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Seunghyun Tina Lee, Yilin Elaine Liu, Xiao Xiong, and Jon Sanford
Georgia Institute of Technology, Atlanta, GA
{tinalee; yliu451; xxiong6}@gatech.edu, jon.sanford@coa.gatech.edu

Voting systems must be usable by all eligible voters regardless of their skills, abilities, and experiences. However, current voting systems do not provide accessibility to all voters, including those with physical and cognitive limitations. To make voting easier for people with and without disabilities, we developed a universal voting interface that integrates a simplified and flexible ballot design that includes multimodal I/O interfaces. The formative usability study results demonstrate people with various types of disabilities could perform the voting tasks on EZ Ballot using their preferred input. In order to refine the EZ Ballot interface, the study found the specific issues on design such as instruction, selection of candidates, confusion about going back, incorrect gestural interaction, and write-in interface.

INTRODUCTION

Voting systems must be usable by all eligible voters regardless of their skills, abilities, and experiences. Although some existing voting machines offer a minimal level of accessibility by adding assistive inputs (e.g., keypad, sip-and-puff, dual switch) and outputs (e.g., speech output) (Piner & Byrne, 2011) onto existing electronic hardware and/or software architecture, they do not accommodate all voters with visual, dexterity and cognitive limitations.

To compound the problem, the setup process for ensuring that these specialized assistive technology (AT) devices are operational is often complex (Piner & Byrne, 2011) and beyond the capabilities of non tech "savvy" poll workers. As a result, many voters with disabilities are unable to vote by themselves, if they can vote at all.

To address these problems, we developed a prototype of an innovative voting interface, the EZ Ballot, which integrates a simplified ballot design with a range of I/O interfaces into the same voting system for all users. The linear layout of the ballot structure fundamentally re-conceptualizes ballot design to provide a simple and intuitive voting experience regardless of ability or I/O interface. Furthermore, the prototype seamlessly integrates multimodal input and output interfaces with the ballot structure, providing flexibility to accommodate voters most likely to have problems with voting machines, including people with cognitive, visual, and dexterity limitations.

RELATED WORK

When voters use accessible voting machines, those with vision, cognition, and dexterity limitations experience a variety of problems. Research indicates that blind and visually-impaired voters take significantly longer to vote than sighted voters (Piner & Byrne, 2011). In addition, voters with visual limitations have more difficulty navigating a ballot, which often leads to confusion (Burton & Uslan, 2004; Gilbert et al., 2011; Runyan & Tobias, 2007). These problems can often be attributed to the accessible features that are added to standard ballots that are designed to be used visually. In contrast, voters with cognitive limitations, can be confused and overwhelmed by the amount of information and the visual complexity of a full-face DRE (i.e., candidates listed on a full-face computerized screen) or the lack of overall orientation in scrolling DRE (i.e., candidates listed on a scrolling computer screen) ballots (Ott, Heindel, & Papandonatos, 2003). To provide access to voters with dexterity limitations, a variety of assistive technology inputs (e.g., sip-and-puff, jelly switch devices) have been added to voting machines. In addition to creating set up problems for poll workers who are unfamiliar with these input devices (Runyan & Tobias, 2007), they can negatively affect the voting experience.

Many researchers have focused on developing alternative ballots. *Zoomable* voting interface provides an overview of the entire ballot as well as a detailed zoomed view of each race (Herrnson et al., 2007). Prime III (Gilbert et al., 2011) is a multimodal electronic voting system that enables voters to cast their ballots using touch and/or dual switch. Enhanced and Extended Usability (EEU) prototype (Vanderheiden, 2004), consists of touch screen interface integrated with physical tactile buttons using the large arrow shaped buttons to move back and forth through the races. In addition, it provides zoom capability, "touch to hear", and "voice confirm" features for individuals with visually impairments. Even though Prime III and EEU have same as our goal that one ballot for everyone, they have not been evaluated objectively by people with various limitations.

DESIGN OF THE EZ BALLOT

Instead of adding more AT and customization for existing DRE machines, EZ Ballot has eliminated the need for special accessible features through using the universal design (UD) guidelines (Connell et al., 1997) as the underlying rationale for design decisions. As a result, EZ Ballot is a simple, intuitive and flexible tablet-based system (see Figure1) that integrates a linear ballot design with a range of input and output interfaces (Lee, Xiong, Yilin, & Sanford, 2012). Ballot I/O features including buttons, touch inputs, speech inputs were specifically designed to accommodate a range of abilities including the cognitive, visual, and manipulative abilities that are most likely to be adversely affected by ballot design. Design decisions to accommodate different abilities and based on the UD Principles are described below.

