been several proposes of semi-autonomous wheelchair navigation systems (Demeester et al., 2008; Andrea et al., 2012; Bonarini et al., 2013; Galindo et al., 2006a; Galindo et al., 2006b; Fernández-Madrigal et al., 2004). These studies propose to facilitate the participation of humans into the robotic (autonomous) system and therfore improve the overall performance of the robot as well as its dependability. However, not all levels of motor impairment lead to the same available human-input capacity to the system. Some users might be able to generage richer input to the system than others. The research work done in this paper will be used as a prelude for a novel user-wheelchair control paradigm that shall take into consideration the needs and abilities of individuals with severe motor impairments to control a PWC in a user-controlled, to a semi-autonomous to a fully autonomous way. The previous depends on the degree of disability and the amount of input the user can give in a fast and efficient way.

Section 2 describes the system used in this research. Whereas, section 3 deals with the description of the methos that have been choosen in order to achive the scope of the project. A pilot test has been planned to test the different modalities, which is handle in Section 4. Furthermore, a comparison of the different modes under the pilot test is achieved in Section 5. And, finally, section 6 presents the conclusion and future research work.

2 SYSTEM DESCRIPTION

The C400 Permobil PWC is depicted in Figure 1. It comes with an Easy Rider wheelchair interface, from HMC International, an Easy Rider display unit and a joystick. It offers 8 modes of operation (1-way joystick, 4-way joystick, 1, 2, 3, 4 or 5-switches, and Sip and Puff Control), and the one of interest is the standard 4-way joystick mode to control the PWC. The standard joystick mode accepts as input signals a reference value of 5V and two analog voltage values in the range of 4V to 6V to proportionally move the PWC from right to left and from back to forward. To this end, an interface to send velocity control commands (VCC) from the computer to the motors has been designed using an Arduino UNO board. The arduino board receives two VCC bytes (one for left-right and one for forward-backward) and generates two pulse width modulated (PWM) signals in the range of 0 to 5V. The signals are converted to analog voltage using a simple RC low-pass filter and stepped-up using a single supply non-inverting DC Summing Amplifier. The resulting voltage is used to emulate the analog joystick position as an input to the Easy Rider interface. The Easy Rider interface then sends the necessary control signals to the wheelchair's CAN bus motor controller.

The ITCS (Caltenco et al., 2011), consists of two separate parts, the intra-oral device and an external

Figure 1: C400 permobil wheelchair.

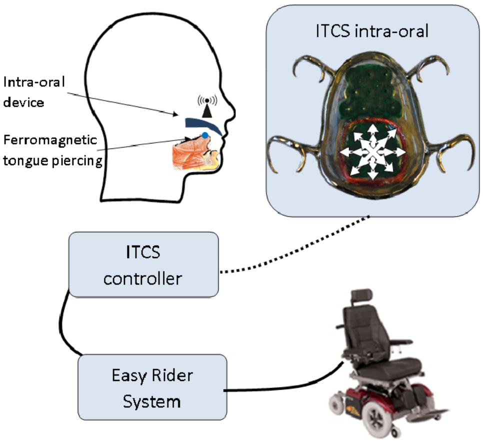

Figure 2: Overview of the Inductive Tongue Control System (ITCS).

controller. The intra-oral device detects tongue movements and wirelessly transmit signals to the external controller, which connects to the Easy Rider interface via the Joystick Input and to the computer via bluetooth. The ITCS's external controller interprets and process tongue movement signals and transforms them into joystick or mouse commands that can be sent to the wheelchair or the computer 2. The computer is a Lenovo T540p with an Intel(R) Core(TM) i5-4200M CPU @ 2.50GHz running Ubuntu 12.04 (precise).

The interaction to the external world is carried out by a Hokuyo UTM-30LX scanning laser range finder. It has a sensing range from 0.1m to 30m. Measurement accuracy is within 3mm tolerance up to 10m of the sensor's range. The scanning rate is 25 milliseconds across a 270 range.

