Int. J. Human-Computer Studies 109 (2018) 102–111

Contents lists available at ScienceDirect

International Journal of Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

A user-centered design and analysis of an electrostatic haptic touchscreen system for students with visual impairments

Amelia Bateman, Oliver K. Zhao*, Andrea V. Bajcsy, Mathew C. Jennings, Bryan N. Toth, Alexa J. Cohen, Emily L. Horton, Anish Khattar, Ryan S. Kuo, Felix A. Lee, Meilin K. Lim, Laura W. Migasiuk, Ramkesh Renganathan, Amy Zhang, Márcio A. Oliveira

University of Maryland, College Park, USA

ARTICLE INFO

Keywords:
Haptic
Visual impairment
Assistive technology
User-centered design
Electrostatic touchscreen
Mathematics education

ABSTRACT

Students who are visually impaired face unique challenges when learning mathematical concepts due to the visual nature of graphs, charts, tables, and plots. While touchscreens have been explored as a means to assist people with visual impairments in learning mathematical concepts, many devices are not standalone, were not developed with a user-centered design approach, and have not been tested with users who are visually impaired. This research details the user-centered design and analysis of an electrostatic touchscreen system for displaying graph-based visual information to individuals who are visually impaired. Feedback from users and experts within the visually-impaired community informed the iterative development of our software. We conducted a usability study consisting of locating haptic points in order to test the efficacy and efficiency of the system and to determine patterns of user interactions with the touchscreen. The results showed that: (1) participants correctly located haptic points with an accuracy rate of 69.83% and an average time of 15.34 s out of 116 total trials, (2) accuracy increased across trials, (3) efficient patterns of user interaction involved either a systematic approach or a rapid exploration of the screen, and (4) haptic elements placed near the corners of the screen were more easily located. Our user-centered design approach resulted in an intuitive interface for people with visual impairments and laid the foundation for demonstrating this device's potential to depict mathematical data shown in graphs.
© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

In 2013, approximately 694,000 school-aged individuals in the United States reported some level of visual disability (Erickson et al., 2014). According to the 2014 federal quota census data, 61,739 students are eligible for adapted educational materials through the Act to Promote the Education of the Blind. While some of these students attend schools specifically dedicated to those who are blind, many are educated in the mainstream school system, which are frequently ill-equipped with adequate assistive technologies (American Printing House for the Blind, 2015).

For students who are visually impaired, math and science concepts pose a unique challenge due to the visual nature of data embedded in graphs, charts, tables, and plots (Nam et al., 2012). Tactile models such as embossed paper and pin boards with yarn are often used to present these ideas to students with visual impairments; however, the translation from the visual to the tactile domain results in a loss of information (Smith and Smothers, 2012). Although more complex solutions such as the Talking Tactile Tablet have been used in classrooms for testing purposes, they rely solely on audio output, are not easily refreshable, and limit user interaction to a finite set of buttons (Landau et al., 2003).

In contrast to tactile technologies, haptic feedback mechanisms have been used for a variety of different applications since the 1960s, with initial research directed toward assisting people with visual impairments (Israr et al., 2014). For instance, the Optacon used input from an optical sensor to actuate an array of vibrating pins so that an individual could feel and interpret written text (Linvill and Bliss, 1966). Another device, the Tactile Television, converted camera images of basic shapes into an array of vibrating points (Collins, 1970). These initial studies on haptic assistive technology were a precursor to an influx of research in the field of surface haptics.

More recent developments in surface haptics have been consumer- and experience-driven, resulting in products developed for gaming and entertainment. For instance, the Marvel Avengers Vybe Haptic Gaming Pad primarily aims to enhance the gaming experience of neurotypical individuals (Israr et al., 2014). The Novint Falcon–a haptic device designed to replace a computer mouse–was developed as a gaming device, but has also been studied as an accessibility tool for users with visual

* Corresponding author.
E-mail addresses: ozhao32@stanford.edu (O.K. Zhao), marcio@umd.edu (M.A. Oliveira).

http://dx.doi.org/10.1016/j.ijhcs.2017.09.004
Received 3 May 2016; Received in revised form 18 March 2017; Accepted 9 September 2017
Available online 11 September 2017
1071-5819/© 2017 Elsevier Ltd. All rights reserved.

impairments. The researchers used the Falcon's haptics as well as audio cues to display graphs and charts created in Microsoft Excel (Doush et al., 2010). This device enables the user to either actively interact with or passively perceive graphics and also demonstrates the potential of surface haptics to be used in assistive technologies. A similar device, the PHANToM, was used by Yu, Ramloll, and Brewster to present line graphs to both sighted users and users with visual impairments (Yu et al., 2001). Participants were tasked with exploring line graphs using the PHANToM force-feedback controller in order to find interesting features such as the maximum and minimum values and any points of intersection. While participants could generally discern the shape of line graphs, the perception was "often distorted and inaccurate due to the limitations of the force feedback device."