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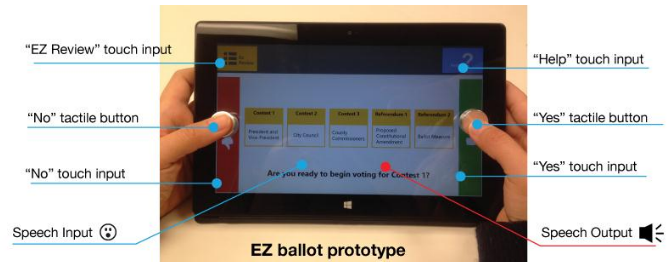

Figure 1. EZ Ballot prototype

Designing for a Range of Abilities

Principle 2. Flexibility in Use. Multimodal interfaces that combine human natural input modalities such as speech, touch, and gestures provide accessibility for diverse users (Obrenovic, Abascal, & Starcevic, 2007; Oviatt & Cohen, 2000). Several design features of the EZ Ballot provide multiple ways for diverse groups of users to interact with the interface. To input responses, users have four choices: a tactile button, touch input, speech input, or stylus. The prototypes of the physical tactile buttons are two conductive rubber buttons covered with aluminum metal. The "yes" and "no" physical tactile buttons and touch screen buttons are placed on each side of the screen where the tablet is typically held (see Figure 1). The speech inputs allow voters to answer either "yes" or "no" verbally. This also ensures privacy as others do not know the specific candidate that is being selected (i.e., any audio output is provided through headphones).

To allow users to browse other pages, EZ ballot provides navigation between contests and candidates without making a decision on each page. The user can navigate between pages by using finger swiping gestures on the touchscreen (Saffer, 2008). Several studies have found that gesture inputs using simple multi-finger interaction techniques are more appropriate for visually-impaired individuals because they are potentially eyes-free (i.e., users do not need to watch the screen closely) and button-free (i.e., users do not need to press buttons precisely or see labels on the buttons) (Hurtienne et al., 2010; Turunen et al., 2010). For example, blind users can select items without hitting a target on the screen (Bonner, Brudvik, Abowd, & Edwards, 2010). Similarly, novice low-vision users have been shown to use this swiping gesture successfully (Lee & Sanford, 2012). For a distinguishable mapping structure of the contest and candidates, navigation between contests requires left and right swiping gestures (see Figure 4), and navigation between contests requires up and down swiping gestures (see Figure 5). For example, the swiping right to left takes the user back to the previous contest, and the swiping left to right moves the user forward one contest.

SliderType is a multimodal write-in interface (UD2) that provides three ways of input: direct touch, sliding and lifting, and a magnified box with two arrow controls. The letters are horizontally displayed out in an alphabetic order to reduce cognitive learning curve. "The classic QWERTY keyboard layout is very difficult and dissuading" for people with cognitive impairments (Granata, Chetouani, Tapus, Bidaud, & Dupourque, 2010).

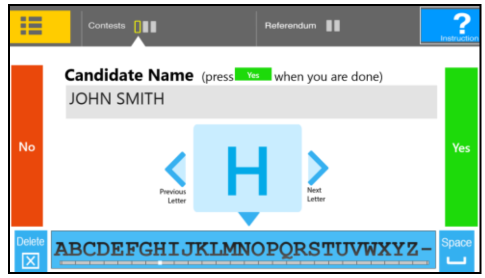

Figure 2. Write-in Interface

The slider is located at the bottom of the tablet and is enabled with audio output. The delete and space key are located at the corners of the screen to simplify the touchscreen navigation for visually-impaired people, since blind users find edge and corners better on touchscreen (Oliveira, Guerreiro, Nicolau, Jorge, & Gonçalves, 2011).

Cognitive Abilities

Principle 3. Simple and Intuitive Use. EZ Ballot has a ***simple and linear structure*** (see Figure 3) that provides two main advantages: a directed guide and a matched audio interface. A directed guide allows users to follow a particular sequence of steps so that users can easily manage to stay focused. Studies (Chaudry, Connelly, Siek, & Welch, 2012; Parikh, Ghosh, & Chavan, 2003) have suggested a linear structure rather than a hierarchical information structure for low-literacy or novice users (who can be majority of voters) because they lose focus during navigation. In addition, the nature of the linear structure resembles that of the linear audio interface, which can benefit users who are visually impaired or reading disabled. Thus, the visual structure of the EZ Ballot can easily be linked to the audio interface, providing equal access to both sighted and non-sighted users.

