VizTouch: Automatically Generated Tactile Visualizations of Coordinate Spaces

Craig Brown
Department of Computer Science
The George Washington University
cbrown16@gwmail.gwu.edu

Amy Hurst
Information Systems Department
University of Maryland, Baltimore County UMBC
amyhurst@umbc.edu

ABSTRACT

Visual mathematical concepts have long been challenging to access for people with limited or no vision. Given that functions and data plots are typically presented visually; there are few affordable and accessible solutions for individuals with limited or no vision to interpret data in this format. We have developed software that leverages new affordable 3D printing technology to rapidly and automatically generate tactile visualizations. In this paper, we describe development of the VizTouch software through a user-centered design process. We worked with six individuals with low or limited vision to understand the usefulness of 3D printed custom tactile visualizations, and their design. We describe how VizTouch can be used to make data visualizations in education, business, and entertainment accessible.

Author Keywords

Assistive Technology, Human-Computer Interaction, Tactile Visualizations, Rapid Prototyping

ACM Classification Keywords

K4.2 **[Computers and Society]:** Social Issues – Assistive technologies for persons with disabilities

General Terms

Design, Economics, Human Factors, Standardization.

INTRODUCTION

Visualizations are frequently used to build understanding of mathematical concepts, illustrate trends in data, or understand complex datasets. For example, students learning linear functions may find it easier to comprehend the "rise over run" characteristic of a line's slope by counting the rise on the y-axis and the run on the x-axis, and computing the ratio instead of analyzing the abstract form of the linear equation (y = mx + b).

TEI 2012, Feb 19-22, 2012, Kingston, Ontario, Canada.

Students with vision impairments face significant challenges in learning math [3], and tend to score lower than sighted students on standardized tests. This is attributed to many factors including a lack of sufficient training given to general education mathematics teachers [2], and the difficulty in finding the least intrusive accommodations for students [1]. Some mathematical concepts can be expressed to students with limited vision using Nemeth Braille [14], a compact tactile language to represent arithmetic problems and equations, but it is not commonly taught. In general, Braille literacy is quite low in the United States (fewer than 10% of the legally blind population are Braille users) and only 10% of blind children are learning it [8]. While work is being done to increase Braille literacy, another solution is needed to express mathematical concepts that are not easily represented by alphanumeric characters and symbols, such as bar graphs, line graphs, and pie charts.

The need for accessible visualizations is not limited to the classroom, and is relevant to many professional and leisure activities. Graphs have become an integral part of our everyday lives as we interpret data around us. In politics, news publishers might use a graph to illustrate trends in public sentiment on policy issues over time. In economics, professionals consult financial news agencies or government websites, which use visualizations to demonstrate the latest developments in economic trends and business cycles. In business, individuals may attend meetings with budget or progress information graphically displayed in slideshows. At home we see plots of weather trends, health data such as our weight or blood pressure, and our energy usage in both digital and paper media.

Solutions that improve the accessibility of visualizations to individuals with limited (or no) vision must be affordable, easy to learn, and easy to acquire. Past work has explored technologies such as Braille embossers and haptic devices. The community, however, has found such solutions to be high in cost and user overhead, and have limited versatility and scalability [9]. We suggest leveraging rapid prototyping technologies to produce tactile visualizations that are versatile, durable, affordable, and accessible.

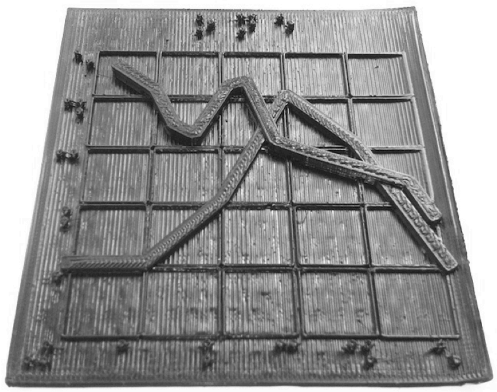


Figure 1. 3D printed visualization of a line graph. The VizTouch software automatically generated the 3D model of this prototype from a .csv data file.

This paper describes the design of tactile visualizations that can be easily generated and created with rapid prototyping tools. We first describe related work on tactile visualization and examine important lessons learned from technological capabilities and limitations. Next, we present VizTouch, our software to automatically generate tactile visualizations from user input (Figure 1). We discuss the implementation of our system and our user-centered design process with 6 individuals with limited or no vision. We conclude with limitations of our existing system and future work.

