The Information Technology and Innovation Foundation

Accessible Voting Technology Initiative

Working Paper Series

Working Paper #009

Smart Voting Joystick for Accessible Voting Machines

Sarah J. Swierenga, UARC

Jennifer Ismirle, UARC

James E. Jackson, UARC

Graham L. Pierce, UARC

Robert Decloniemaclennan, UARC

Aditya Mathew, RCPD

Stephen Blosser, RCPD

Usability/Accessibility Research and Consulting (UARC): usability.msu.edu

Resource Center for Persons with Disabilities (RCPD): rcpd.msu.edu

December 30, 2013

The Information Technology and Innovation Foundation
1101 K Street NW, Suite 610
Washington, DC 20005
(202) 449-1351

This research was supported by the U.S. Election Assistance Commission (EAC) under grant number EAC110149B. Any opinions, findings, conclusions or recommendations expressed in this report are those of the authors and do not necessarily represent the views of EAC or ITIF.

Table of Contents

Acknowledgements

This research was funded through a grant from the Information Technology & Innovation Foundation (ITIF), Accessible Voting Technology Initiative (AVTI) to Michigan State University (ITIF Subgrant No. 2013004; Prime Grant No. EAC110149B – U.S. Election Assistance Commission). Principal Investigator: Dr. Sarah J. Swierenga, Michigan State University, Usability/Accessibility Research and Consulting.

We want to acknowledge the Michigan State University ECE 480 capstone engineering team for the design and implementation of the first iteration of the Smart Voting Joystick prototype. Team members:

- Yangyi Chen
- Tyler Dennis
- Graham Pence
- Behdad Rashidian
- Joy Yang

We would also like to acknowledge Jay Nemchik and Christopher Casey, User Experience Interns at MSU UARC, for their assistance with data analysis.

Executive Summary

This report describes the development and usability testing of the Smart Voting Joystick prototype, a dual-axis joystick with auditory and haptic feedback, designed to improve access to private and independent voting for individuals with motor- and dexterity-related disabilities.

The Smart Voting Joystick was designed using a collaborative and iterative process that brought together undergraduate Engineering students interested in designing for individuals with disabilities; rehabilitation engineers from the Michigan State University (MSU) Resource Center for Persons with Disabilities (RCPD); and User Experience Researchers from MSU Usability/Accessibility Research and Consulting (UARC). Feedback from representative users, as well as best design practices from the usability, accessibility, and engineering research literature, was incorporated throughout the design process.

Evaluation of the Smart Voting Joystick prototype was conducted at UARC, and sought to test the joystick's potential for improving access to voting by collecting qualitative and quantitative data on the usage of the joystick prototype by six participants with varying degrees of dexterity and motoric disabilities.

The usability evaluation demonstrated that the current iteration of the joystick largely met the needs of users with moderate dexterity impairments, and participants with more severe impairments strongly endorsed the use of a joystick, though modifications will be necessary to ensure that the prototype can be successfully used by this group, as well. Adjusting specific features of the joystick, buttons, and user interface (including button debounce time and joystick size, shape, and feedback settings) would likely improve its usability for both groups; recommendations for enhancements are provided based on the data analysis. During the usability evaluation researchers also identified and analyzed a variety of different usage strategies for interacting with the joystick, including pushing, pulling, grasping, striking, and flicking, and given the limited availability of research on this topic, the results represent a significant contribution to the literature.

The Smart Voting Joystick has demonstrated tremendous potential to enable voters with physical impairments to vote privately and independently, without significant discomfort and within a reasonable amount of time. Initial reactions from the public have also been positive, with interest from election officials around the country. While further refinement could improve the joystick's usability for individuals with severe dexterity impairments, the current iteration of the prototype has strong potential for commercial development.

Introduction

Individuals with disabilities report encountering many barriers to participation in social and civic life, including substantial impediments to voting in elections in the United States. As a result, people with disabilities are less likely to vote than individuals who do not have disabilities (7% less likely in 2008; 3% less likely in 2010) (Kaye, Kang, & LaPlante, 2000). The most common barriers to voting cited by people with disabilities are related to problems with voting equipment, transportation, having an illness, and voter registration problems. Although progress has been made, voting equipment that is currently designated "accessible" cannot be successfully used by individuals with many common disabilities, and the amount of time or effort required to vote using such equipment can be prohibitive (Swierenga & Pierce, 2012). In 2013, the U.S. Government Accountability Office found that 46% of polling locations still utilize voting systems that are not completely accessible, such as stations that do not accommodate wheelchairs (GAO, 2013). As a result, individuals with disabilities are far more likely to require the assistance of another person when voting, infringing on their right to cast a private ballot.

This research project addresses one of these barriers by creating an input device that is more easily used by people with limited use of their hands and arms. According to the U.S. Census Bureau, 6.7 million people in the United States have difficulty grasping objects (Brault, 2012). Furthermore, an estimated 125,000 people in the U.S. use a joystick to control a powered wheelchair (Fehr, Langbein, & Skaar, 2000; Kaye et al., 2000). Since joysticks offer precision and control and many users are already familiar with them, this input device should be a reasonable solution for an accessible voting system. Studies have also shown that force feedback can enhance user performance and accelerate learning (Rosenberg, 1996; Chen & Agrawal, 2013), and its inclusion is therefore ideal.

Background

Beginning in the 1970s, The Artificial Language Laboratory at Michigan State University (MSU) began developing augmentative communication systems for individuals that couldn't speak. Stephen Blosser, Mechanical/Rehabilitation Engineer, joined the lab in 1978 as Technical Director. Many successful joystick-based control devices were developed during this time that enabled individuals with proprioceptive and neuromuscular coordination challenges to speak. Some of these innovations were presented at the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) and other conferences. One paper from the lab, entitled "A Customized Joystick for Computer Control," was presented at the Annual Conference on Engineering in Medicine and Biology (ACEMB), and informed physicians of the benefits of adjusting the forces and kinematics of input devices to match a patient's threshold for control (Blosser & Eulenberg, 1985). Such research continues to be relevant today as we search for the best methods to enable individuals with disabilities to vote independently.

User experience researchers at MSU Usability/Accessibility Research and Consulting (UARC) have been involved in a number of accessible voting projects over the past several years, such as the Usability in Civic Life Project (usabilityinciviclife.org), which included the Local Election Officials (LEO) Usability Testing Toolkit and the Better Ballots project, in collaboration with the Brennan Center for Justice. The team has also worked on several research projects with the National Institute of Standards and Technology. The first such project involved developing a test protocol for Voting System Test Laboratories to conduct usability conformance testing of accessible voting systems with persons who are blind, have low vision, or have dexterity impairments, in order to ensure that they can vote independently using electronic systems (Swierenga & Pierce, 2012). The second project involved the creation of an accessible user interface and interaction design for accessible mobile (i.e., tablet) voting systems (Swierenga, Pierce, & Blosser, 2013; Swierenga, Pierce, Jackson, & Decloniemaclennan, 2013). The latest project will prototype, evaluate, and refine the accessible mobile voting user interface and interaction design.

Current Project

For the current project, the UARC team partnered with rehabilitation engineers from the MSU Resource Center for Persons with Disabilities (RCPD) and Engineering students (one senior engineering student capstone design team from the MSU Electrical and Computer Engineering department as well as students in an introductory Engineering course) to create a smart dual-axis joystick with a force feedback feature and three external buttons that interacts via a USB interface with a computerized ballot that mimics the interaction with a typical voting system.

The project consisted of three phases: Research and Experience Design, Solution Design and Implementation, and Refinement and Evaluation. During the Research and Experience Design phase, students met with UARC and RCPD experts to understand voting environment needs for persons with dexterity and mobility limitations. The researchers also reached out to other voting research groups, including those at the Georgia Tech Research Institute and the University of Baltimore, to gather additional insights for user and technology requirements. During the Solution Design and Implementation phase, the capstone design team built a fully functional prototype of the Smart Voting Joystick, with both single- and dual-axis modes. The device was designed using a collaborative and iterative process that integrated feedback from users with motoric and dexterity disabilities, as well as best design practices from the usability, accessibility, and engineering research literature. While integral display (i.e., visual display of progress/input on the joystick itself) was initially expected to be included, it was determined that it would be redundant and distracting once the joystick was attached to a voting system with its own display, and it was therefore not pursued or included.

The resulting Smart Voting Joystick prototype has adjustable tension and provides the user with auditory and haptic feedback (Figure 1). The students presented this project at the MSU Engineering Design Day in April, 2013; the project was also presented at the EAC/NIST Accessible Voting Technology Research workshop in Gaithersburg, MD (Chen, Dennis, Pence, Rashidian, & Yang, 2013a; Chen, Dennis, Pence, Rashidian, & Yang, 2013b; Swierenga et al., 2013; Swierenga & Pierce, 2013; Swierenga et al., 2014).

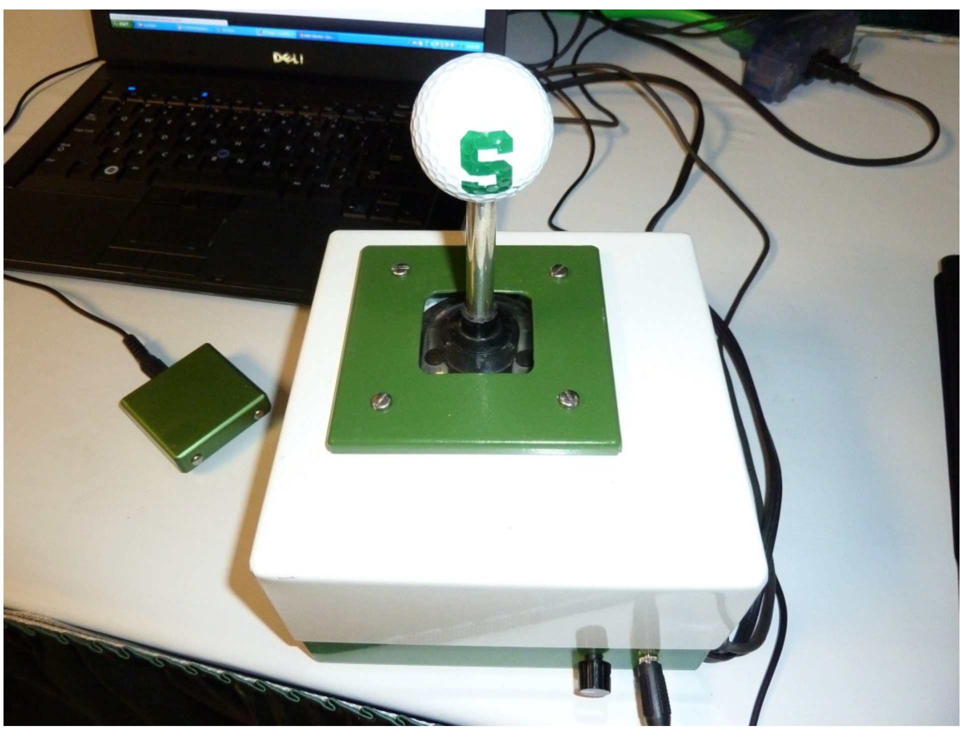

Figure 1. First iteration of the Smart Voting Joystick, created by the student capstone team.

In a separate sub-project, a team of engineering professors and teaching assistants, and professional staff from RCPD oversaw 60 students from an introductory design engineering class (EGR 100) in 10-12 person teams. These teams created multiple options for quick mounting that would not only accommodate a joystick, but also tablets, trackballs, mice, buttons, and other input devices that could be used to make voting more accessible (see Attachment 1).

During the Evaluation and Refinement phase, the developers from RCPD and the usability and accessibility researchers from UARC continued to refine the joystick that was initially created by the students, including an exploration of the size of handles and knobs for the joystick (see alternative designs in Attachment 1). A computer-based mock ballot was also developed that could be easily controlled by the joystick to allow user testing.

UARC researchers conducted a concept usability evaluation of the Smart Voting Joystick with six persons with motor and dexterity disabilities in October of 2013. The results of the usability evaluation are presented in this report.

Smart Voting Joystick Description

Figure 2. Smart Voting Joystick alongside Enter, Review, and Help buttons.

The Smart Voting Joystick prototype (Figure 2) was used in conjunction with three buttons, and was connected to a desktop computer that displayed the sample voting ballot (Figure 3). The dual-axis joystick can be moved in four directions: up and down to scroll through the options in a contest/screen, and left and right to move between contests/screens. It also includes a single-axis mode. Users experience force feedback when moving the joystick, which includes auditory and haptic feedback. The joystick is also programmable, so that its operation can be modified through firmware changes in the future. The three buttons were Enter (used to make selections), Review (used to jump to the ballot review screen), and Help (used to jump to the help screen).

The Smart Voting Joystick allows for software adjustments to several features, including force feedback (felt as a "pulse" when the joystick is moved) and return-to-center force (how much effort is required to move the joystick), and debounce delay time (minimum time between inputs; actions taken within this interval are ignored). Replacement and alternative handle designs can also be used. However, in order to allow comparison across users, the force feedback, return-to-center force, debounce delay time, and joystick handle were kept consistent for all users during testing. The Smart Voting Joystick also has the option of single- or dual-axis modes, but only the dual-axis mode was used in testing. For more detailed specifications of the Smart Voting Joystick prototype, see Attachment 2.