3 METHODS

Robot operating system (ROS) (Quigley et al., 2009) is proposed as the software architecture to achieve the different modes the user can select to drive the PWC. The navigation stack (NS), which is a set of configurable nodes, has been configured properly to the shape and dynamics of the PWC to be performed at a high level. Broadly speaking, the heart of the navigation stack is the move base node which provides a high level interface between odometry, PWC base controller, sensors, sensor transforms, map server and Monte Carlo localization algorithm (AMCL) nodes to the local and global planners.

The global map is created by the gmapping package, which is an odometry-laser based SLAM (simultaneous localization and mapping). Then, during the functioning of the PWC, the NS uses sensors to avoid obstacles on the path. And, also uses these sensors to feed a costmap package to build a local map.

The localization and tracking position of the PWC in the map is achieved by the AMCL node, which is a type of particle filter obtained by a proper substitution of the probabilistic motion and perceptual models into the algorithm of particle filter, (Dieter et al., 1999)

To ensure a collision-free path planning, the NS uses the dynamic window approach planner (DWAP) (Fox et al., 1997) and the Dijkstra's algorithm nodes. Thus, given a global plan to follow and a costmap, the DWAP creates the velocity commands that drives the PWC in the collision-free configuration space from a start to a final goal location. For this purpose, an Arduino rosserial command velocity interface node has been created. Figure 3 depicts the system interaction methods between the PWC, sensors and the NS.

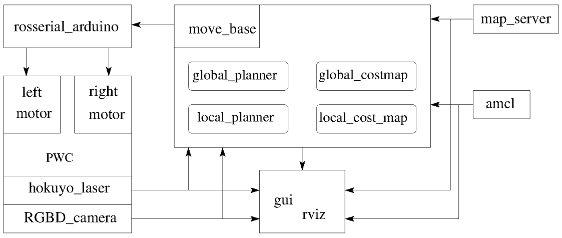

Figure 3: System interaction methods.

4 PILOT TESTS

The C400 Permobil wheelchair as it is shown in Figure 1 serves as experimental testbed. In this work, three modes; hand-joystick mode (JM_H, tongue-joystick mode (JM_T, and autonomous mode (AM) are tested by the research team, which is comprise of two males aged 30 and 48 years. Each of these tests were run once and carried out with real data in an indoor environment. Which was an L-shaped corridor as depicted in Figure 4. To this end, the map of the indoor environment was built prior to the tests,

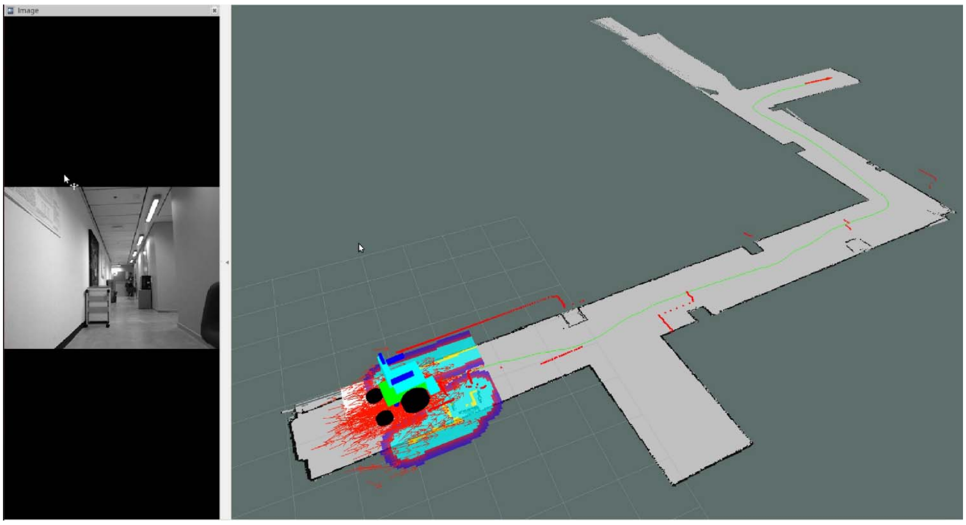

Figure 5: RVIZ set up for showing the different modes.