EXISTING VISUALIZATION ALTERNATIVES

Past work has explored how audio and tactile interfaces can be used as an alternative to presenting information visually. Existing solutions include high-tech devices and the creative use of low-tech materials.

Creating Tactile Displays with Embossers

Embossers impress dots and lines on a piece of copy paper or malleable plastic paper to form Braille lettering and tactile graphics. Currently embossers are expensive, costing upwards of $5000 [5,20] and can be difficult to use. Some of the major limitations to such approaches have been seen when trying to distinguish the grid lines from the lines of the functions [9]. While some embossers can emboss up to seven levels of height, all seven levels cannot be easily distinguished from one another. Also, these embossers use Braille-sized dots as the texture to represent both data lines and grids, leaving users confused between the two [9]. Common solutions to this problem include putting the grid on an underlying separate sheet of embossed paper or using different materials to give different textures to grid lines and function lines. However, this solution can be difficult to interact with, and requires extra graph assembly overhead.

Ladner et al. combined Braille printers with image processing techniques and human intervention to make tactile graphic translations [9]. This solution allowed complicated diagrams to be accurately translated into tactile versions. Ladner estimated that on average, only 15 minutes would be needed to translate any one graph. One major drawback of this solution was that highly skilled human intervention would be needed to aid the process. Additionally, users could not customize their content or generate it on the fly, so manufacturing had to be done by skilled professionals using complicated software (Photoshop), in addition to expensive Braille embossers.

Do-It-Yourself and Low-Tech Tactile Displays

Handmade or Do-It-Yourself solutions are practical alternatives for people without access to higher-tech solutions. Accessible graphs have been made with many different materials including string, glue, and office supplies. The American Printing House for the Blind has developed corkboard solutions, which use rubber bands and thumbtacks to build graphs on a physical corkboard [4]. While an affordable solution, this method is limited to the type of graphs that can be produced (and works best with standard bar graphs).

Another solution is for a sighted person to print a graph on paper and trace the lines with a paint pen, to create relief. We interviewed someone who did this, in order to create an accessible version of his slides for a presentation. He commented that this technique was very tedious and took hours to complete because he had to retrace the lines several times. Another one of our participants recalled having a teacher or friend “draw” visualizations on her hand when she was in school, which meant she couldn’t study alone and had to ask her friends for extra help.

While handmade solutions can be effective, they often require significant overhead to produce, especially if they are trying to represent large and complicated data sets. They also may or may not be reproducible or durable.

Interactive Haptic Devices and Tangible User Interfaces

Haptic devices leverage the sense of touch, typically by way of force feedback impulses which can simulate the presence of structure in open three-dimensional spaces. Past research has been done to demonstrate how this technology can be utilized to help users without vision to feel structures which they cannot see [21,24]. The Phantom Omni [16] is a haptic pen that has been used to trace the trend lines and functions represented on a graph and produce frictional feedback cues to indicate the presence of multiple lines on a single graph [24]. While powerful, this technique also requires significant user training. Users have also found it difficult to distinguish feedback, as they would often confuse cues signaling the different slopes of a single line, as opposed to indicating the presence of two separate lines. Finally, “tracing” the shape of a graph can be difficult when users slip off the path unexpectedly (which most frequently happens at the corners and intersections).

McGookin et al. [13] created interactive tangible graphs using physical icons that are tracked using a camera system. While powerful, this solution required a complex setup, and focused on creating graphs that are accessible, not making pre-existing graphs accessible.

Audio Interfaces

Past research has demonstrated that audio can also be used to effectively communicate mathematic information to individuals with vision impairments either as the only modality [19], or with multiple modalities [19,10]. 3D audio interfaces can also be used to help blind learners localize a specific point in 3D space [12]. While audio interfaces offer an interesting alternative to tactile representations of data, they must be carefully designed so as to not overwhelm the user with the cognitive load requirements for large datasets.

Summary of Existing Systems

There are several options to make visualizations accessible to individuals with limited vision. Braille printers, can print up to seven different levels of height, but these heights are difficult to distinguish from one another. Additionally, their representation of text and lines as a series of raised dots limits the textures they can produce. Finally, the durability of these solutions is highly variable. While haptic devices can provide direct interfaces with electronic data, they are difficult for users to interpret and leave room for inaccurate interpretations of the data series at hand. Audio technologies provide some assistance to low vision users, but may require a significant amount of support from users themselves.

LEVERAGING A NEW GENERATION OF RAPID PROTOTYPING DEVICES

Given the many limitations of existing solutions, we propose a new system to streamline the software and hardware aspects of creating tactile graphics.