Figure 3. Linear structure of the EZ Ballot

EZ Ballot provides a ***consistent response structure*** of yes and no answers. Because the process is simple and easy, even for novice users, the voting process does not require any training. The system asks yes and no questions, so users simply have to answer either "yes" or "no" by following a particular sequence of steps that allows them to vote independently (see Figure 4 and 5).

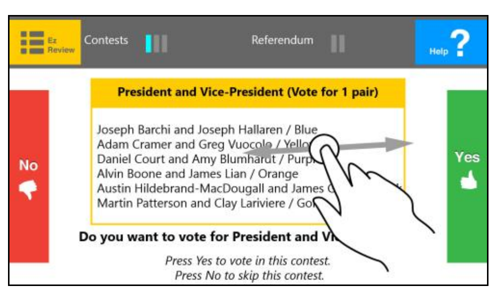

Figure 4. A screenshot of contest 1 overview page

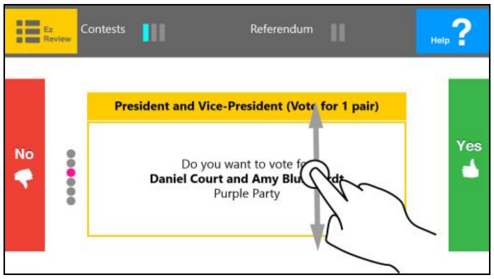

Figure 5. A screenshot of a candidate page

Principle 5. Tolerance for Error. EZ Ballot provides two ways verification prompts and a sub-review, to ***confirm a selection or identify mistakes*** during voting process. A verification prompt displays "Are you sure you want to vote for Daniel Court and Amy Blumhardt from the Purple party?" (see Figure 6), and a sub-review page displays "you voted for Joseph Barch and Joseph Hallaren from Blue party" (see Figure7). If users press "No" in the verification prompt page, the interface reverts back to the previous selection question. If users press "No" in the sub-review verification page, the interface reverts back to start over the selection of candidate.

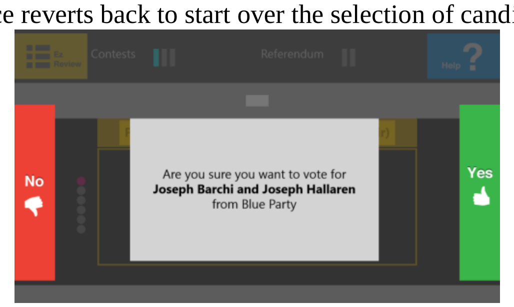

Figure 6. A screenshot of prompt for verifying selections

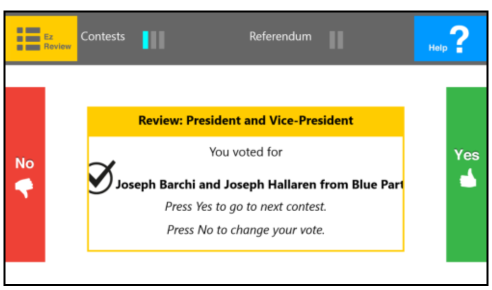

Figure 7. A screenshot of review page for verifying selections

Visual Abilities
Principle 4. Perceptible Information. EZ Ballot uses different modes for ***redundant presentation*** of information by integrating simultaneous visual and audio output interfaces desired by visually impaired voters (Burton & Uslan, 2002; Pierce, 2005; Runyan & Tobias, 2007), rather than using separate outputs that are found on most current systems. Without the need for an additional audio system and separate keypad, EZ Ballot presents each screen including buttons both visually and verbally. In addition, all touch screen buttons provide redundant visual cues through color, icons, and text. The buttons are color-coded as green, red, yellow, and blue. Internationally recognizable green and red represent "yes" and "no." However, since red and green are indistinguishable to individuals who are color blind, the buttons are differentiated by text and common icons.

EZ Ballot also provides ***continuously adjustable*** visual settings. Although several current voting machines offer a visual interface with magnification options, they are limited to two magnification levels and 2x normal font size, which does not accommodate low-vision users who require magnification to four times normal (Runyan & Tobias, 2007). On EZ Ballot, users can change the size of the text (100% to 500%) by either pressing buttons or spreading and pinching two fingers on the screen (Figure 8).

