

Joystick Control for Powered Mobility: Current State of Technology and Future Directions

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Abstract

Recent advancements in control interface technology have made the use of end devices such as power wheelchairs easier for individuals with disabilities, especially those with movement disorders. In this article, we discuss the current state of control interface technology and the devices available clinically for power wheelchair control. We also discuss our research on novel hardware and software approaches that are revolutionizing joystick interface technology and that allow more customizability for individual users with special needs and abilities. Finally, we discuss the future of control interfaces and what research gaps remain.

Introduction

By 2010, approximately 4 million Americans will be users of wheeled mobility devices in community settings, with about 17% using electric power wheelchairs (EPW) or scooters^{1, 2}. The number of device users continues to grow³ as does the number of people who cannot use the technology available today. A survey study by Fehr, et al⁴ demonstrated that approximately one quarter of a million individuals cannot use EPWs because of a variety of impairments in motor function, sensation, or cognition. The authors concluded that about half of the individuals who cannot currently operate an EPW by conventional methods could benefit if new technology were developed that could accommodate their needs and abilities.

Most classic research on control interfaces in general has focused on unimpaired individuals such as surgeons, pilots, and computer operators⁵⁻⁷. These studies demonstrated the ability of control interfaces to distinguish between intentional or unintentional movements.

While there are some conventional control interfaces on the market today that can compensate for some unintentional movements like small amplitude tremor during tasks like EPW driving, we do not yet have the technology that can accommodate many severe movement disorders like larger amplitude tremor or involuntary movements like severe athetosis. Riley and Rosen⁸ showed that customization of a joystick to an individual user can significantly improve an individual's performance with that control interface. Hence, in the last five years, more research has started to focus on combinations of hardware and specialized software applications could theoretically be used to create a customized device for each individual user. While newer joysticks allow customization of a variety of features, completely customizable joysticks for EPWs is not yet a reality in clinical practice, and later in this article we discuss novel research aimed to make this customization possible. First, we will examine the current state of control interface technology.

Proportional Control

The standard EPW joystick commonly prescribed in the clinic is a type of proportional control, so named because the device's output (here, the wheelchair's velocity) increases as the stick is progressively moved away from center. These devices can also be referred to as movement sensing joysticks (MSJ) because the stick physically moves as a user exerts force on it. Other proportional input devices such as trackballs, some head arrays, or touchpads are also available. Similar controls used by unimpaired individuals are automobile accelerator pedals and

video game joysticks. Efficient use of proportional controls generally requires a certain amount of intact proprioception, joint mobility, and dexterity.

Individuals who do not have the ability to operate proportional controls must use a combination of switches with or without scanning control. While switch and scanning control is outside the scope of this manuscript, the reader should be aware that many options are available besides the technology mentioned in this article, and switches can be added to some of the newer joysticks.

Profiles and Features Overview

Most joysticks have a variety of profiles which can each contain a plethora of different parameter settings⁹. Below is a detailed description of the most common parameters and features used to date. Some devices contain “off the shelf” profiles such as those for a new user, which can be used as a starting template. A clinician may want to have available a wide array of different profiles set up in order to appropriately evaluate clients for power mobility. Each consumer, too, may want more than one profile to accommodate for variations in his or her condition, to accommodate for fatigue or during times of disease flares, for example. Clearly, the number of parameter combinations is almost limitless, so it is important to have a few standard templates established as a starting point for further customization. Decisions about the types of devices and settings to select for an individual depend on a person’s current level of

function as well as the individual's prognosis. Underutilization of these features is probably one of the biggest obstacles to harnessing the potential of today's joystick technology.

Controllers

The joystick is comprised of the interface between the user and the device i.e. the stick, and also a controller which acts as the intermediary between the human input on the stick and the output of the EPW. Controllers contain the electronics and software, modify the signals from the interface, and convert them to output which is passed along to the device being controlled. The controller can be integral i.e. the main controller integrated into the chair and used by the client, or remotely placed, such as one used by an attendant. A non-expandable controller regulates the speed and direction of the power wheelchair drive mechanism and can also be used to control up to two power seating actuators that allow the user to change the orientation of the seat. Typically, non-expandable controllers can accept only a proportional joystick as an input device. An expandable controller can accommodate many other proportional input devices besides a standard joystick, such as a touchpad or proportional head array as well as non-proportional input devices such as a sip and puff or head array switches. This type of controller will also operate 3 or more power seating actuators, sometimes requiring an additional component to do so. An expandable controller may also be used to operate such devices as a separate display for a different control interface, an alternative and augmentative communication device, a computer, or an attendant control.

Mounting and Compatibility Issues

Appropriate mounting of the input devices is critical to functional operation for any user and requires a thorough clinical assessment to determine the best access point for the device. Some joysticks have a built in handrest for stability, and the shape of the stick can often be changed to accommodate the body part that is being used to operate it.