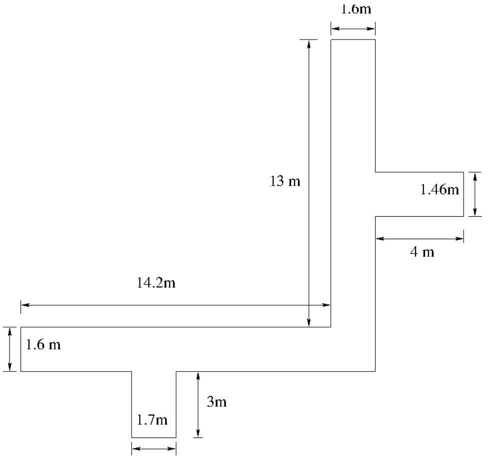

Figure 4: Schematics of the map.

this was achieved by using the Hokuyo laser, which has been placed in front of the PWC. In each measurement the laser scans a total of 712 readings distributed along 180^0. Obstacles where placed on a corridor to test the accuracy of the navigation in AM. Then, while driving the PWC in JM_H, the gmapping and the laser_scan_matcher nodes interact to build up the map.

To visualize the map making process and the navigation in the three different test modes, the RVIZ visualization tool node is used. And, it has been set up to be able to show the following topics: /map from the map _server node, the raw/obstacles and inflated_obstacles from costmap_2d node, the /scan from hokuyo node, /particlecloud from amcl node and the /camera/rgb/image_mono from image_view which is part of the oppenni_launch driver. Finally, the robot description format (URDF) which is an XML format for representing a robot model is used to create a differential driving vehicle model corresponding to the wheelchair.

Figure 5 shows the RVIZ setup. The mono camera is depicted in the left part. Whereas, in the right part the particle cloud is represented as red arrows that surrounds the URDF model, the local map is represented as inflated obstacles and obstacles, these are shown as a sky-blue and yellow colours respectively. The obstacles in the global map are represented as black, while the light and dark grays represents the empty and unknown areas.

In JM_H, the user is able to manipulate the PWC using commands emulated from the control level, e.g. forward (F), backward (B), right (R), left (L) and stopping (S), which is the neutral joystick position. The trajectory of the PWC for the JM_H test can be depicted in Figure 6.

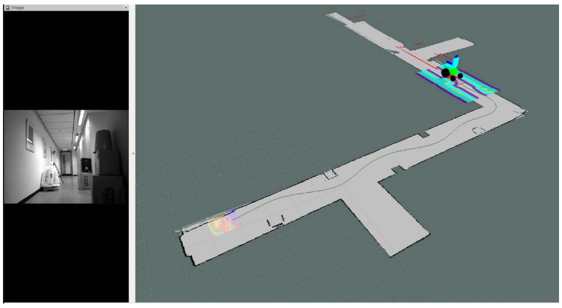

Figure 6: Permobil C400 in Joystick-mode.

In JM_T, the user is able to use the ITCS to emulate the joystick in the cavity of the mouth. During the execution of the velocity commands, the user has to hold the position of the tongue over the corresponding sensor in order to direct the PWC towards that direction and to avoid obstacles and have a successful trajectory. This test is depicted in Figure 7

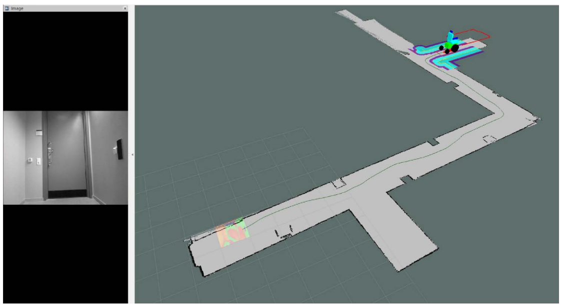

Figure 7: Permobil C400 in ITCS-mode.