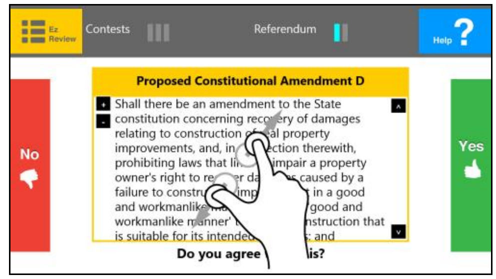

Figure 8. A screenshot of visual adjustable setting

To maximize ***legibility*** of essential information, EZ Ballot presents a large text size and high contrast between foreground and background colors and prioritizes visual information according to its importance using a large, boldface font. For example, to draw the user's attention, the title of a contest and the text of questions are bold (see Figure 5). In addition, to enable visually-impaired users to easily locate information through audio instruction (Oliveira et al., 2011), review and help buttons are placed in the corners of the screen.

Manipulative Abilities
Principle7. Size and space for approach & use. The ***oversized buttons*** (i.e. minimum cross measure of 19.05 mm) provide targets on the touch screen that are large enough for users with a range of dexterity. One study (Jin, Plocher, & Kiff, 2007) suggested that optimal touch screen size for older adults with poor manual dexterity suggested, the size of button is at least 19.05 mm.

Principle 6. Low physical effort. To reduce effort in pressing buttons while holding the device, yes/no buttons are located along the sides of the device where they can be activated by a user's thumbs.

FORMATIVE USABILITY STUDY OF EZ BALLOT
Participants. Nineteen adults (9 female; 10 male) who are eligible to vote participated in this study. Eleven participants have visual disabilities (6 totally blind (B), 5 low vision (LV)), five have dexterity disabilities (D) (2 no arm function, 2 dexterity with hand, 1 wheelchair user), and three have mild cognitive disabilities (MC). All participants were native English speakers and the age range was 24-64 years, with a mean age of 47.68 ± 11.23 years. Participants self-reported their level of touch screen expertise in the range of 1-10 (where 1 = novice and 10 = expert)with a mean of 5.68± 3.17.

Materials. A high-fidelity EZ Ballot prototype application was developed for the Windows Surface tablet using the C#

programming language and .NET libraries for the WinRT (Windows Runtime) architecture. Gesture interactions such as swipe and pinch were available, but speech input was not fully implemented. Rather, candidate names were provided verbally. Audio sounds were recorded with a human female voice. A standard sample ballot with fictional candidates' names was used to avoid asking people to vote in a contest where they might have their own opinion (Quesenbery & Chisnell, 2009).

Procedures. After signing an informed consent form approved by Georgia Tech IRB, we conducted pre-test interviews consisting of demographic questions, previous computer and touch screen experiences. Then participants performed a standard set of voting tasks using EZ Ballot. These included: voting for one candidate, voting for two candidates, typing "John Smith" using the write-in interface, voting on a referendum, reviewing the vote, changing the vote, and casting the votes. Other than the directions for whom they need to vote, participants did not receive any training on how to use the interface. During the trials, we observed the participants' interaction and recorded usability issues by observing the frequency of participants who encountered the specific issues. Following each test trial, participants completed a post-trial interview to elicit in-depth, qualitative feedback about the usability of each design feature (e.g., verification message, preferred input). Participants' interactions with the tablet were recorded using a video camera mounted over the Microsoft Surface tablet to enable natural interaction with the device. Each session lasted 90 minutes.

RESULTS

Observed Usability. We identified 5 types of issues on user interface of EZ Ballot: instruction of EZ Ballot, selection of candidates, confusion about going back, incorrect gestural interaction, and use of the write-in interface.

Instruction. Two participants who were not familiar with technology (e.g., touch screen) were confused about how to start. Four totally blind participants and one low vision participant were confused by the audio instruction about where the yes and no buttons were located. Five participants were confused about how to change their votes: two tried to directly select candidate's name on the verification page, two were confused about the Yes and No instruction when adding multiple votes in a contest, and one cognitive participant did not understand how to change her vote even though instruction displays "Press No to change your vote."

Selection of Candidates. Four participants were confused about how to select a candidate. Three directly selected names of candidate at first, then they figured out they had to use the yes and no inputs. One tried to touch the indicator dot to select a certain candidate.