Rapid Prototyping Tools: 3D Printers and Laser Cutters

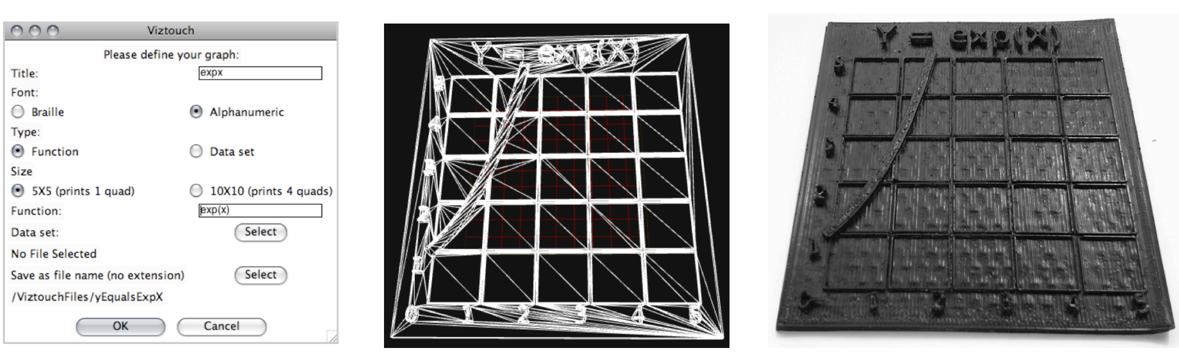
A new generation of rapid prototyping tools are available that make small-scale home manufacturing possible. One example is the MakerBot 3D printer [11], which is significantly less expensive than other 3D printing technologies and designed for use in the home. This 3D printer can create durable hard plastic pieces made out of ABS (Acrylonitrile Butadiene Styrene) plastic. Affordable 3D printing technologies, such as the MakerBot are relatively new and currently require maintenance and mechanical knowledge. As a result, it may not be realistic to assume that individuals with limited vision could operate these machines independently as they exist now. However, given the rate at which these machines have been improving, we believe that they will become as robust and commonplace as photo printers in a few years.

Laser cutters can produce etchings and cuts on a number of inexpensive materials such as plastic, hardboard, cardboard, wood, and even paper. Laser cutters typically operate very quickly, and can cut or etch large surfaces from only a SVG (Scaleable Vector Graphic) file. While it may not be realistic to expect users to own and operate their own laser cutter, they are available in community-based workshops and hackerspaces. Alternatively, there are online manufacturing services such as Ponoko [17] that manufacture digital files in small quantities.

VizTouch Development

VizTouch enables end-users to automatically generate tactile visualizations that are easily manufactured on rapid prototyping equipment. VizTouch was written in Python and integrates three separate open source projects: Veusz [23], Inkscape [6], and OpenSCAD [15]. Veusz, a scientific plotting package, allows users to create plots of any function or data set. Inkscape, a vector graphics design program, can easily read, manipulate and export many image file formats. OpenSCAD, a programmatic computer aided design program, can interface with 2D images and build rich 3D models that can be manufactured with 3D printers.

VizTouch plots the equation or dataset the user enters in the GUI with Veusz and sends the image output to Inkscape. Inkscape then performs several transformations such as removing extra white space, eliminating arbitrary object groups, and converting all polyline objects to simple paths. Inkscape then exports the image file to a .ps (PostScript) file that is then converted to a .dxf (Desktop Cutting Plotter) by pstoedit [18].



A. B. C.

Figure 2. VizTouch pipeline to create Y=exp(X). A) Python interface for user to type equation or provide a .csv data file B) Wireframe view of automatically generated 3D model C) 3D printer output. VizTouch supports both alphanumeric and Braille output, our participants suggested alphanumeric output for individuals with low vision since Braille reading rates are low.

This .dxf is read into OpenSCAD, and is combined with the supporting geometry of our graphs (grid, axis numbers, graph titles) in OpenSCAD. We then export the final 3D model as a .stl (stereolithography) file that is readable by multiple rapid manufacturing machines (Figure 2B). This paper focuses on VizTouch with a 3D printer, but this pipeline could be easily adapted by any number of other rapid prototyping machines.

VizTouch User Interface

VizTouch displays a simple dialog box (Figure 2A) which enables users to define the details of their graph, including the graph title, font (Braille or alphanumeric), whether to plot a function or a data set, size (full graph or first quadrant), .csv (Comma Separated Values) data set file, and a final destination to save the .stl file. VizTouch is able to generate files in under one minute.