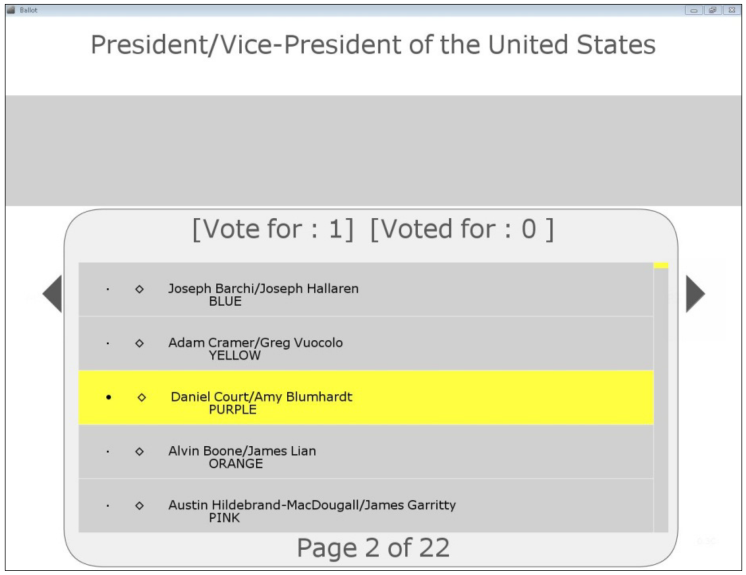

Figure 3. President/Vice-President contest on the sample ballot.

Joystick Interaction

After scrolling to a desired candidate or choice, the user must press the Enter button to select it. If a user wishes to change their selection, they must first deselect the existing choice by moving to it and pressing Enter, scrolling to the desired candidate, and pressing Enter to select them. To move to the next contest, the user can either move the joystick to the right twice (or to the left twice to go back), or to the right or left (forward or back, respectively) once to select the arrow icon and then press the Enter button to activate it. The Help button can be pressed to view instructions for the ballot again (they are initially presented before the user begins voting), and the Review button can be pressed to reach a screen that displays selections that have been made thus far.

For the code and algorithms used in the ballot user interface, see Attachment 3.

Usability Overview

Usability Defined

Usability refers to how easily a specific task can be accomplished with a specific tool. The International Organization for Standardization (ISO) defined usability as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 1998). Effectiveness was defined as "accuracy and completeness with which users achieve specified goals," efficiency was defined as "resources expended in relation to the accuracy and completeness with which users achieve goals," and satisfaction as "freedom from discomfort, and positive attitudes towards the use of the product." While other conceptualizations of usability have been proposed (cf. Nielsen, 1993; Rubin, 1994; Quesenbery, 2003), the ISO definition is the most widely accepted and is used by Usability/Accessibility Research and Consulting in evaluating usability.

> Usability
>
> Ease of achieving a specific goal with a specific tool.
>
> *Effectiveness*: How well the goal is met.
> *Efficiency:* How much energy it takes to achieve the goal.
> *Satisfaction:* How happy a user is with their experience.

Benefits

Implementing usability considerations into design can save time and costs associated with development, maintenance, training, support, documentation, and litigation, and can increase user satisfaction, productivity, task completion, and trust (Marcus, 2005). The return on investment for usability efforts is high:

- Cost-benefit ratios can exceed 1:100 (Karat, 2005)
- User satisfaction can increase by as much as 40% (Harrison, Henneman, & Blatt, 1994)
- Training and supervisory time can decrease by 30-35% (Dray & Karat, 1994)
- Productivity can be increased by 70% (Nielsen, 2007)

The earlier in the production process that usability is implemented, the greater the benefits and savings. It is estimated that for every $1 spent fixing usability problems in the initial design of a system, $10 needs to be spent once it is in development, and $100 once it has been released (Glib, 1988).

Method

Participants

Six participants, five male and one female, took part in the usability testing of the Smart Voting Joystick. All were adult Internet users with dexterity or mobility impairments, with two participants from MSU and four from outside the University. The two MSU participants were not compensated for their participation, in compliance with MSU employment policies; the four non-MSU participants were compensated $50 for their time. This sample included participants with a wide range of dexterity impairments, which clearly split into two groups: there were four participants with moderate dexterity impairments, including muscular weakness (Group 1); and two participants with much more significant dexterity impairments, including functional limitations of spasticity and control, and lack of significant verbal communication capacity beyond yes/no (Group 2).

The four participants of Group 1 included a user experience intern, a student adviser, a retired college instructor, and one participant who is currently unemployed but has worked in higher education. The two participants of Group 2 included an assistant director of sports and a college student. The ages of the participants ranged from 31 to 60; three participants were between 31 and 36 years old and three were between 53 and 60 years old. All of the participants use a desktop computer regularly, and three participants use a tablet or smartphone regularly. Four participants use a keyboard and mouse as computer input devices and two use a joystick. One participant uses a touchscreen tablet and three participants use other devices including touchpads on a laptop, a talking board and voice output communication aid, and a custom buttons.

All participants had voted in a federal or state election prior to taking part in this study; three participants voted by absentee ballot/mail-in, two participants had another person assist them in filling out a paper ballot at a polling place, and one participant filled out a paper ballot at the polling place without assistance. For more detailed participant information, see Attachment 4.

Participants were recruited by the MSU Resource Center for Persons with Disabilities (RCPD) as a sample of convenience.

Materials

Usability evaluations were conducted at the facilities of Usability/Accessibility Research and Consulting, within University Outreach and Engagement at Michigan State University, East Lansing, Michigan.

In the testing room, the test computer and the Smart Voting Joystick (Figure 4) rested on an electronically controlled adjustable-height table. The computer was a Dell Optiplex 780, with an Intel Core 2 Quad Q9400 2.66 GHz CPU and 4.00 GB RAM, displayed on a 19" Dell AX510 LCD monitor at a screen resolution of 1280x1024 at 60 Hz, running Windows 7 Enterprise. Video was captured with a Logitech QuickCam Ultra Vision V-UBH44 USB camera and Morae© (v3.2.1) software (www.techsmith.com/morae). A separate Sony video camera was also used.

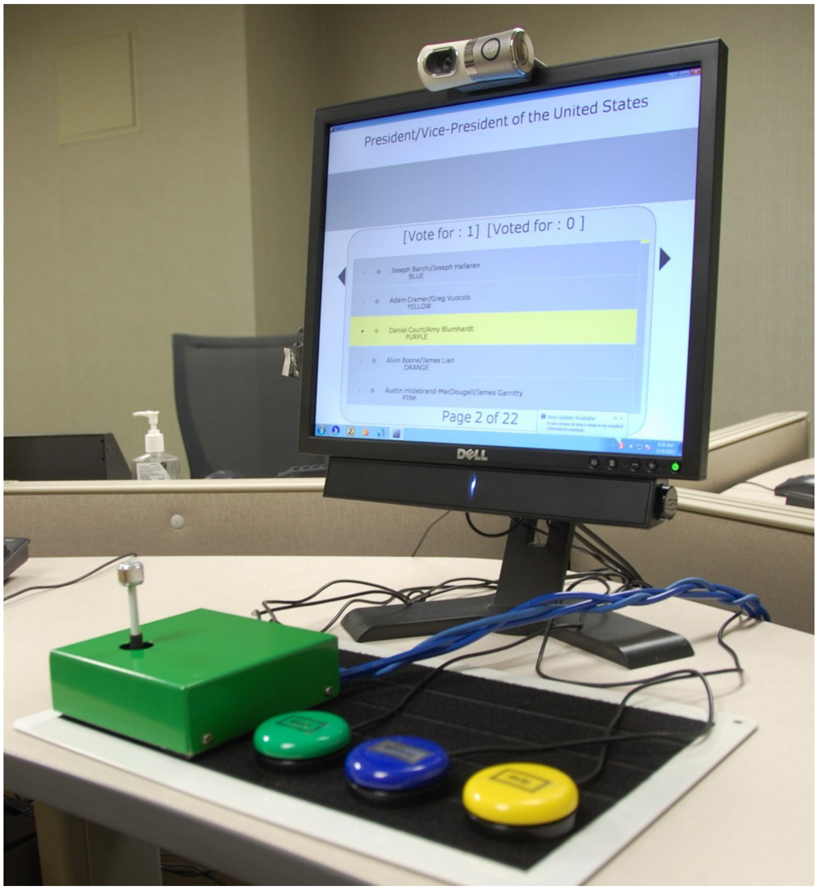

Figure 4. Testing Station for the Smart Voting Joystick

The dual-axis Smart Voting Joystick was connected to the test computer that ran the ballot; this ballot was built as a custom user interface and programmed with *Processing* and *Java* (see Attachment 3 for details). The joystick stem and knob had a combined height of 2.4 inches, with the knob being 0.6 inches and the stem 1.8 inches. The knob of the joystick had a circumference of 1.7 inches, and the stem had a circumference of 0.25 inches. The joystick box (not including the stem) was six inches square, with a height of 2 inches. Each independent button was 2.5 inches in circumference and 0.8 inches tall.

The force feedback of the Smart Voting Joystick was set to a 30 ms pulse of 2.5 Newtons, and the return-to-center force was set at 0.6 Newtons. The debounce delay was set at 100ms to allow ample room for errors and buttons being held down. In addition to this, the Arduino code was designed such that a click is only registered after the switch returns to its original state, removing key repeat and associated errors (see the end of Attachment 3 for this code).

Velcro mounting was used for the joystick and buttons to allow for repositioning to accommodate different users without slippage or movement during use. A 14" x 17" steel plate was covered with Velcro, and the joystick and buttons could be fastened anywhere in the Velcroed area. The bottom of the plate was fitted with rubber grips to prevent it from sliding on the table surface.

Users also had the option to "plug in" to the buttons themselves. One user in our testing connected the Enter button to the foot pedal in their powered wheelchair.

For each participant, adjustments were made to the positioning of the joystick and buttons, and the height of the table (which could be lowered or raised). For example, some participants preferred the joystick to be on the left and the buttons on the right, or vice versa. Although adjustments were made to joystick and button position, the order and relative spacing of the three buttons was maintained for each participant.

See Attachment 2 for more technical specifications.

Procedure

Testing was designed to answer the following questions:

- What do users like and dislike about the characteristics of the Smart Voting Joystick (e.g., buttons, feel, size, etc.)?
- What are user reactions to the "feel" of the Smart Voting Joystick for navigating the mock ballot?

Each one-on-one usability session lasted approximately 90 minutes and included several components:

- Verbal overview of the study: Participants were given a description of the general nature of the study, and the order of activities that would take place was provided (Attachment 5).

- Informed consent: The consent form (Attachment 6) was either given to participants to read, or read out loud to them by the experimenter if they so desired. Each participant was asked to sign the Consent Form before participating in the study.

- Demographic questionnaire: A questionnaire was administered to gather background information on participants' age, job or college major, computer and input device usage, and voting experience. (See Attachment 4 for detailed results)

- Voting task: Participants were asked to use the Smart Voting Joystick prototype to vote a sample ballot for a mock election, using specific instructions (Attachment 7) given to them to read or read out loud to them. These instructions directed participants on how to vote on each of twenty-one contests, and also asked participants to go back and change a particular selection that had already been made. In the interest of time, no write-in candidates were included in the protocol. Participants were asked to think aloud, as they were able, to describe any confusion while performing tasks to aid researchers in identifying areas of difficulty, as well as patterns and types of participant errors. If a participant encountered significant difficulties and was unable to complete the task, the session functioned as an in-depth interview.

- Post-study questionnaire: After voting, participants completed post-study questionnaire (Attachment 8) to provide ratings and assess their experience using the Smart Voting Joystick, and were asked to provide additional comments and feedback.

Metrics

Usability was evaluated in terms of its three constituent components: effectiveness, efficiency, and satisfaction. Effectiveness was measured as the percentage of votes completed accurately. Efficiency was measured as the average time to perform the voting task, and assessed based on issues observed during performance of the task. Satisfaction was measured by the post-study questionnaire, written feedback, and comments made during the session. While effectiveness and efficiency measures were quantitative, satisfaction was measured qualitatively.

Analysis

Both audio and video recordings of the testing sessions were made in order to capture the participants' actions on-screen and their interactions with the joystick and buttons. A separate video camera was used to record the overall scene for each session. Three to four members of the research team took written notes as participants completed tasks.

After user testing was completed, the research team reviewed the video and audio recordings to transcribe relevant user quotes and feedback, compute overall voting completion times and accuracy, record difficulties and successes in completing the voting process using the Smart Voting Joystick, and document the variety of usage behaviors employed by participants.

Results

Some of the participants encountered difficulties using the Smart Voting Joystick prototype, but the majority expressed interest in using the joystick to vote in the future, and indicated that they would recommend the Smart Voting Joystick for others who have difficulty using their arms or hands. Participants also gave a variety of suggestions for enhancements and options to further improve the joystick and buttons.