Confusion about going back. Four participants did not realize they could go back to previous page by pressing No at first: two low vision and one dexterity participants were confused about how to go back to previous page when accidently selecting wrong candidates or review, and one used vertical swiping gesture to go back to the previous page. After reading instruction of "Press No to change vote" on the page, they could go back to the page by pressing No.

Incorrect Gesture. Four totally blind participants got confused about direction of swiping for gestures (e.g., horizontal to move between candidates and vertical to move between contests), and they often did not place their fingers in the right place on the screen to use the gestures.

Write-in Interface. Three mild cognitive and two dexterity participants were unfamiliar with the concept of "write-in candidate." Six participants were confused about how to use the in write-in interface: two blind were confused about where the slide bar with alphabets were located and three blind were confused about select/enter a letter by sliding and lifting the finger, and one dexterity were confused how to enter the letter using the box and arrows. In addition, six participants were confused about how to correct the letter in write-in interface: one did not know how to correct the letter without help, one was looking for the erase button to correct the letter, one pressed left arrow button to correct the letter, and three totally blind participants were confused or forgot from audio instruction where the delete button was located.

Post-trial Interview

Perceived ease of use. Participants self-reported their perceived ease of use on voting with just Yes and No as a range from 2-5 with a mean of 4.2± 1.0 (where 1 was very difficult and 5 was very easy). Participants who responded that Yes and No voting is very easy commented that the Yes and No voting is simple and intuitive enough to vote independently: "I think it simplifies it. It makes it easier and you don't have to think about it" Participants who responded that Yes and No voting is difficult commented they have some difficulty with touch screen itself.

Verification process. Nine participants (50%) commented they liked both the prompt and sub-review verification process, because they want to double-check their vote during the process. On the other hand, eight (44.4%) participants commented that the review process was too redundant and becomes tedious in voting process. Among those, six participants preferred only the sub-review, one preferred the prompt, and two totally blind participants preferred to review just once at the end of the voting process to make the process quicker.

Preferred input. Nine participants (50%) preferred the touch input, followed by four (1 dexterity, 3 totally blind) (22.2%) who preferred the push button, three (2 low vision, 1 dexterity) (16.6%) who preferred speech input, and two (1 low vision, 1 dexterity) (11.1%) who preferred stylus. There was no correlation between preferred input and types of disability.

DISCUSSION

The study demonstrated that people with various types of disabilities could perform voting tasks on a single voting interface based on universal design principles. Most participants (78.9%) thought that Yes and No voting was easy and simple, even though some people with cognitive impairments had difficulty understanding general concepts of voting. However, some blind participants thought the redundant review process slowed down the process, while others thought that the review processes were important because they helped them to vote accurately. Interestingly, participants' preferred method of input varied, which suggests that providing flexibility through multi-modal inputs is important. Only three out of eleven people with visual disabilities preferred to use the physical push button. It may be because most participants with a visual disability have experience with using their own touch screen devices. While more number of participants preferred the touch input, other participants preferred the physical push buttons or speech input.

The study also identified usability issues such as instruction, selection of candidates, confusion about going back, incorrect gestural interaction, and use of the write-in interface that require refinements. Visual and audio instruction should be refined using simpler and concise wording so that users will clearly understand the ballot and respond by only yes and no answers. In addition, we will develop an instruction tutorial that makes it easier to understand how the hardware works for first time users. Interestingly, participants who are already familiar with gesture interaction, appreciated that they could use swipe, pinch, scrolling gesture on voting interface regardless of participant disability types. To reduce the confusion of gesture interaction, the ballot interface should provide simple and clear visual and audio cues to indicate the directionality of the gestures for each page. In addition, gesture interaction should change from a localized gesture spot to encompass the entire screen so that blind users can interact using gestures anywhere on the screen. Because gesture interaction on the EZ Ballot is an option, people who are not familiar with gesture interactions can use just Yes and No inputs.

The innovative slide type write-in interface proved challenging for many users. While this input method could be confusing with experienced QWERTY keyboard users, most participants who were confused at first, eventually figured out how to use the slide type write-in method. In fact, two participants with visual disabilities particularly liked the slide write-in method because all the alphabet keys are in a single row. For people who were already familiar with QWERTY keyboard, we may need to provide an option of choice if they prefer to use QWERTY keyboard.

Future work will further iterate the design based on usability data. The design will be evaluated by accessibility, usability, and universal design experts, refined a second time and then evaluated for voting performance of users in comparison to an existing electronic ballot.

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