Not all control interfaces can be used with all EPW bases. Intellectual property issues and incompatibility issues between components and brands limits a clinician's ability to create a truly fully customizable device which is another hurdle to advancements in this field. Software must also be updated frequently, which may require an SD card, a flash upgrade, or download via computer. Some systems, when taken "off the shelf" have factory settings, and a programmer or SD card may be needed to modify the device for a particular user. Some systems, on the other hand, are "plug and play," meaning some of the modules can be recognized and programmed automatically.

Programming

Many different joystick parameters can be programmed or customized. Usually a separate programming device is used to program these features, but some parameters can be

programmed through the display on the input device itself. In other cases, programming files can be transferred by mini-USB or memory stick. Some devices may allow memory back up of a program for later use. This may be particularly important for a clinician who spends a great deal of time creating a custom program and who wants to use it for a similar client or tweak it later for the same client. Occasionally, a new programming device may be needed if the control interface technology changes substantially. If an input device is not programmed appropriately, the device may be very difficult to control, which could result in the client appearing to fail an initial assessment for power mobility, an unsafe driving condition, or could result in fatigue during use.

Some programming devices also allow programming of parameters during use of the EPW so they can be tested in real time. Diagnostics may be available that can help the programmer troubleshoot errors. Parameters such as the wheelchair speed or angle of seat tilt can sometimes be monitored in real time.

There are several different parameters that can be programmed. Changing torque can provide more power at lower speeds. Sensitivity and acceleration can also be set, controlling how quickly the EPW will respond to the user input. Some manufacturers refer to changing the sensitivity as “tremor damping;” however, this use of the term does not refer to filtering a specific frequency of movement. The dead zone (also sometimes called the deadband or neutral zone) is the distance through which the joystick can be moved but for which no EPW output will be generated. Some models offer an alternate mode in which the EPW’s other features, such as a

communication device can be used but the chair is disabled from driving mode. Another difference among interfaces is the tracking technology which is used to reduce the compensatory movements a user must make, such as for caster alignment after making a turn.

Display and Access Methods

The joystick display may be in color or black and white, and some are backlit. Generally, several different languages are supported and font or style can be changed. The display screen on some models is difficult to view for individuals with low vision. Some models display pictures or symbols which can be helpful for clients who cannot read or with low vision. Audible displays are not yet conventionally available. Some models now also have clocks, odometers, or auxiliary modes for storage and display of image files such as photos or object images, which clients may desire not only for “leisure” but also to assist with communication.

Additional features

Various buttons, dials, or toggle switches may also be present to allow the user to switch modes, shortcut to a different function, control power or speed, access different profiles or power seat functions, or allow the joystick to operate as either a proportional control or a switch. Additional switch jacks may be available to allow additional switches to be added. Newer models may contain an infrared output signal that can control end devices such as televisions or

telephones, X-10 control which allows for control of some appliances, or Bluetooth to control an on screen keyboard or full, "un-tethered" mouse control.

The Future of Joystick Technology

Isometric controllers for power mobility devices are not yet commercially available but are emerging as an alternative input device with much promise, especially for users with spasticity or complex movement disorders¹⁰. Isometric joysticks (IJs), as opposed to proportional joysticks, are non-compliant devices that sense force exerted on them; they do not change position perceptively when a subject applies force. An automobile brake pedal is an example of an isometric control. Once the brake engages, the pedal barely moves, but pressing harder with the foot proportionally increases the braking action. IJs can detect intent of motion by sensing force without the need for large displacements of the stick. That is, IJs require only the production of a simple, graded muscle force rather than the movement of multiple joints in the forearm and hand. Zhai, et al¹¹ have shown that although isometric controls are initially less intuitive to use, once mastered, they may be less fatiguing and produce smoother movement trajectories.

A few previous studies¹²⁻¹⁵ have compared IJs to MSJs and have shown that IJs have better accuracy in tasks such as computer target acquisition. However, these studies also reported that because IJs lack damping features, they were very poor at attenuating unintentional movements. Thus, IJs were initially thought to be too sensitive in the face of movement

disorders and even in normal physiologic tremor. For those individuals already familiar with MSJs, it was thought that proportional control may still be the best option. Yet, because of the desirable features of IJs that allow them to be operable by those with limitations in range of motion and motor control, our work has focused on improving these types of controls.

We have developed The Human Engineering Research Laboratories (HERL) IJ¹⁶⁻²¹ (see Figure 1) which uses a programmable embedded microcontroller that provides some flexibility in how the user's input is interpreted. The HERL IJ has been tested in both computer access tracking tasks and in real world driving by subjects with and without upper limb impairments. In prior work, subjects who used the IJ had quicker trial times and fewer movement errors during forward and circular driving than when they used the MSJ^{17, 18}. To allow better customization of the IJ, Spaeth, et al. then developed a Force Sensing Algorithm (FSA)²² that allows an IJ to act as a simple isometric device and a Variable Gain Algorithm (VGA)²² that allows an IJ to simulate many of the features of an MSJ.