Usability Results

Group 1: Participants with Moderate Dexterity Impairments

Participants	Time spent voting the sample ballot	Time to go back and change a vote	Percentage of accurate votes
Participant 1	10:33	00:36	96%
Participant 3	6:58	00:26	100%
Participant 5	8:53	00:21	100%
Participant 6	10:51	00:38	100%

Overview

- Three of the four participants in Group 1 were able to complete the ballot 100% accurately using the Smart Voting Joystick, and one participant voted incorrectly on a single contest.
- The average time to complete the ballot was 9 minutes and 19 seconds, and the average time to change a vote was 30 seconds.
- Three of the four were given minimal guidance by the moderator as they moved through the voting process using the joystick. For example, when one user accidentally went past a contest before voting and then became confused, the moderator directed the user to go back to the previously missed contest and continue voting.
- In general, the participants in this group were successful and accurate when using the Smart Voting Joystick to vote. However, the majority indicated that they would prefer less force feedback and return-to-center force, as well as a thicker and shorter joystick. They would recommend the joystick to those with similar needs to themselves, but were not certain that the joystick would work for everyone with dexterity and motor impairments.

Joystick Interaction Strategies

The majority of users in Group 1 pushed or pulled the joystick with one or more fingers. Two participants grasped the joystick at times while pushing or pulling, and one participant grasped the joystick for nearly the entire session. Three of the participants rested the side of their hand or their wrist on the joystick box while using the joystick.

Pushing or Pulling

Pushing or pulling ranged from participants softly nudging the joystick (Figures 5 and 6), to somewhat more forceful pushing or pulling (Figures 7 and 8). Pushing or pulling of the joystick also varied from participants using one or two fingers (from the side or on top of the knob), a thumb, or all of their fingers or palm from the side. While pushing or pulling, participants rested their hand on the joystick box or hovered just above it.

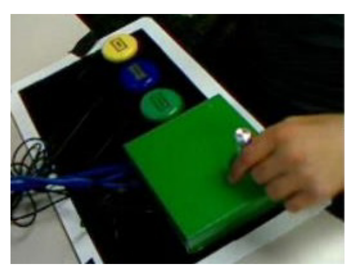

Figure 5. Nudging with index finger.


Figure 6. Nudging with thumb.


Figure 7. Pulling with all fingers.


Figure 8. Pushing with two fingers.

Grasping

At times, participants grasped the joystick knob or stem with one or two fingers and their thumb (Figure 9), or used a hand resting on top of the joystick with one finger making most of the joystick movements (Figure 10). One participant grasped the joystick for nearly the entire session, varying between grasping the joystick with the whole hand to move it (Figure 11), or switching to a looser grip to nudge the joystick with only a thumb or fingers. This participant also switched to slightly wrapping their fingers around the stem of the joystick near the end of the session to scroll down, possibly due to fatigue. At times, when this participant was using a looser grip to move the joystick, they would pass a desired candidate or go on to the next contest before voting, accidentally moving the joystick more than intended while using this type of grip.


Figure 9. Grasping knob and stem with two fingers and thumb.


Figure 10. Grasping top of joystick.

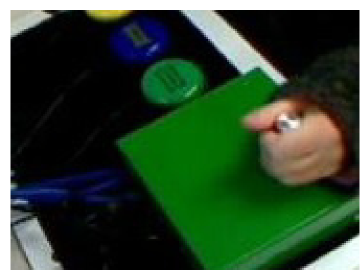
Figure 11. Grasping with entire hand.

Button Interaction Strategies

Three of four participants in Group 1 used one hand for the joystick and the other hand for the buttons, and one participant used the same hand for both the joystick and the buttons. The three participants who used both hands rested their button hand on the table at times and sometimes hovered over the buttons. Two of the participants in Group 1 used one finger to press buttons, and two participants used their whole hand to press buttons.

Joystick and Button Interaction Analysis

- None of the four users in Group 1 did held the joystick down to scroll through candidate lists, instead moving the joystick up or down one selection at a time.
- To move between contests, three of the four participants moved the joystick twice to the right to go to the next contest, or twice to the left to go back to a previous contest. One participant moved the joystick once to the left or the right to reach an arrow icon, then pressed the Enter button to move between contests.
- To reach the Review screen at the end of the ballot, all four participants in Group 1 used the joystick to go on to the next screen, instead of clicking the Review button.

- Three of the four participants voted with the joystick on the left side and the three buttons (Enter, Review, and Help) on the right side. Two of these three participants used both hands (one to operate the joystick and one to operate the buttons), and one used the same hand to operate both the joystick and the buttons.
- One of the four participants in Group 1 voted with the buttons on the left side and the joystick on the right side. This participant used both hands, with one to operate the joystick and one to operate the buttons.
- None of the four participants in this group had issues selecting more than one choice for the multiple candidate contests.
- Two participants received error messages because they attempted to choose a different candidate before deselecting a previously selected candidate for a single candidate contest.
- Participants in Group 1 expressed a preference for the dual-axis joystick, as opposed to a single-axis joystick that would only move either left and right or up and down.

User Comments

- Two participants were very surprised when they first moved the joystick.
    - "Whoa, that feels weird. … Had to get used to the clicking noise it made."
    - "It's got a little kick in it."
- Three participants were confused when they did not see a desired candidate's name on the screen among the first five candidates, until they eventually realized they could scroll down to see more candidates.
    - "I don't see him."
    - "How come I don't see their name?"
    - "[For contests with many candidates, have] some other way of knowing what the other ones are, so I know there is that many people … maybe you don't even know there are more candidates below there."
- One participant had difficulty moving the joystick the desired amount of times for the first half of the ballot. For example, this user often went past the desired candidate without meaning to, or on the next contest by accident. At times, this user also did not move the joystick to move on to the next contest after selecting a candidate with the Enter button, and had to be reminded by the moderator.
    - "Sometimes you hit it once, sometimes you hit it twice. … Just not sure if I'd gone on to the next one."
- One participant was unsure about the Review button and going back to change a vote.
    - "The Review [button] makes sense, but I can almost think of it being a review of what that issue or content means. … The one thing I was worried when I was going back, was I erasing all the ones going back? Is it saving those, or am I erasing my votes?"
- One participant indicated it was easiest to scroll down with the joystick, versus moving left or right.
    - "[It's easiest] to move toward me."
- Three participants thought the feedback of the joystick was somewhat strong, and would prefer weaker feedback. One participant also thought that the feedback indicated that they had pushed the joystick to its limit.
    - "[The feedback] was somewhat strong. The first time it happened scared me, and literally made me jump. So some type of note that you will feel it. … It's almost like it's stamping something, like did I already just vote? Like it punched a hole in the card or something. I didn't need it to be as strong as it was, but I can see that for other people it could be beneficial."

  - "[I pushed it] until I got the feedback. I never knew I could [go further]. I thought that was it, once I got the feedback—thought it was like my warning. I thought almost like I would break the system, based on the feedback, like that's telling me to release it."
  - After being prompted to try holding the joystick down, one participant felt the feedback was "not quite as bad," and that the joystick "kicks more" if only pushed part-way towards an edge.
- One participant mentioned specifically preferring to move the joystick up or down one selection at a time, instead of holding the joystick up or down to scroll, and that including page-up and page-down functions might be better for long lists instead of having to scroll through each candidate.
  - "I didn't want to go by it …. For that big of a [list], paging would be better."
- One participant felt fatigue in their arm at the end of the session, and mentioned that they would prefer a joystick with less return-to-center force.
  - "[After using] the joystick, I found my muscles are burning. The pumping was okay. It does jerk my hand, but it doesn't hurt. For that amount of material though there was too much [return-to-center force]."
- Two participants felt that a shorter and thicker joystick would be easier to use and would allow them to have more control. One participant also indicated that a shorter and thicker joystick would be easier to use "because of the feedback."
  - "I have pretty good hand dexterity. I'd say a bit thicker [stem] though. I'm so used to my wheelchair joystick where you can cup it in the V of your hand … and with just this much [on the joystick], I don't feel like I have control, so I have to hold it up [higher on the knob]. Something bigger, and maybe one constant [thickness]. … More level with the table height, with less of a raised box. And some kind of arm trough or sloped grade."

Group 2: Participants with Severe Dexterity Impairments

Participants	Time spent voting the sample ballot	Time to go back and change a vote	Percentage of accurate votes
Participant 2	*	*	*
Participant 4	29:39	5:38	87%

*Task not successfully completed

Overview

- While participants in Group 2 had sufficient strength to move the joystick, they had impairments that limited their ability to make fine movements, which resulted in a significant number of unintended actions and mistaken inputs and increased the time and effort required to vote.
- Participant 4 completed the ballot successfully with only minimal help (similar to participants in Group 1).
- Although Participant 2 voted a portion of the ballot independently, they encountered difficulties and were unable to complete the voting task successfully. These difficulties primarily related to a lack of left arm support, and problems with specific features of the joystick (i.e., size and shape) played a contributing role. This participant was given significant help with navigating the ballot throughout the session. As a result, this session functioned more as an in-depth interview where researchers were able to make important observations and collect valuable subjective data, but the task time and accuracy of votes could not be used in analysis.

- Both participants employed a wider variety of usage types and strategies than participants in Group 1, including inventive strategies like operating the joystick with the forehead or chin.
- Despite the fact that one participant was able to vote successfully, the testing demonstrated that the Smart Voting Joystick, as it is currently configured, does not cater to the needs of this user group specifically. However, both participants strongly endorsed a joystick in principle, and noted that adjusting specific features of the joystick, buttons, and user interface would likely improve its usability for this user group.

Joystick Interaction Strategies

The two participants in Group 2 used a variety of methods and movements (usually in conjunction with each other) to operate the Smart Voting Joystick, including pushing, pulling, striking, and flicking the joystick, and grasping the joystick at times while making these movements. Neither of these participants rested their hands on the table, though one used the joystick box at times to stabilize or rest their hand when bringing it toward the joystick to make a movement.

Pushing or Pulling

Like Group 1, this group used pushing and pulling movements to interact with the system, ranging from nudges to more forceful movements. Movements were generally more forceful and were far more varied than in Group 1, including the use of a forehead (Figure 12) or chin, closed fist, palm of hand (Figure 13), knuckle of a finger or thumb (Figure 14), a thumb, all fingers, fingertips over the top of the joystick, or a gap between fingers (Figure 15).

Figure 12. Pushing with forehead.

Figure 13. Nudging with palm.

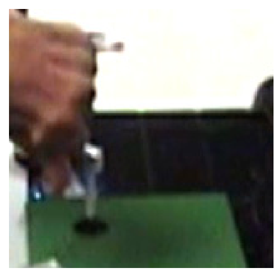

Figure 14. Nudging with knuckle of index finger and thumb.

Figure 15. Pushing with gap between index and middle finger.

Striking or Flicking

Unlike Group 1, this group also used striking and flicking, which are more forceful movements than pushing or pulling, to navigate and make selections. Participants used their hands to strike the joystick at times in order to move it or to grasp it (Figures 16-17), and they also flicked the joystick with their palm, fingers, or fingertips to move it (Figure 18).

Figure 16. Striking with back of hand.

Figure 17. Striking down on joystick with closed fist.

Figure 18. Flicking with fingertips.

Grasping

At times throughout the voting process, both participants in Group 2 grasped the joystick stem or knob with one or two fingers and a thumb (Figures 19-20) to move the joystick. Participants also grasped the joystick with their entire hand (Figure 21), alternating between grasping from the left and right side of the joystick and with a hand or palm on top of the joystick. For these participants, grasping resulted in the most unintended actions (e.g., accidentally switching to a new contest) of any usage type. However, most of these errors were related to aspects of the ballot interface design and could be resolved with minor changes, such as requiring the use of multiple input devices to switch between contests (i.e., requiring the users to move to the arrow icon then pressing select to move between contests). Based on this data, grasping is a potentially effective usage type and one that users from this group will likely employ during the voting process, but joystick and interface designers need to ensure that grasping does not result in a high number of unintended inputs.

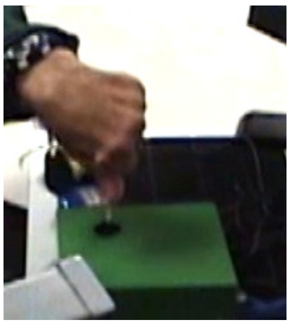

Figure 19. Grasping stem of joystick with thumb and finger.

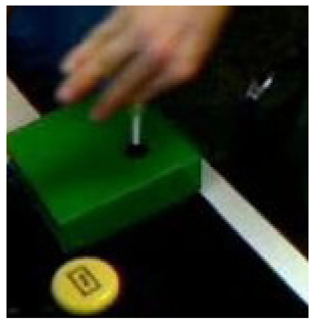

Figure 20. Grasping knob of joystick.

Figure 21. Grasping and holding joystick with hand.

Button Interaction Strategies

When pressing the buttons, both of the participants in Group 2 used an entire hand, with a fist, side of the hand, or fingertips. Neither of these participants rested their hands on the table (as Group 1 often did), but instead hovered over the joystick and buttons between movements.