VizTouch Output

Tactile graphs produced by VizTouch are distinguished by their titles. Our current prototype allows users to specify a unique 4-character title and quadrant number at the top of each print. These titles are displayed in either standard Braille or with alphanumeric characters. This format was ultimately chosen after prototyping several versions with our participants. VizTouch produces visualizations of the Cartesian coordinate system on a single piece representing one quadrant, or four pieces that can be combined.

VizTouch was designed to directly translate visual information into a tangible form and preserve the original layout and affordances of graphs. We did this so our visualizations would be familiar to individuals with limited vision, or those who had lost their sight. Given the freedom 3D printers offer, it is tempting to design new visualization paradigms, but past work has shown that tests that are made accessible to blind and low vision children should use similar constructs as the original tests [1].

USER-CENTERED DESIGN PROCESS

VizTouch was evaluated by 6 blind or low vision participants, and 1 sighted individual who works with people with limited vision. We developed two rounds of prototypes and tested them on two groups of users. Group 1 had more mathematical experience and used visualizations more frequently in their jobs. They performed simple usability tests with the tactile graphics and gave design feedback. This feedback was used to create the Round 2 designs, which were tested by both groups. Group 2 only interacted with improved prototypes, and their interviews focused on how they would use this technology.

Group 1: Demographic Information

All three participants in Group 1 were working age professionals between the ages of 25 and 65 (specific ages were not collected). Table 1 summarizes their vision abilities, degree of vision loss, and its onset. Participant P1 has the most math experience and has advanced degrees in Economics and Law. In school she frequently used many crafty solutions to aid her mathematics education, including a low-tech glue gun solution for visualizing graphs in college. Participant P2 is an adaptive technology specialist at the same institution as P1, and has vast instructional experience teaching others how to use assistive technology in their professional lives. P3 was a former therapist and social worker, and studied math up to college algebra.

Participant	**P1**	**P2**	**P3**
Gender	Female	Male	Female
Degree of Vision Loss	Blind	Low Vision	Blind
Age of Vision Loss	12	38	31
Braille Use	Minimal	None	Minimal
Profession	Economist/ Lawyer	Technologist	Therapist

Table 1. Demographic information for Group 1.

Round 1 Prototypes: Laser-Etched Grid

We explored what textures could be produced with a laser cutter and created a laser-etched prototype of a grid on hardboard with a variety of different textures for distinguishing the different features of the grid itself (Figure 3). This prototype was generated with a Universal Laser System VLS3.60 [22].

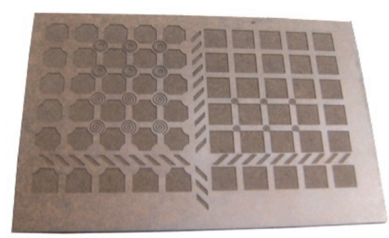


Figure 3. Participants had difficulty interacting with this Laser-etched grid and distinguishing between textures.

This prototype was evaluated with P1 and P2, and both said the etched textures were difficult to distinguish. P1 found it nearly impossible to distinguish any of the various features without a significant amount of help from a sighted observer. The most she was able to derive on her own was the square gridlines on the right side of the board. P1 also noted that despite the textures of the x and y-axis being quite similar, it was easier to track the x-axis while moving her finger horizontally than it was to track the y-axis while moving her finger vertically. Furthermore, after locating a value on the x-axis, she would subsequently get lost when she tried to back track and find the y-axis.

Due to user difficulty distinguishing between coordinates, we did not believe etching provided any advantages over existing Braille embossed solutions. In fact, we found etched Braille dots to be easier to feel than continuous, etched stretches of hardboard. Based on the negative response to the etched grid, we stopped evaluating it and instead focused on 3D printed visualizations.

Round 1 Prototypes: 3D Printed Visualizations

All 3D printed prototypes were roughly 3” x 3.5” x ~.15”, and took one hour to print on a Thing-O-Matic MakerBot 3D printer. We explored making the prints smaller but found that smaller prints were more difficult to discern, and smaller pieces, such as Braille lettering, broke off.

The majority of the manufacturing time for these visualizations was spent building the 3” x 3.5” x .09” platform. We chose this design over one with a reusable platform so our prototype would be a single piece of plastic that didn’t require any cleanup after production or assembly by the user. Our estimation is that each prototype costs less than a 25 cents to manufacture (US).