In *AM*, the user is able to select the coordinates of a destination point on a map of the known environment using the ITCS to control the mouse pointer with the tongue. Then, the NS takes care of localization of the PWC in the environment and also the path planning and the avoidance of obstacles during the navigation. The previous action avoids the need of constant input from the user. Figure 8 shows the smooth path traveled by the PWC, in which the obstacles where successfully avoided and the goal has been reached.

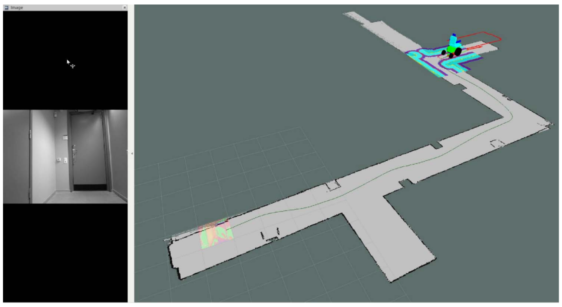

Figure 8: Permobil C400 in autonomous mode.

5 RESULTS OF THE TESTS

The comparison of the three modes of operation is done in their dependent variables of measurement (t, CO, V). Where, t is the time from an initial to a final position, CO is the number of obstacle collisions, and V is the average velocity.

Table 1 presents the different modes of operation together with their dependent variables.

In JM_H, the PWC takes from initial to a final position $1:40$ minutes, the path is smooth and the user does not collide with any obstacle. In JM_T, the PWC takes $2:15$ minutes and it does not collide with any obstacle. Whereas, in *AM* the PWC takes $2:00$ minutes and it just slightly touches an obstacle with its right front wheel as it shown in Figure 9. But this action does not prevent the PWC to achieve the desired goal.

Figure 9: The PWC slightly touches the box with the front right wheel.

In the previous Table, it can be noticed that JM_H is faster than the other two modes, because there is a direct interaction between the PWC and the user. Moreover, the user is proficient and has experience in controlling hand-operated joysticks. In the other hand, in *AM* the algorithms for localization, path planning, obstacle avoidance and control have to interact as one unit in other for the PWC to achieve its desired goal, making the system to have a delay with respect to the JM_H. In JM_T is the slowest of the three modes, this fact could be because the user was inexperienced in using the tongue to control the wheelchair and in interacting with the ITCS, this situation can be improved by mastering the interaction with the ITCS.

6 CONCLUSIONS

A C400 Permobil PWC has been updated with a communication interface for sending and receiving velocity commands and a Hokuyo sensor for automation purposes. So then, a pilot test was performed in a corridor's laboratory where three control modalities were tested and compared.

- JM_H: The wheelchair was controlled using the included joystick
- JM_T: The PWC is controlled by velocity commands that are given by a ITCS device which has been placed in the cavity of the mouth.
- *AM*: Automation algorithms that are part of the ROS-NS were tested. In this mode, the destination selection was performed by the ITCS device, while the wheelchair control was autonomous.

Table 1: Comparison Between operation modes.

	t (min)	CO	$V\ \frac{m}{sec}$
Hand-joystick mode (JM_H)	$1:40$	0	0.260
Tongue-joystick mode (JM_T)	$2:11$	0	0.198
Autonomous-mode (AM)	$2:00$	1	0.216

The tests carried out in the present research have serve as a prelude for the development of a shared-control paradigm for individuals with severe motor impairments. There is a necessity to broad the capabilities of the shared control algorithms, where they need to be tested in clutter environments and narrow doorways. In these tests, users with severe upper-limb motor impairments should be taken into account when driving the power wheelchair. The abilities and needs of users with high-level spinal cord injury is different from those of spastic users, or users with ALS. Therefore, the amount of user-control and the amount of automation should be different for different users, depending on the amount and quality of input the user can give to the system. We believe that this new paradigm will revolutionize the way the power wheelchair users with severe upper-limb impairments interact with a wheelchair and the environment.

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