Joystick and Button Interaction Analysis

- In general, Participant 4 used both hands to operate the joystick (one to press the buttons and one to operate the joystick), and Participant 2 used one hand for both the joystick and the buttons (and forehead and chin at times) and their foot pedal for the Enter button.
- Many of the obstacles Participant 2 faced operating the joystick seemed to be related to a lack of arm support. For instance, to operate their wheelchair joystick, the participant relied on the strong support provided by the wheelchair armrest to stabilize a forearm and operate the joystick largely with wrist and fingers. However, because of the joystick position during the study, similar arm support was not provided, meaning that the participant was forced to utilize their whole arm, unsupported, to operate the joystick. After it became clear that this participant would not successfully complete the ballot, the moderators attempted to adjust the setup to provide better arm support but were unable to do so, given the configuration of the joystick and table at the time.
- Both users did better when striking, flicking, or occasionally nudging the joystick, whereas grasping the joystick caused the most unintended actions, including unintentionally switching between contests and scrolling farther than intended. As a result, both users relied primarily on striking and flicking to vote the ballot, but also indicated they would have preferred a joystick they could hold without causing unintended inputs.

- Although motions like striking and flicking were more successful, there were still a significant number of unintended inputs when participants employed this usage type. For instance, when Participant 4 would move a hand toward the joystick to strike or flick it with an open palm or when this participant would move a hand away after such an action, they would often accidentally hit the joystick with a thumb or finger, undoing the intended action.
- To reach the Review screen, both of the participants in this group pressed the Review button, instead of using the joystick to proceed to this screen at the end of the ballot.
- Participant 2 had more trouble with contests that involved voting for multiple candidates (e.g., select two), whereas Participant 4 had more trouble with voting in contests with long lists of candidates or options, and experienced the most trouble with contests that had both long lists and required multiple selections.
- While Participant 4 experimented with scrolling quickly through the list of candidates by grasping and holding the joystick up or down, both participants preferred to scroll through candidates one by one.
- Both of the participants in Group 2 voted with the buttons on the left side and the joystick on the right side. One of these participants used the foot pedal on their wheelchair as the Enter button, with the other two tabletop buttons (Help and Review) to the left of the joystick.
- While both participants were able to operate the buttons, they often inadvertently pressed the button twice (for Participant 2 this was true of both the provided buttons and the wheelchair-mounted pedal). This meant that participants would often select an item then unintentionally deselect it, and indicates that button sensitivity and careful timing of when buttons are active and inactive are crucial to preventing unintended inputs.
- To move between contests, both participants in this group preferred to move the joystick once to the left or the right to reach an arrow icon, and then to press the Enter button/pedal. However, unintended inputs resulted in both participants often accidentally switching between contests by moving the joystick twice to the right or left when trying to scroll up and down a list of options.

User Comments

- Although both users in Group 2 had far more difficulty operating the joystick than Group 1 and gave mixed reviews of the joystick in the post-study questionnaire, they were both very optimistic about the potential for a voting joystick.
- When asked if a more button-oriented design (e.g., four directional buttons instead of a joystick) would have been easier to use, Participant 4 was adamant that based on their previous experience a joystick was the best input device for this type of task. Furthermore, this participant was fully able to independently operate their wheelchair using a joystick (which was shorter, thicker, spherical, and provided substantial arm support), indicating that their difficulties may be related to features of the specific joystick design instead of the approach itself.
- Both participants in Group 2 thought that the pace of scrolling was appropriate.
- One participant indicated that the "pumping" of the joystick was helpful, and unlike Group 1, both participants indicated that they felt the joystick feedback was too weak.
- Participant 2 expected the joystick to operate as a single-axis joystick, and felt that this would have been easier to use than a dual-axis joystick.
- Participant 4 indicated that moving the joystick away from themselves was easier than moving it towards themself (presumably because moving it towards themself required either flicking or pulling, while moving it away allowed the use of nudging or striking motions). When asked, this participant said that the voting process would have been

easier if the cursor had started at the bottom of the list of candidates instead of the top (so that they would need to scroll down less often).

- Both participants in this group indicated that they would have preferred a joystick that was shorter and thicker, which would have been more consistent with joysticks these participants used previously for successfully interacting with information technology (Participant 4), and operating powered wheelchairs (both participants).
- In contrast with Group 1, both participants in this group stated that they wanted a joystick that was "stiffer" (offering more return-to-center force) and provided stronger feedback.

Post-Study Questionnaire Results

Participants were asked to give ease-of-use ratings for completing tasks using the joystick and ballot. While there were a few low ratings across participants, the ease of use for the joystick and ballot were generally positive, with the majority answering 4 or higher on a 5-point scale for positive statements about the Joystick (Strongly Disagree – Strongly Agree; full text of the Post-Study Questionnaire can be found in Attachment 8). The majority of participants felt that the ballot was navigable and the joystick was easily operated. Those that rated the joystick lower for ease of use either felt fatigue from using the joystick to vote, or had physical difficulties using the joystick due to lack to control and support while using the joystick. Most participants were satisfied with the pace of scrolling using the joystick, but some users did not realize that the joystick could be held down in a direction for constant scrolling.

Participants were also asked to give feedback based on their experience with the joystick. There was a noticeable disparity between Group 1 and Group 2's ratings regarding the feedback of the joystick: Group 1 felt the feedback of the joystick was a too strong, while Group 2 felt that the joystick needed even stronger feedback. Concerning the size of the joystick, some of the participants in Group 1 felt the joystick should be thicker and shorter, with a smaller box beneath it. Participants in Group 2 also mentioned that the joystick was too small, and indicated that the shaft of the joystick should be larger and easier to grip (like a wheelchair joystick). Both groups were satisfied with the placement of the joystick on the table.

Participants also rated the ease of use, placement, and size of the buttons used in conjunction with the joystick. For each category, all participants rated the buttons a 4 or higher on a five-point scale; users all agreed that the buttons were well-placed, that the size of the buttons was suitable, and they were easy to use.

Participants gave feedback on whether they would personally use the joystick, and most agreed that they would if it were available in the next election. Some participants were either not sure, and one participant indicated that they would find it easier to write than use the joystick (due to fatigue issues). When asked whether they would recommend the joystick to others who have difficulty using their arms or hands, the responses were generally positive, with all participants answering 4 or higher.

Users had several suggestions for improvements, such as the ability to change the proximity or spacing of the joystick and buttons, as well as providing users with the option to change a variety of settings before voting using the Smart Voting Joystick (such as the amount of feedback) and the option of a brief tutorial on how to use it. The following are comments made by users while answering whether they would recommend the joystick, indicating the need for more customization:

- "It worked for me, but not convinced it would work for everyone. Proximity—some may need it more spaced out, others may need the ability to re-arrange, or if they only have one hand or arm that they are able to utilize, and some may need it more or less sensitive. [A settings or options page] would be great."

- "I can see for some people, it will be an issue to reach it properly and operate it. For people with similar needs as me, I would [recommend it]. If you had it on a 'boom thing' it might be easier, if you have spring systems in there to help with positioning. For what gets put into [polling] places … because then you are covered for people with lower seating or higher seating, tilt, swivel … and then you don't have to worry about [whether] this person can't quite get in there as far."
- "I wonder if having the whole board [with the joystick and buttons] on something that could slide out or around [would help]."
- In Group 2, one participant liked the joystick a lot and was very enthusiastic, and one participant endorsed the joystick, but had a concern about it working for everyone.

See Attachment 8 for detailed Post-Study Questionnaire results.

Recommendations

Based on usability testing of the Smart Voting Joystick prototype, several design recommendations for the joystick, buttons, and the ballot interface can be made. Implementation and further testing of these recommendations should enhance the capabilities of the Smart Voting Joystick. Future research directions and conclusions are also discussed for issues that were observed, but for which a solution is not yet clearly apparent. These issues may be solved by implementation of the design recommendations, but further research would be necessary to reevaluate them.

Design Recommendations

Smart Voting Joystick and Buttons

- Because the moderate and severe dexterity groups had different preferences for the amount of feedback and return-to-center force for the joystick, these features need to be adjustable. In order to optimize accessibility and preserve voting privacy, the feedback and the amount of effort to overcome the return-to-center force of the joystick need to be easily adjustable by users and/or poll workers before voting begins. Further research needs to be conducted to determine the range of feedback and default settings that need to be available to users.
- As indicated by nearly all participants, the joystick should be shorter and thicker, and potentially more spherical, to allow for easier usage when grasping or pulling the joystick (making it similar to the joysticks on their own powered wheelchairs). For example, a shorter, rounder joystick could prevent users with low motor control from "snagging" the joystick when moving their hand in to strike it or away from it after striking it. The joystick box itself could also be placed into a cut-out in a table or board to alleviate the height issue. More research needs to done to determine optimal dimensions for the joystick, and whether interchangeable components should be available at polling places.
- Sufficient arm support needs to be provided, as users with severe dexterity impairments had difficulties using the joystick because they could not stabilize their hand or arm. One participant relied heavily on the strong support and stability provided by their armrest in order to operate their wheelchair joystick, and therefore was unable to complete the voting process using the current Smart Voting Joystick (even though they expressed their desire to use a joystick for this type of task).

Ballot Interface

- Because participants often unintentionally went on to the next contest when moving the joystick (i.e., by moving the joystick to the right twice), the ballot interface should require the use of multiple inputs to go to the next contest. For example, requiring the users to move to the arrow icon and press the Enter button when they wish to move between contests can help avoid unintentional succession in the voting process. Labeling these arrows "Previous Contest" and "Next Contest" would also make it clear how users navigate the ballot.
- The majority of users indicated they would like an optional tutorial to be offered before voting to get a feeling for the joystick and for the ballot. Adding an optional practice contest allows interested users to explore without impeding or forcing other users to do the same. A "Settings" option might also be offered before participants begin voting to allow setup of the feedback force and other features.
- The instructions provided at the beginning of the ballot need to clearly describe how users can change a vote, and also explain that moving back through the ballot does not erase any votes that have already been made.

- The progress users have made needs to be clearly provided on the screen at all times to remind users which contest they are on and how many contests they have completed thus far (e.g., "Contest # of #: Name of Contest").
- The font size used for the ballot must meet Web Content Accessibility Guidelines 2.0 requirements.

Future Directions

One area that needs additional attention is the enhancement of the self-adjusting features to accommodate a wider group of users, especially users with severe dexterity impairments. Using state-of-the-art motion control would also provide meaningful haptic feedback and filter tremor and other unwanted reflexes. These features will help determine the purposeful movements of users, enabling them to vote with fewer difficulties and errors. These features are easily implemented in a joystick; their use with keyboards, touchscreens, and mice is far more challenging.

The Smart Voting Joystick also needs to accommodate wheelchair users without the use of an expensive electronically controlled adjustable-height table, and must also be easily adjustable in terms of arrangement of the joystick and buttons (whether the joystick is on the left and the buttons on the right, or vice versa). To accomplish this, universal mounts have been investigated (see Attachment 1 for more information), and further research is needed to determine the best option.

Although the Smart Voting Joystick prototype includes a preset debounce time to help prevent a button from being pressed unintentionally immediately after being pressed intentionally, some participants still made unintentional button-presses. Therefore, a longer debounce setting is needed, and further research and testing must be conducted to determine the optimal duration.

Throughout all of the sessions, users made unintended inputs when using the joystick, including moving on to the next contest accidentally and scrolling past the desired option. Users also selected or deselected a candidate unintentionally while using the buttons. Providing an option to adjust the feedback and return-to-center force, and providing a shorter, thicker, and rounder joystick could alleviate these issues, as could a longer debounce time for the buttons. For example, users with severe dexterity issues felt that a joystick with more return-to-center force could prevent them from moving the joystick unintentionally, because it would then take more force to move the joystick in a direction, helping to ensure that minor joystick movements would not cause an unwanted input. Implementation of the design recommendations already discussed could alleviate the issues with unintended inputs, but further evaluation should determine whether these issues are still present and if additional modifications are necessary.

Because of the different functional requirements for the moderate and severe dexterity groups, it will be necessary to offer a joystick with both single-axis and dual-axis modes (which is available for the current joystick, but was not tested). Participants with moderate dexterity impairments preferred a dual-axis joystick, whereas those with severe dexterity impairments expressed interest in a single-axis joystick that would allow them to move through the ballot sequentially to avoid accidentally moving on to the next contest. However, a ballot interface that requires users to use multiple inputs to advance to the next contest (see above) instead of using the joystick alone could provide those with severe dexterity issues with a usable dual-axis joystick. As a result, the type of joystick would need to be revisited and evaluated after implementation of other design recommendations.

We recommend conducting another evaluation after the recommendations are addressed in the design. A new set of 5-6 participants would perform the same tasks. Additionally, usability evaluation also needs to be conducted with the Smart Voting Joystick connected to voting systems currently used in polling places. The option of allowing users to "plug in" other inputs also needs to be tested.

Conclusion

The Smart Voting Joystick has tremendous potential to enable voters with physical impairments to vote privately and independently, and do so without significant discomfort and within a reasonable amount of time, in contrast to existing options. Through the usability testing of this prototype, user feedback and suggestions for enhancements were collected, and qualitative data on the usage of a joystick and buttons by those with moderate to severe dexterity impairments were gathered. The Smart Voting Joystick has received interest from election officials on a national level, with several states reaching out for more information. Media coverage of has increased awareness of this project and the need for such research.