For the purposes of our initial work¹⁰ we wished to compare a customized IJ to standard of care, that is, to a conventional joystick that consumers receive in the clinic. This study showed that if an IJ is customized appropriately, it has a very short learning curve and its performance is on par with that of an MSJ. One drawback to isometric control is a user's tendency to overexert force on the device, much more than what is needed to control it. However, our subsequent research²³ shows that this is likely a factor that can be mediated with much less training than was once thought.

Additional parameters are also emerging as ways to further customize joysticks¹⁰. When individuals exert force in forward, reverse, or side directions, their movement axes are sometimes biased away from 90 degree angles. Thus, we developed tuning software which can bias the axis angles in order to align directional movement of the chair with the intentional directions of the user. As mentioned before, dead zones are now also being used. However, current devices on the market allow limited customizability of deadzones, which are usually circular in shape. We have developed tuning software that allows for more complex deadzone shapes. Additionally, we have found that customizing gain is important for those with impaired strength or motor control and that the mechanical template inside the joystick case that limits stick excursion may not be adequate to control force production in some situations like outdoor driving²³. It may be necessary to customize the template, or the maximum force on the joystick that should be recognized in each direction. These parameters can also be programmed virtually for isometric joysticks even though the sticks have no observable excursion. We have also investigated various correction algorithms that can significantly decrease the error and variability in movement produced during joystick use²⁴.

Some standard proportional joysticks contain low pass filters, and some have built in damping features due to the nature of the rubber boot around the joystick post²⁵. These filters allow damping of high frequencies such as those from environmental vibrations. However, low pass filters are often inadequate for filtering some human unintentional movement such as tremor. If the filter is set in the range of human tremor, inevitably some intentional human movements are also cancelled. One solution is employing adaptive notch filters which can

dampen frequencies within a small range. This method has been useful for surgeons performing microsurgery⁶, but has not always been sufficient when tested in individuals with disability and tremor²⁵. Future research will focus on creating a “smart filter” that could continuously monitor the vibration frequencies from various sources and adjust accordingly. Previous research²⁶ on dynamic coupling principles might also be applied to help overcome the effects of frequencies that are transmitted to the hand when EPWs are driven over rough terrain.

We have collected large amounts of data in individuals with such diagnoses as athetoid and spastic cerebral palsy, multiple sclerosis, various forms of tremor, and in control subjects, and future work is aimed at comparing tuning parameters to identify overarching themes that are common to each diagnostic group. Identification of such parameters would allow for development of a series of default tuning parameters that could be available as software packages for particular diagnostic groups and which then could be further customized according to individual user needs.

One useful addition to joysticks may be haptic feedback in the form of vibration or audio signals that indicate when users have produced adequate force to about half of the template maximum, or when they are exceeding the threshold needed to control it. This may allow gain to be adjusted and may counteract some of the effects that are due to limited proprioception. It may also be worthwhile to consider using a joystick with variable compliance, such that the stiffness of the joystick varies along a spectrum from an MSJ to an IJ.

Of course, as our control interfaces advance, so must the controllers. As more complex algorithms are developed, the need for more advanced controllers that can handle the mathematics will increase. Most current EPW controllers also ignore the wheelchair dynamics, making them unable to ensure the same performance with variations in loads or terrain. Cooper, et al. are developing an advanced controller based on a kinematic and dynamic model of a wheelchair (NIH R03 HD048465-01) that will be able to be augmented with advanced algorithms and that will accommodate a variety of interfaces²⁷.

Another worthwhile direction of future research is developing a device for recording the signals generated from control interfaces—not only joysticks, but also other input devices like switches. Currently, there is no technology that allows clinicians to observe and analyze the signals generated by the user. Access to such data would allow clinicians to custom tune the interface, identify algorithms that could be applied (e.g. tremor filter), identify targets for training (e.g. excessive use of force on a joystick that results in arm fatigue), or identify efficacy of treatment on functional use of an interface (e.g. medications or interventional injections for spasticity). We aim to design and develop a technology (I-Log) that can record and analyze input signals.

It is likely that in the future, people will be able to use a single device for not only their computers and wheelchair driving but also environmental control of many target devices like garage doors, keyless entry, home lighting, heating and air conditioning thermostats, and a universal remote for home entertainment products; portable augmentative communication aids;

or alternative methods to operate a mobile phone. The development of integrated controls would offer third party payers the option of funding single multifunctional controls rather than separate, and would benefit the many users who lack funding for the many different devices they may need in their everyday lives.

The overall goal of improving control interface technology is to allow those who might otherwise not be able to drive an EPW to have independent mobility and to give marginal drivers better control over their EPWs and other end devices. Developing better control interfaces that can be used despite motor impairments and movement disorders may improve computer access, mobility, community interaction, and ultimately quality of life for millions of individuals⁴.

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Figure 1: Human Engineering Research Laboratories Isometric Joystick