Electrostatics, a subfield of surface haptics, focuses on the development of haptic effects by applying voltages to a conductive surface in order to create friction on a user's finger. The researchers pioneered the development of electrostatic haptic technology when they created a tactile display by applying different voltages to an array of pins in order to produce texture (Strong and Troxel, 1970). Recently, researchers at Disney have continued this work by developing the TeslaTouch touchscreen device (Bau et al., 2010), which was analyzed as a tool to aid the visually impaired (Xu et al., 2011). This particular study included three participants who were totally blind and indicated that various representations of shapes have differing levels of effectiveness in conveying information. Specifically, participants were able to identify a solid shape at almost twice the rate of outline-only or solid-with-outline representations. The TeslaTouch system is novel but inherently infeasible for personal use, as it requires the user to be connected via a wrist strap and the device to be connected to a personal computer.

Other touchscreens have been explored as potential solutions to assist people with visual impairments in learning mathematical concepts. The researchers combined haptic and auditory modalities using a Series 1000 TouchSense Demonstrator device, and reported 66% success rates when sighted users were asked to navigate to specified Cartesian coordinates.[1] In a shape recognition task, users had difficulty discriminating shapes from one another, which the authors hypothesized was due to the variety of exploration methods utilized (Toennies et al., 2011). In a follow-up study with updated hardware (a Samsung Galaxy Tab 7.0) and users with visual impairments, the 66% navigation success rate was reproduced. However, when users were asked to identify the coordinates of given points, no combination of haptic/auditory grid and points yielded over 75% success (Gorlewicz et al., 2014). These studies have been foundational to the research presented in this paper, which aimed to extend the work of Gorlewicz et al. by investigating the role of exploration strategies in successful interpretation of haptic signals and by isolating the haptic sensory channel to optimize that modality prior to integrating auditory features.

Although previous research has used haptic technologies to address the unique needs of people who are visually impaired, a significant portion of the work published about tactile and haptic assistive devices does not include testing with individuals with visual impairments (Horton et al., 2016). We adopted a user-centered approach to the design of an electrostatic touchscreen system that provides graphical information to individuals with visual impairments. In addition, we conducted a usability study consisting of a haptic localization task in order to validate the efficacy and efficiency of the system and to determine patterns of user interactions with the touchscreen.

2. A user-centered design approach

The user-centered approach was dependent upon feedback in the form of interviews with assistive device experts as well as preliminary tests with users with visual impairments. Fig. 1 depicts the iterative design process, which alternated these feedback sessions with hardware and software development.

2.1. First round of interviews

The first interviews focused on identifying the technological needs of students with visual impairments and their educators. We interviewed six individuals: a technology expert from the International Braille and Technology Center for the Blind (IBTC), the president of the Maryland chapter of the National Federation of the Blind (NFB), and the principal, vice-principal, and two elementary math teachers from the Maryland School for the Blind (MSB). The interviewee from the NFB is totally blind, while all other interviewees are sighted. Each of these sessions was conducted individually and at the interviewee's workplace. Each interviewee gave demonstrations of the technologies used in his or her classroom or office, and the expert from IBTC gave us a hands-on tour of the many technologies kept at the center. The first round of interviews was used to determine which hardware and software features are highly regarded among commercially available educational assistive devices, a goal which was made transparent to the interviewees.

The visit to the IBTC was aimed at understanding current trends in assistive technologies for people with visual impairments, as well as the primary challenges faced by users of these systems. The interview included questions such as "What categories of technologies are most widely used?" and "Which technologies receive the most criticism from educators and users? Why?" The responses revealed that although several devices had strong graphical precision, their general cost and bulkiness prevented them from being popular among the visually impaired community. Common concerns included: (1) the size and cost of high-tech devices, (2) cross-compatibility problems caused by the many types of assistive devices and their various operating systems, and (3) the dependency of devices on host computers, which renders them non-portable.

The interview with the NFB chapter president was similar to the previous interview, featuring questions about the fields of assistive technologies and education administration. The interviewee echoed the technology concerns raised by the IBTC expert, which strengthened the merit of these claims. In addition, she noted that in her time as an education administrator, teachers reported several challenges, such as finding adequate desk space for each student's own device and using devices designed without sighted instructors in mind. She encouraged us to ask about teachers' individual experiences with these concerns at the Maryland School for the Blind.

At the MSB, our interview questions differed from those asked previously, as they were directed at educators themselves, rather than technology and education experts. We asked educators about math curricula, the grade levels of various graphical mathematical skills, and the technologies they employed in their classrooms. Such questions included "How do you introduce your students to a new mathematical concept?" and "How are tests, homework, and classwork administered to students?" The teachers currently use Swell Touch Paper, Wikki Stix, and the Draftsman Tactile Drawing Board (see Fig. 2), but find that these tools provide neither immediate (speed of creating the first graphic) nor refreshable (ability and speed of creating subsequent graphics) interfaces. Graphs must be individually composed by hand or printed onto non-reusable paper, and are therefore not quickly adaptable to the students' learning needs. Despite their limitations, these low-tech media were preferred by teachers over higher-tech devices like the IVEO tablet, which reportedly took 1.5 h per graph to program. The educators identified refreshability, ease of programming, and intuitive display of information as essential qualities of assistive devices.

The educators also noted concerns about the design of educational assistive devices for classroom use. One of the essential missions of the MSB is to prepare students for integration into mainstream classrooms, but these classrooms have a number of limiting factors such as small

[1] Although the hardware used in this study is mechanically-actuated as opposed to electrostatically controlled, the texture generated through both methods produces a vibrotactile effect.

Download English Version:

https://daneshyari.com/en/article/4945746

Download Persian Version:

https://daneshyari.com/article/4945746

Daneshyari.com