The present study yielded promising results on the usefulness and usability of the Smart Voting Joystick to allow persons with dexterity and mobility disabilities to vote independently. Michigan State University and its partners will continue to seek ways to enhance the usability of accessible voting systems.

Media Coverage

The Smart Voting Joystick project has received a great deal of media attention after a press release from MSU was published regarding the project. Video of the joystick in use is available in this press release: MSU-Created Joystick Advances Independent Voting.

The following sources provided coverage of the Smart Voting Joystick:

Bott, C. (2013, November 1). Engineering students create voting joystick. The State News. Retrieved from http://statenews.com/article/2013/10/engineering-students-create-voting-joystick

Casting ballots independently. (October 29, 2013). MSU Engineering News. Retrieved from http://www.egr.msu.edu/news/2013/10/29/casting-ballots-independently

Joystick advances independent voting. (2013, October 29). Bio-Medicine. Retrieved from http://news.bio-medicine.org/?q=medicine-news-1/joystick-advances-independent-voting-119187

Joystick advances independent voting. (2013, October 29). Electronic Component News. Retrieved from http://www.ecnmag.com/news/2013/10/joystick-advances-independent-voting

Joystick advances independent voting. (2013, October 29). Phys.org. Retrieved from http://phys.org/news/2013-10-joystick-advances-independent-voting.html

Joystick advances independent voting. (2013, October 30). Product Design & Development. Retrieved from http://www.pddnet.com/news/2013/10/joystick-advances-independent-voting

MSU-created joystick advances independent voting. (2013, October 29). Fox 47 News. Retrieved from http://www.fox47news.com/news/wearespartans/MSU-Created-Joystick--229695291.html

MSU-created joystick advances independent voting. (2013, October 29). Michigan State University Today. Retrieved from http://msutoday.msu.edu/news/2013/msu-created-joystick-advances-independent-voting/

MSU engineering students help advance a joystick for voting independently. (2013, October 30). CBS Detroit. Retrieved from http://detroit.cbslocal.com/2013/10/30/msu-engineering-students-help-advance-a-joystick-for-voting-independently/

MSU researchers create voting joystick for disabled. (2013, Ocbober 29). WZZM 13 Grand Rapids. Retrieved from http://www.wzzm13.com/news/article/272339/2/MSU-researchers-create-voting-joystick-for-disabled

MSU researchers invent voting tool. (2013, October 30). WILX 10 Lansing. Retrieved from http://www.wilx.com/news/headlines/MSU-Researchers-Invent-Voting-Tool-229792491.html

New voting joystick could enable people with dexterity impairments to cast ballots independently. (2013, October 30). The Medical News. Retrieved from http://www.news-medical.net/news/20131030/New-voting-joystick-could-enable-people-with-dexterity-impairments-to-cast-ballots-independently.aspx

'Smart Voting Joystick' improves accessibility at the polls for the disabled. (2013, November 13). Capital Gains. Retrieved from http://www.capitalgainsmedia.com/innovationnews/Joystick0739.aspx

References

Blosser, S., & Eulenberg, J. B. (1985). A Customized Joystick for Computer Control. In *Proceedings of the 38th Annual Conference on Engineering in Medicine and Biology* (p. 47.4). Chicago, IL: The Alliance for Engineering in Medicine and Biology.

Brault, M. W. (2012, July). *Americans with disabilities: 2012 household economic studies*. Available from http://www.census.gov/people/disability/

Chen, X., Agrawal, S. K. (2013). Assisting versus repelling force-feedback for learning of a line following task in a wheelchair. *Neural Systems and Rehabilitation Engineering*, *21*(6), 959-968.

Chen, Y., Dennis, T., Pence, G., Rashidian, B., & Yang, J. (2013a, April 24). *Accessible Voting Joystick*. ECE 480 Final Report. Michigan State University, College of Engineering. Student project website available at http://www.egr.msu.edu/classes/ece480/capstone/spring13/group05/

Chen, Y., Dennis, T., Pence, G., Rashidian, B., & Yang, J. (2013b, April 26). *Smart Voting Joystick for Accessible Voting Machines*. Student engineering capstone team poster for MSU Design Day. Michigan State University, College of Engineering.

Dray, S. M., & Karat, C. (1994). Human factors cost justification for an internal development project. In R. G. Bias & D. J. Mayhew (Eds.), *Cost-Justifying Usability* (pp. 111-122). Boston: Academic Press.

Fehr, L., Langbein, W. E., & Skaar, S. B. (2000). Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey. *Journal of Rehabilitation Research & Development, 37*(3), 353-360.

Glib, T. (1988). *Principles of Software Engineering Management*. Reading, MA: Addison Wesley.

Government Accountability Office (2013). *Voters with disabilities: Challenges to voting accessibility.* Retrieved October 28, 2013 from http://www.gao.gov/products/GAO-13-538SP

Harrison, M. C., Henneman, R. L., & Blatt, L. A. (1994). Design of a human factors cost-justification tool. In R. G. Bias & D. J. Mayhew (Eds.), *Cost-Justifying Usability* (pp. 203-242). Boston: Academic Press.

International Organization for Standardization (1998). *Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: Guidance on usability*. (ISO Reference No. 9241-11:1998[E]).

Karat, C. M. (2005). A Business Case Approach to Usability Cost Justification for the Web. In R. G. Bias & D. J. Mayhew (Eds.), *Cost-Justifying Usability: An Update for the Internet Age* (2nd ed., pp. 103-141). San Francisco: Elsevier.

Kaye, H. S., Kang, T., & LaPlante, M. P. (2000). *Mobility Device Use in the United States. Disability Statistics Report 14*. Washington, DC: U.S. Department of Education, National Institute on Disability and Rehabilitation Research.

Marcus, A. (2005). User Interface Design's Return on Investment: Examples and Statistics. In R. G. Bias & D. J. Mayhew (Eds.), *Cost-Justifying Usability: An Update for the Internet Age* (2nd ed., pp. 17-39). San Francisco: Elsevier.

Nielsen, J. (1993). *Usability Engineering*. Cambridge, MA: Academic Press/AP Professional.

Nielsen, J. (2007, October 9). Intranet Usability Shows Huge Advances. *Alertbox: Current Issues in Web Usability*. Retrieved March 28, 2013, from http://www.useit.com/alertbox/intranet-usability.html

Quesenbery, W. (2003). Dimensions of usability. In M. Albers & B. Mazur (Eds.), *Content and complexity: Information design in technical communication*. Mahwah, NJ: Lawrence Erlbaum Associates.

Rosenberg, L., & Brave, S. (1996). Using force feedback to enhance human performance in graphical user interfaces. In *Proceedings of CHI 96 Conference on Human Factors in Computing Systems* (pp. 291-292). ACM.

Rubin, J. (1994). *Handbook of usability testing*. New York: John Wiley and Sons.

Swierenga, S. J., Blosser, S., Pierce, G. L., Chen, Y, Dennis, T., Pence, T., Rashidian, B., & Yang, J. (2013, April 1). *Voting with Joy: Student Project to Create a Smart Voting Joystick for Accessible Voting.* Poster presentation at the EAC/NIST Accessible Voting Technology Research Workshop. Gaithersburg, MD: Department of Commerce, National Institute of Standards and Technology.

Swierenga, S. J., & Pierce, G. L. (2012). *Testing Usability Performance of Accessible Voting Systems: Final Report*. East Lansing, MI: Michigan State University, Usability/Accessibility Research and Consulting.

Swierenga, S. J., & Pierce, G. L. (2013, April 1). *Testing Usability Performance of Accessible Voting Systems.* Poster presentation at the EAC/NIST Accessible Voting Technology Research Workshop. Gaithersburg, MD: Department of Commerce, National Institute of Standards and Technology.

Swierenga, S. J., Pierce, G. L., & Blosser, S. (2013, April 2). *Smart Voting Joystick*. Presentation at the EAC/NIST Accessible Voting Technology Research Workshop. Gaithersburg, MD: Department of Commerce, National Institute of Standards and Technology.

Swierenga, S. J., Pierce, G. L., Blosser, S. R., Matthew, A., Decloniemaclennan, R., & Jackson, J. E. (2014, March). *Smart Voting Joystick for Accessible Voting Machines*. Presented at the 29th Annual CSUN International Technology & Persons with Disabilities Conference, San Diego, CA.

Swierenga, S. J., Pierce, G. L., Jackson, J., & Decloniemaclennan, R. (2013, April 2). *Accessible Mobile Voting Systems*. Presentation at the EAC/NIST Accessible Voting Technology Research Workshop. Gaithersburg, MD: Department of Commerce, National Institute of Standards and Technology.

Attachment 1: EGR 100 Student Contributions to Project

Introduction

Student teams in Engineering 100 (EGR 100) exercised a lot of creativity when creating approaches to make voting accessible for individuals with disabilities. Some teams worked together to make a kit containing a joystick and several other user interfaces and mounts. These user interfaces were designed to accommodate different types of disabilities and will transform a typical voting booth into a universally-designed accessible voting experience for individuals with disabilities.

Figure 22. Game joystick before modifications.

Some teams used a voting machine that consists of a laptop computer running the MSU voting ballot. Other teams used an iPad.

Students have prepared printed user manuals, video tutorials, and posters that describe these projects. They are available through The Resource Center for Persons with Disabilities at Michigan State University.

Accommodating individuals with motoric disabilities

1. Interfacing a typical USB game joystick.

Many individuals with motoric disabilities (dexterity or ambulatory) use joysticks to drive their powered wheelchairs and other functions. One team purchased a game joystick (Figure 22), and installed a program "Joystick to mouse" that enables the joystick to navigate the ballot and make selections. In Figures 23-24, Branden uses a modified game joystick and custom mounts to navigate the ballot.

Figure 23. Brandon sitting in his wheelchair at an adjustable height desk with the joystick fastened to the right corner. The joystick is sitting just to the left of the joystick handle.

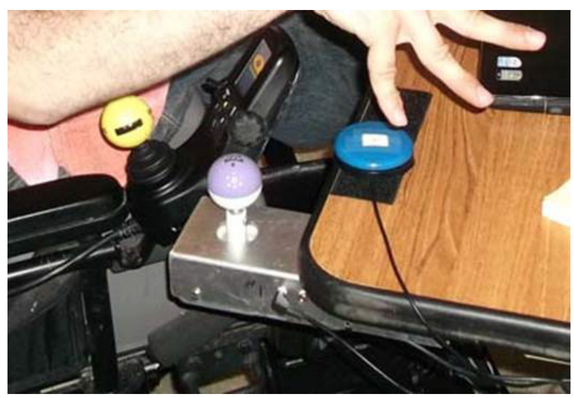

Figure 24. Brandon has moved his hand from the joystick handle to activate the Enter switch.

2. Purchasing and interfacing momentary switches for clicking.

For making selections in the voting ballot, individuals with dexterity challenges often need separate switches for creating the left click of a typical computer mouse. This team purchased several momentary switches and installed a jack on the game joystick to plug them in. A momentary switch is a switch that changes state only while it is pressed, and when it is not pressed it goes back to its normal position. These switches could be used with the person's hand, foot, or other body part (Figures 25-26).

The cable connector from these momentary switches used a standard 1/8 inch diameter monaural mini plug. A versatile switch created at MSU is the SCATIR switch. This infra-red switch is similar to the one used by Stephen Hawking. The SCATIR switch was used and mounted by the EGR100 students.

Figure 25. Momentary single switch used by a hand or other body part. This rugged metal switch was manufactured by the Artificial Language Laboratory, Michigan State University. The name of the switch is TAS, which stands for totally active surface.

Figure 26. This custom-made MSU switch can be used with the foot, hand, head or any body part. It is a very rugged metal switch that can be run over by a car without damage yet can be adjusted to less than 5 grams actuation force.

3. Adjustable Mount for voting joystick and switch.

Several EGR100 teams addressed the very challenging issue of mounting joysticks and switches so that they are adjustable and quickly positioned (Figures 27-33). Several commercially available mounts were purchased and tried. The most successful mounting technique was to cover the surfaces with Velcro, enabling quick repositioning.

Figure 27. EGR100 student is sitting in a wheelchair with his Velcro-covered board mounted to the arm of the wheelchair. There are three round button switches on the board that he is using to make selections from the ballot running on a notebook computer.

Figure 28. This switch and mounting arm were purchased from Ablenet. This young man is operating the switch with the side of his head.

Figure 29. This is the first joystick made by the ECE480 capstone students. EGR 100 students mounted this joystick to the front left side of an adjustable-height desk.

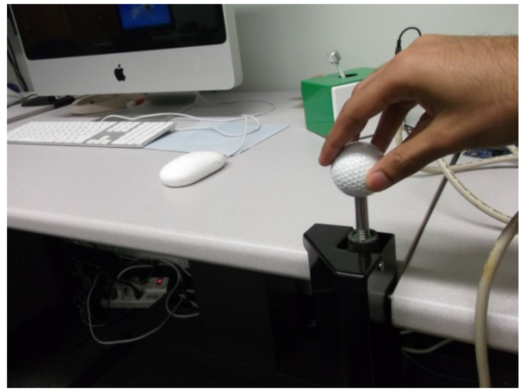

Figure 30. This is another joystick made by the ECE480 students. It is fastened to the front right of an adjustable-height desk.

Figure 31. The surface of this heavy gauge steel plate is covered with Velcro loop. The joystick and three buttons have Velcro hooks on their bottom sides. They can be easily positioned anywhere on this surface. The bottom of the heavy steel plate has polyurethane feet that do not easily slip as the joystick is operated.

Figure 32. This 8 by 11 inch board is covered with Velcro loop. It can be placed on the floor or desktop to hold the buttons.

Figure 33. This cardboard prototype switch holder sits on the floor and has a platform that is height and angle adjustable via a scissors mechanism. A switch is attached to its top surface.

4. A special mount was created that enabled voting using an iPad (Figures 34-35).

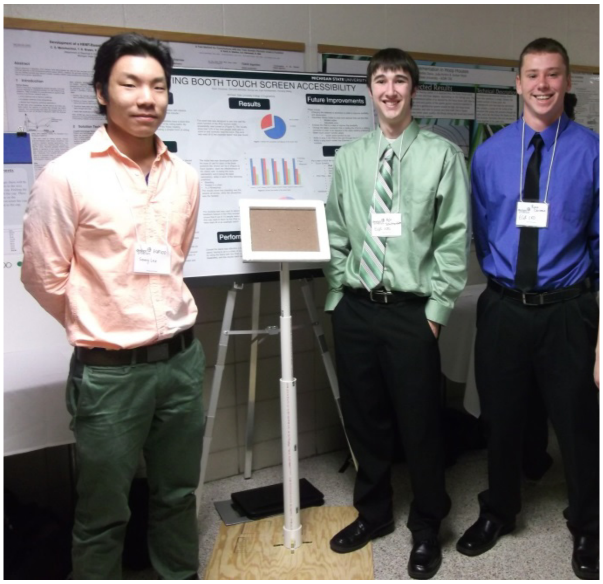

Figure 34. Three EGR100 students show their floor pedestal iPad holder they built. It is constructed from plywood and telescopic PVC pipe. It holds the iPad at a convenient angle for operation. Thumbscrews are used to adjust the height.

Figure 35. A student demonstrates using the iPad holder described in the left picture.

5. Several EGR100 teams interfaced a variety of input devices and used them to navigate the MSU ballot.

These input devices included: a touch pad, sip and puff switch, trackball, single and double switches, touch screen, etc. Sip and puff was interfaced through a scanning program to advance the selection with sip and choose with puff. This program was also used to interface a single switch or double switches. Programs such as http://www.mayer-johnson.com and http://www.tobii.com/en/assistive-technology/global/products/software/tobii-communicator/ were used.

Accommodating individuals with cognitive and reading disabilities

6. Demonstration of voting using a touchscreen.

The MSU ballot worked very easily with a touchscreen. Names and pictures of the candidates and other choices could be selected by direct pointing and touching. This will help individuals with dyslexia and other learning disabilities. It will also enhance use for others with poor vision.

Accommodating individuals with low vision and blindness.

7. Screen readers were used to vote the ballot providing voice feedback. Jaws, SAtoGo, Narrator, Window Eyes, and NVDA were used. A set of headphones would need to be provided for this accommodation.

8. Students demonstrated the use of screen magnifiers including SAtoGo, Zoomtext, and Magic to accommodate individuals needing screen magnification to vote.

9. A Braille display was used for tactile feedback of the ballot.

Voting choices were displayed on the refreshable Braille cells.

Accommodating individuals who are both deaf and blind

10. A Braille display and Pac Mate were borrowed from the Resource Center for Persons with Disabilities.

Several iPhone apps and PC programs were also tested. (https://nfb.org/images/nfb/publications/bm/bm06/bm0609/bm060913.htm)

11. A small hand held vibrator was used with Morse code feedback.

This was similar to an application such as pocket SMS: http://tech2.in.com/features/apps/pocketsms-app-for-the-deafblind/376842.

Attachment 2: Smart Voting Joystick Technical Specifications

Design Objective

This joystick is designed specifically to navigate a voting ballot and to provide tactile feedback as the user moves from item to item. This current version of the Smart Voting Joystick (Figure 36) is designed with the following features:

Figure 36. Joystick and buttons.

1. Emulate the size and feel of a standard return-to-center wheelchair control joystick
2. Provide software adjustable return-to-center spring force
3. Rugged design using high strength metal components
4. Long life construction using solid state hall effect sensors
5. Software adjustable force feedback
6. Quiet, non-distracting, operation
7. Replaceable and alternative handle designs
8. Programmable sensitivity adjustments for speed, force and range of motion
9. Low profile enclosure for easy table top mounting
10. Velcro mounting to enable easy repositioning to accommodate different users

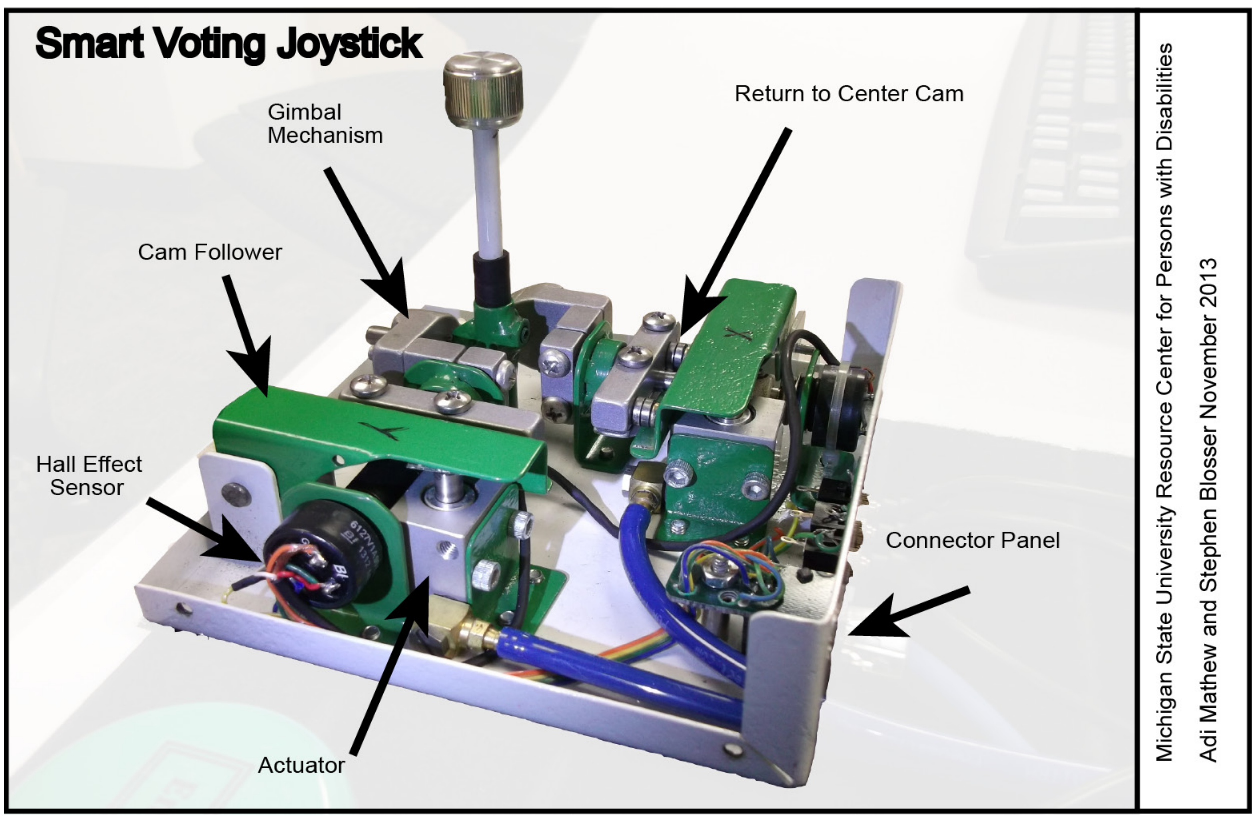

Figure 37. Interior of the Smart Voting Joystick.

Referring to the internal view of the Smart Voting Joystick (Figure 37), these design objectives are accomplished using the following components.

Gimbal Mechanism

This component is a variation of the gimbal device by the Greek inventor Philo of Byzantium (280–220 BC). This joystick gimbal separates the x and y rotational motion of the stick and delivers it to the return-to-center cam and Hall effect sensor for each axis.

Return-to-center Cam

Each x and y shaft have a cam clamped to it. This cam has two rollers that contact the cam follower.

Cam Follower

This lever pushes against the cam causing the stick to return-to-center. The force for this action is obtained from two sources. A weak coil spring adds just enough force to the cam follower to keep the stick vertical. This minimal stick force is about 2¼ oz or 0.6 Newtons. The second source for adding proportional levels of force is the actuator.

Actuator

In this prototype version of the joystick the actuator used was a small pneumatic cylinder[1]. This cylinder was controlled by servopneumatic controller valves[2]. The actuator provides two functions for the joystick. One is to simply increase the return-to-center force of the joystick (Figure 38). This force is then programmable by the servopneumatic system. The second function is to provide haptic feedback to the user. This haptic feedback is also programmable.

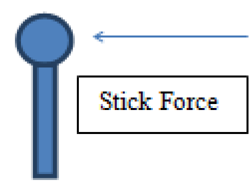

Figure 38. Joystick stick force.

In the current implementation we create a short (30 ms[3]) pulse to inform the user that they have moved from one selection to the next. This pulse is simply a time when the return-to-center stick force is increased. This force can be any value between the minimum 0.7 Newtons to about 20 Newtons. During our usability test we set this value to about 2.5 Newtons.

Joystick Interface Module

The joystick is interfaced through its connector panel to a joystick interface module. This module contains an Arduino microcontroller and servopneumatic system. This reads the position of the Hall effect sensors and controls the return-to-center force and haptic feedback. The interface connects to the host computer via a USB computer interface. This is described in the Smart Voting Joystick electronic system schematic.

---

[1] A coreless dc motor servo may also be used as a feedback device. Electrically actuated servos may be more desirable in a mass produced device.

[2] Servopneumatic valves and systems are featured at the Festo Corporation web site: http://www.festo.com/cat/en-us_us/products__88733

[3] 30 ms=30 milliseconds or 3/100 of a second

Circuit Description

All functionality of the Smart Voting Joystick is controlled by a microcontroller located on the Arduino Leonardo. This computer and its accompanying software program is the "smart" in the voting joystick. The different operations of the system are provided through the following components (and shown in Figure 39).

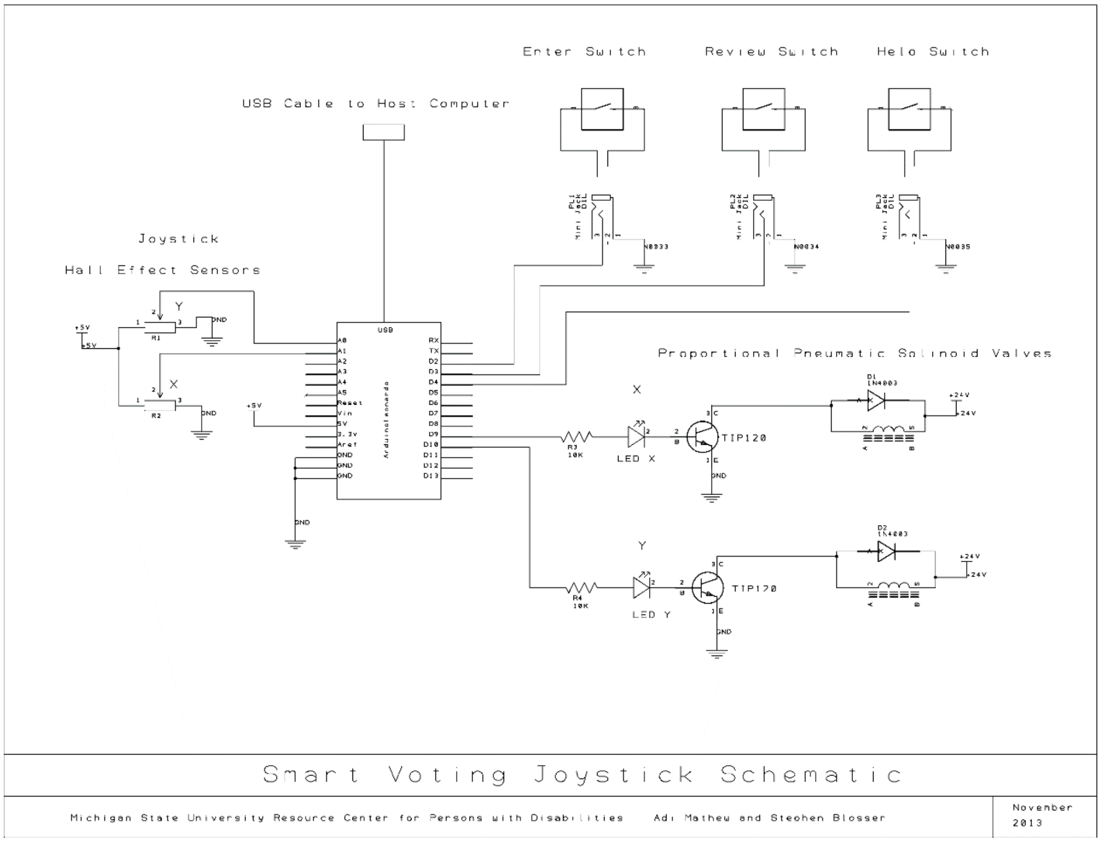

Figure 39. This diagram shows all the electrical connections of the Smart Voting Joystick system. It has an Arduino Leonardo in the center with Hall effect sensors on the left and solenoid valves on the right. Enter switches and USB ports are shown on the top.

Arduino Leonardo

Arduino is an open-source physical computing platform based on a simple i/o board and a development environment that implements the [Processing](http://www.processing.org/) (http://www.processing.org/)/ [Wiring](http://wiring.org.co/) (http://wiring.org.co/) language. This platform provides the USB interface needed to communicate to the host computer that will be displaying the ballot.

Joystick Hall Effect Sensors

These potentiometer style rotary position sensors detect the position of the joystick shaft and handle. There are two sensors, one for X and one for Y. Each sensor outputs a voltage on pin 2 between 0 and 5 V proportional to the position of the shaft. This analog voltage is connected to the Arduino analog voltage port where it is converted to a digital number.

Standard potentiometers would also work for position sensors in this application. Hall effect sensors are superior because they are solid-state, more precise and have a much longer service life.

Enter, Review, and Help Switch Interface

Three 1/8 inch monaural mini jack switch ports are provided on the back of the joystick. These are interfaced directly to the Arduino digital I/O port as inputs. The digital I/O port has internal pull up resistors. When the switch is pressed these digital I/O lines are pulled to ground and read as zero.

Proportional pneumatic solenoid valve interface

Arduino digital I/O lines D9 and D10 are configured as outputs. When these lines output a high signal they turn on the LED, TIP120 NPN transistor, and pneumatic solenoid valves. This sends air pressure to the joystick actuator.

The actuator can serve to provide a feedback pulse or to increase the return-to-center joystick force.

The amount of air pressure can be controlled in two ways. The air pressure is adjustable with a mechanical pressure regulator. Simply turning the knob on this regulator will adjust this pressure. The second method for controlling the pressure is through pulse width modulation (PWM). By sending a variable duty cycle pulsing signal to the proportional pneumatic solenoid valve this pressure can be controlled.

Conclusion

This prototype pneumatic system served well to demonstrate the asset of quick response force feedback. This joystick design was preceded by several models that had electrical feedback actuators. These actuators were constructed using inexpensive motors and solenoids. The first joystick, which was constructed by the ECE 480 capstone design team, used a commercially available feedback mechanism that consisted of an electric motor and gear train.

The shortcoming of these electrical motor actuators is slow response. Fast feedback response makes this haptic signal more meaningful as the user tactilely perceives movement of the cursor from one selection to the next. The slowness of these systems is due to the high mass of iron used in the electric motor rotors.

A mass producible design for a Smart Voting Joystick may include an electrical actuator constructed with coreless motors. These are motors without any iron in the movable rotor. Their rotors consist of only copper conductors. This design has a much faster response time and would serve well in the Smart Voting Joystick of the future.

Attachment 3: Code and Algorithms

The software for this project can be divided into 2 main categories:

1. Hardware level
2. Software/GUI

Hardware Code

The code in this segment is used to interface with the Arduino and uses the provided libraries to read the interaction of the user with the device and give feedback based on that changing input. The goal of this part of the project is to control the hardware behind the feedback, so as to give the user just the right amount of feedback, as well as send relevant input information to the connected computer, thereby giving the user both haptic and visual feedback.

Function(s)

- Read input, i.e., how much the user has pushed the joystick handle.
- Calculate a dynamic feedback response delay, i.e., the delay between each pulse of the feedback mechanism.
- Send this feedback to the feedback mechanism and recalculate based on new positioning.

Implementation

- Reading input is made easy with the Arduino's prebuilt libraries. However, the most important parts in this segment are:
  1. Separation of X and Y axes readings
  2. Keeping NO delay between axes
  3. A code outline would look like:

```
void loop() {
      int a = calc(xPin) ,
          b = calc(yPin) ;
}

int calc(int _Pin) {
      return analogRead(_Pin) ;
}
```

Calculation of the dynamic feedback delay is somewhat arbitrary, since it depends on the hardware implementation of the feedback mechanism. For instance, in previous iterations of the joystick wherein the feedback was servo actuated, this was dynamically calculated using recursive function calls (around a normalized value of the input reading). However, with the pneumatic feedback system, the delays are calculated around a base delay of 30ms. Calculation of further delays is still dynamic, but there is no need to make calls recursive.

```
_pin = input_pin ;
const del = 30 ; //Delay value to begin with
.
.
.
void feedback(int _pin) {
       if (calc(_pin) <= joyCenter) {
              delVar = del + (calc(_pin)-75)/2
              digitalWrite(_oPin,HIGH) ;
              delay(delVar) ;
       }
```

```
}
/* 75 is chosen as it is approximately 1/8th the total range of axis
motion after A/D conversion on the Arduino */
```

- As demonstrated in the previous code sample, sending the calculated feedback out is as simple as setting the appropriate pin high, with the constantly updated delay value. This would be done on both axes separately, and in our final implementation was used to calculate separate delays for opening and closing of the valves, as this gave greater control over the actual feel of the feedback.

Notes

In the version of the joystick that was used in the usability tests, the delaying algorithm above was split to separate delay calculations for opening and another delay for closing the valves of the pneumatic feedback system. While essentially the same, this change allowed for much greater control over the feedback response and feel. The following code demonstrates these changes:

```
_pin = input_pin ;
const del = 90 ; /* larger delay value to allow time for user to feel
the feedback before the valve closes, a value of 75ms would give a
sharper feel*/
.
.
.
void feedback(int _pin) {
	if (calc(_pin) <= joyCenter) {
		delVar = del + abs((calc(_pin)-500))/2
		digitalWrite(_oPin,HIGH) ;
		delay(delVar) ;
	}
}
/* 500 is used when closing the valve as it is approximately half the total range of axis motion after A/D
conversion on the Arduino */
```

Another point to keep in mind when implementing button functionality through the Arduino is to not only keep an adequate key debounce delay, but also to ensure a key press/input is sent only on key release.

```
void buttons() {
	while(digitalRead(_button) == LOW) {
		delay(100) ; //debounce delay
		if(digitalRead(_button) == HIGH)
			Keyboard.press(keyCode) ;
	}
}
```

User Interface and Software

Code in this section is used to provide the end user with an interface to vote with that is customized to feel natural when used with a dual-axis joystick. Figure 40 displays the basic interactions a user would have with the user interface using the joystick. The ballot is divided into pages, with each page containing a list. Horizontal motions of the joystick would swipe through pages and vertical motions would scroll through each list. This basic functionality is modified to be more intuitive in the final prototype, however, the code behind it is essentially the same.

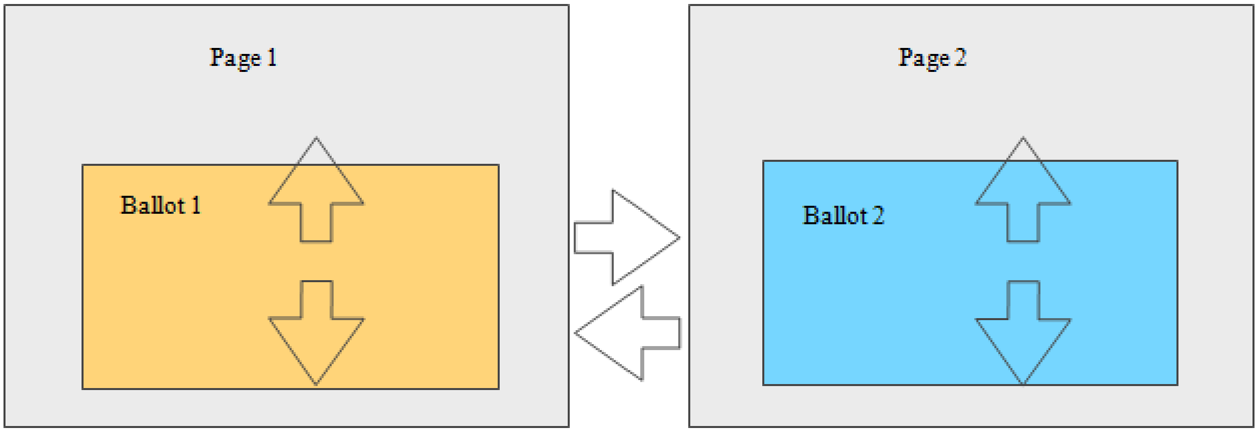

Figure 40. Ballot interface that allows users to scroll vertically through lists, and move horizontally between contests.

Implementation

The majority of this interface was coded in 'Processing,' with more complex functionality implemented in Java. 'Processing' was chosen first, for its ease of prototyping graphical interfaces, and secondly for its strong integration with the open source Arduino frameworks.

Processing is primarily used in the visual arts and interactivity and as such a lot of the graphical elements had to be coded from scratch. A library used to help specifically with the use of list boxes is the controlP5 library by Andreas Schegel (controlP5 website). However, numerous algorithms had to be recoded to make interactions such as scrolling more intuitive when used with a joystick.

The overall outline of the GUI is shown below in Figure 41.

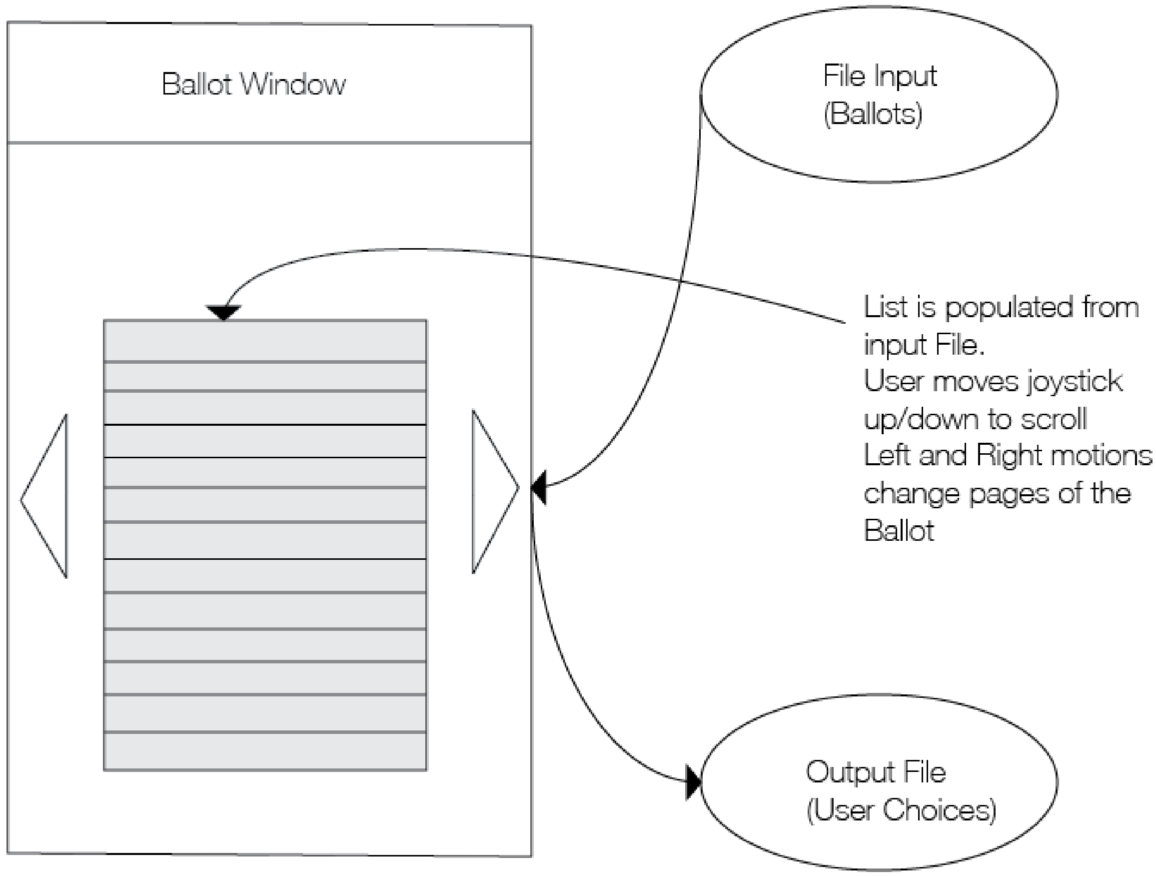

Figure 41. The ballot window displays a list that is populated from the input file, and the output file contains the user choices.

Attachment 4: Demographic Questionnaire Responses

The users who took part in this study included participants with a wide range of dexterity impairments, which clearly split into two groups: four participants with moderate dexterity impairments including muscular weakness (Group 1); and two participants with much more significant dexterity impairments including functional limitations of spasticity and control, and lack of verbal communication capacity beyond yes/no (Group 2).

Group 1: Participants with Moderate Dexterity Impairments

	Participant 1	**Participant 3**	**Participant 5**	**Participant 6**
Job Function/ Title in Agency/ Organization	User Experience Intern	Student Adviser, College of Nat Sci	Retired	Not employed – higher education
Students – Area of Study/ College Major	N/A	N/A	N/A	N/A
Age	31	36	53	51
Do you regularly use a desktop computer?	Yes	Yes	Yes	Yes
Do you regularly use a tablet or smartphone?	Yes	Yes (both)	No	Yes (both)
What input devices do you regularly use with computers?	Keyboard; Mouse	Keyboard; Mouse	Keyboard; Mouse	Keyboard; Mouse; Touchscreen Tablet; Other: touchpads on laptop
Have you ever voted in a federal or state election?	Yes	Yes	Yes	Yes
If yes, how did you vote the last time?	Absentee ballot/mail-in	Absentee ballot/mail-in	Filled out paper ballot at polling place without assistance	Absentee ballot/mail-in

Group 2: Participants with Severe Dexterity Impairments

	Participant 2	Participant 4
Job Function/ Title in Agency/ Organization	Assistant Director (Sports)	Student
Students – Area of Study/ College Major	N/A	Associate of Arts (planning on going into education)
Age	60	32
Do you regularly use a desktop computer?	Yes	Yes
Do you regularly use a tablet or smartphone?	No	No
What input devices do you regularly use with computers?	Joystick; Other: Talking Board and Voice Output Communication Aid	Joystick; Other: Custom select button
Have you ever voted in a federal or state election?	Yes	Yes
If yes, how did you vote the last time?	Had another person assist me in filling out paper ballot at polling place.	Had another person assist me in filling out paper ballot at polling place.

Attachment 5: Moderator's Guide

I. Overview of Study (3 minutes)

Thank you for agreeing to participate in our study. We are very interested in obtaining your feedback about a Smart Voting Joystick prototype for accessible voting machines. We are trying to understanding how people might use the joystick to vote a sample ballot.

In this session, I'll ask you to use the joystick to vote a sample ballot for a fake election using the instructions I'll give you. Remember that this is an evaluation of the joystick's ease of use and not of your performance. You are testing this prototype joystick for us. After you have attempted to vote the ballot, we will ask you to rate your experience. If you don't have any questions, we'll proceed.

Before we get started, we have some paperwork to get through.

- Consent form – **(5 minutes)**
- Demographic questionnaire **(5 minutes) –** "We gather this information so that we can say something about the group who participated in this study."

II. Task Instructions and Task Scenarios Performance (45 minutes)

- Orient the participant to the joystick and computer screen with the ballot displayed.
- Ask participant to vote the ballot on his/her own.

III. Post-study Questionnaire (5 minutes)

- Ask participants to fill out the post-study questionnaire.
- Give participants a hard copy of the usability test information.

Attachment 6: Informed Consent Form

MSU's Office of University Outreach & Engagement is conducting research to evaluate the usability and accessibility of a smart voting joystick for accessible voting machines. User testing sessions are being conducted to gather this information. These sessions will be videotaped to ensure accuracy of comments and to assist in application of the findings. The findings from these sessions will be used to guide changes to improve the usability of the joystick.

If you agree to participate in the research, you will be asked to use the joystick to vote a sample ballot for a fake election in the presence of a researcher, while being videotaped, and share your thoughts and insights as you move through the ballot. First, you will be asked to respond to an initial brief questionnaire. Then you will be asked to verbally provide your impressions of using the joystick to interact with the ballot. Finally, you will be asked to complete a brief questionnaire evaluating your overall experience. Your participation will take approximately one and a half hours and you will receive $50 compensation for your time and participation (however, MSU employees cannot be compensated for their participation). No risk from participation is anticipated. The information that you provide, along with information from other people, will be used to improve the joystick design.

Any information that you share will be kept confidential; your name will not be associated with your comments. The full videotapes will be seen only by the project team at MSU; however, clips may be shared in informational materials about usability and accessibility testing. Your confidentiality will be protected to the maximum extent allowable by law. The evaluation materials will be stored in a locked location, accessible only by the project team and the IRB for a period of three years. At the end of the study, the hard copy session notes and surveys will be destroyed, but the IRB consent form, recordings, transcripts, and data analyses files will be stored on a secure server in the MSU Usability/Accessibility Research and Consulting lab for a period of three years.

Your participation is completely voluntary. You may choose not to participate at all, may refuse to participate in certain procedures or answer certain questions, or may discontinue your participation at any time without penalty. Your decision to participate will not affect your relationship with Michigan State University, University Outreach and Engagement, or the person who identified you as a potential participant. Agreeing to participate and signing this form does not waive any of your legal rights.

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury (i.e., physical, psychological, social, financial, or otherwise), please contact the Primary Investigator, Sarah Swierenga, by phone at (517) 353-8977 or by mail to Sarah Swierenga, Michigan State University, Kellogg Center, Garden Level, East Lansing, MI 48824.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously, if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

If you voluntarily agree to participate in this research, have your comments videotaped, and have had all of your questions answered, please sign below.

Participant's Signature Date

☐ *By checking this box, I give my permission to videotape the session and allow the researchers to use the videotapes or highlight video clips publicly (e.g., educational materials or conference presentations).*

Researcher's Signature Date

Attachment 7: Voting Instructions

For this test to reflect accurately on the joystick interaction with the accessible voting machine, you should follow these instructions that will tell you the names of individuals to vote for and how to vote on each issue. Please attempt to vote exactly as described.

1. **For Straight Party Ballot:**

   Do <u>not</u> vote

2. **For President and Vice President of the United States, vote for:**

   Adam Cramer and Greg Vuocolo (Yellow)

3. **For Senator, vote for:**

   David Platt (Gray)

4. **For Representative, vote for:**

   Brad Schott (Purple)

5. **For Governor, vote for:**

   Cathy Steele (Independent)

6. **For Lieutenant Governor:**

   Do <u>not</u> vote

7. **For Registrar of Deeds, vote for:**

   Laila Shamsi (Yellow)

8. **For State Senator, vote for:**

   Marty Talarico (Yellow)

9. **For State Assemblyman, vote for:**

   Andrea Solis (Blue)

10. **For County Commissioners, vote for the following candidates:**

    Camille Argent (Blue)

    Mary Tawa (Purple)

    Joe Barry (Pink)

11. **For Court of Appeals Judge, vote for:**

    Michael Marchesani

12. **For Water Commissioner, vote for:**

    Orville White (Blue)

    Gregory Seldon (Yellow)

13. For City Council, vote for the following candidates:

Randall Rupp (Blue)

Carroll Shry (Blue)

Donald Davis (Yellow)

Before you move on to the next contest, go back and change your vote for State Senator to:

Edward Shiplett (Blue)

14. For Chief Justice of the Supreme Court:

Vote to keep Robert Demergue in office

15. For the question of retaining Justice of the Supreme Court Elmer Hull:

Do not vote

16. For Proposed Constitutional Amendment C:

Vote for this amendment

17. For Proposed Constitutional Amendment D:

Vote for this amendment

18. For Proposed Constitutional Amendment H:

Vote against this amendment

19. For Proposed Constitutional Amendment K:

Vote against this amendment

20. For Ballot Measure 101: Open Primaries:

Do not vote

21. For Ballot Measure 106: Limits on Private Enforcement of Unfair Business Competition Laws:

Vote for the measure

Find the Review Screen.

Attachment 8: Post-Study Questionnaire Results

The users who took part in this study included participants with a wide range of dexterity impairments, which clearly split into two groups: four participants with moderate dexterity impairments including muscular weakness (Group 1); and two participants with much more significant dexterity impairments including functional limitations of spasticity and control, and lack of verbal communication capacity beyond yes/no (Group 2).

1. I could operate the joystick easily.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1		1			3	
Group 2		1		1		
Overall		2		1	3	3.8

2. If this joystick were available at the polling place in the next election, I would definitely use it.

	1 Yes	2 No	3 Not Sure
Group 1	3	1	
Group 2	1		1
Overall	4	1	1

3. It was easy to vote in the single candidate contests.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1					4	
Group 2		1		1		
Overall		1		1	4	4.3

4. It was easy to vote in the multiple candidate contests.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1				1	3	
Group 2			1		1	
Overall			1	1	4	4.5

5. It was easy to change my selection.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1			1		3	
Group 2		1			1	
Overall		1	1		4	4.2

6. It was easy to access the Review screen in the ballot.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1					4	
Group 2				1	1	
Overall				1	5	4.8

7. The feedback of the joystick was:

	1 Very weak	2 Somewhat weak	3 Just right	4 Somewhat strong	5 Very strong	Average Rating
Group 1			1	3		
Group 2	1	1				
Overall	1	1	1	3		3

8. The pace of scrolling with the joystick was suitable.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1		1		1	2	
Group 2				2		
Overall		1		3	2	4

9. The size of the joystick was appropriate.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1				1	3	
Group 2	1		1			
Overall	1		1	1	3	3.8

10. The joystick's placement on the table was satisfactory.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1				2	2	
Group 2			1		1	
Overall			1	2	3	4.3

11. The buttons were easy-to-use.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1					4	
Group 2				1	1	
Overall				1	5	4.8

12. The placement of the buttons was suitable.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1					4	
Group 2					2	
Overall					6	5

13. The size of the buttons was appropriate.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1					4	
Group 2				1	1	
Overall				1	5	4.8

14. I would recommend this joystick for others who have difficulty using their arms or hands.

	1 Strongly disagree	2 Somewhat disagree	3 Neither agree nor disagree	4 Somewhat agree	5 Strongly agree	Average Rating
Group 1				3	1	
Group 2				1	1	
Overall				4	2	4.3

Author Bios

Sarah J. Swierenga

Sarah J. Swierenga, Ph.D., C.P.E. is the Director of Usability/Accessibility Research and Consulting (UARC) at Michigan State University. A researcher and a practitioner with over 25 years of experience in the scientific study of users in commercial, military, and academic environments, she possesses extensive skills in user interface design, data collection tools, and methodologies. She co-authored *Constructing Accessible Web Sites*, and wrote a chapter for *The User-Centered Design Casebook*. She served as an alternate member of the U.S. Access Board 508/255 refresh committee. Swierenga is a member of the UXPA Voting and Usability Project, an Invited Expert on the W3C WCAG2.0 Evaluation Methodology Task Force, and is a Certified Professional Ergonomist (CPE).

Jennifer Ismirle

Jennifer Ismirle is a User Experience Intern at Usability/Accessibility Research and Consulting, focusing on usability evaluations and user-centered review and analysis of websites. She recently graduated from Michigan State University with a B.A. in Professional Writing, and she has a B.A. in English. Jennifer has worked on a variety of usability evaluations and analyses of extensive and complex data, including research involving an extensive government website (public and employee sides), the intranet of a large insurance company, and a mobile recreation application.

James E. Jackson

James E. Jackson is a User Experience Researcher at Usability/Accessibility Research and Consulting where he works on grant-funded research as well as usability and accessibility evaluations for internal and external clients. James' research interests focus on better understanding the literate practices of individuals with learning disabilities and the implications those practices have for the usability and accessibility of information systems. James holds a Master's degree in Digital Rhetoric and Professional Writing from the department of Writing Rhetoric and American Cultures at MSU.

Graham L. Pierce

Graham has three significant sets of responsibilities at Michigan State University: First, he is a User Experience Researcher at Usability/Accessibility Research and Consulting, where he is responsible for grant-funded research into accessible voting, as well as for supervising and conducting accessibility and usability evaluations. Second, Graham is the Project Manager of the State of the State Survey at the Institute for Public Policy and Social Research, a quarterly phone survey of Michigan adults that provides current information about citizen opinions on public policy issues. Finally, he serves as the Digital Communications Coordinator for the MSU-EDA University Center for Regional Economic Innovation at the Center for Community and Economic Development. In addition to these primary roles, Graham is the Vice Chair of the MSU Accommodating Technology Community and is highly involved in Lansing's Power of We Consortium and in a number of other university and community groups. Graham earned his Master's degree in Cognitive Psychology at Michigan State University.

Robert Decloniemaclennan

Robert Decloniemaclennan has a M.A. in Human Computer Interaction, and he is a User Experience Intern with Usability/Accessibility Research and Consulting. He performs user interface heuristic reviews and accessibility compliance audits for clients. His areas of expertise include accessible web design, Web Content Accessibility Guidelines (WCAG), mobile and website user interface design, and user experience evaluation.

Aditya Mathew

Aditya Mathew is an electrical engineer and experienced programmer at Michigan State University. Adi's work with programming spans multiple languages across numerous platforms from prototyping with Arduinos to native OS development. He is currently designing and working on an accessible GPS solution for iOS and hopes to pioneer a new class of guided navigation apps.

Stephen Blosser

Stephen Blosser is an engineer who serves as Assistive Technology Specialist at Michigan State University's Resource Center for Persons with Disabilities. Stephen serves and represents MSU as a member of RESNA; as Technical Director & Assistive Technology Design Engineer, Artificial Language Laboratory, Department of Audiology and Speech Sciences; as Chair of the Accommodating Technology Community, advising MSU on what technology to adopt in the service of students with disabilities; as Project Manager in the MSU College of Engineering and RCPD; and as a technology consultant and honorary ambassador for Asian Aid, helping students with disabilities in India.