In this round the following prototypes were printed with Braille axis labels and evaluated with P1 and P2:

1. The cubic function ($Y = X^3$) with a Braille axis label
2. Plot of past 4.5 years of US unemployment rates generated from a .csv file. Data line is 1mm thick, 1mm difference between grid and data (Figure 4).

Evaluation Tasks

Participants were asked to perform basic tasks including reading Braille labels, finding the origin, counting the number of units in the x- and y-axes, and following the shape of a curve. With minimal instruction (only location of the origin), P1 was able to determine the shape of the cubic function. With the unemployment rate graph, she was able to follow the shape of the curve, and correctly follow the rises and dips with her fingers. P2 had similar success with both graphs, but required more assistance since he had a different math background.

Both participants were able to navigate back and forth from the origin to the outer coordinate labels. Similarly, they were able to count and correctly report the number of units along both the x-axis and the y-axis. They all demonstrated the ability to follow the general trend of both single data set and single function prints, starting from where they began on the left side, to where they ended on the right.

Grid Height

Both participants noted that confusion when they could touch the grid while trying to interpret the function. They suggested either lowering the height of the grid lines, or eliminate the lines and use major tick marks instead. Both users were familiar with coordinate spaces, and suggested that grid lines might be useful for someone learning math.

Axis Labels

P1 was able to read both the braille headers and coordinate labels. However, P1 and P2 expressed concern with the use of Braille numbering on the axis. Although P1 was completely blind, she explained that with the advent of

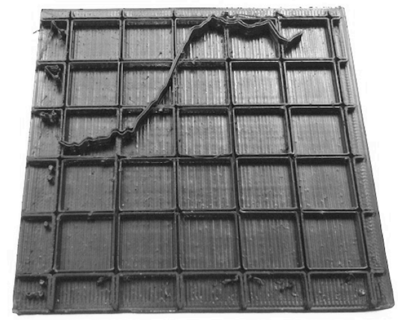


Figure 4. 3D printed graph of US unemployment from Jan 2007 to June 2011. Braille lettering is shown on the y-axis. There is a 1mm difference between grid and

audible technologies such as screen readers, smaller portions of the blind population were dependent upon Braille. P2, who had low vision, said most blind individuals start going blind after the age of 18, and learning Braille was difficult and a lot like learning a new language. P1 and P2 suggested using alphanumeric characters for both low vision users and as a Braille alternative.

Visualization Size

When asked about the potential for printing full graphs on multiple pieces of plastic (to represent four quadrants), both P1 and P2 expressed concerns about simplicity. Specifically, they were concerned about correctly aligning and orienting each quadrant, and overall simplicity of design. We took this as a general warning against including any unnecessary additional parts for assembly. Our current solution, VizTouch automatically prints the number of the quadrant at the top (quadrants 1 and 2) or bottom (quadrants 3 and 4) of the quadrant alongside the title of the graph.

Marking points of Interest

P1 suggested an intelligence feature, which automatically computed important features of the graph. In particular, she suggested that it would be helpful to have the program determine the highest point of unemployment in the unemployment graph, and then print that number next to the point of interest. In this case, unemployment peaked at 10.2% in 2009, but it was virtually impossible for her to tell what the exact value of the number was.

Round 2 Prototypes and Feedback

Our second round of interviews tested prototypes with multiple design changes based on findings from Round 1, including lowering the grid height from 5mm to 3mm, adding titles to the graphs, and exploring multi-quadrant visualizations. Based on the difficulty differentiating the lines, we eliminated the laser-etched prototypes.

This round of prototyping included P3. We were unable to meet with P2 face-to-face, but were able to mail him prototype #2, and get his opinion over the phone. Unfortunately, P1 was unable to participate in this round.

In this round, we tested the following prototypes:

1) Y = cos(X*3), Y = log(X), braille
2) Y = exp(X) alphanumeric (Figure 2C)
3) Two-quadrant visualization of Y=cos(X)+3. (Figure 5)
4) Plot of unemployment data (Identical to Round 1)
5) Plot of two lines on a single graph (Figure 1)

Grid Height

P3 was more successful getting information from visualizations when the grid was 2mm lower than the data (#1,2,3,5), than when it was only 1mm lower (#4). P2 noted a similar improvement in comprehension, as he explained that found it much easier to count spaces, find intersection points, and distinguish the grid from the plotted function.

Graph Titles and Axis Labels

Despite requesting them, alphanumeric characters were not successful. P2 felt that the letters and numbers were simply too small for him to decipher. P3 was slightly more successful, as she was able to determine the “Y =” in a title of a graph that read “Y = exp(X)” (Figure 2C). She struggled to determine the remaining letters. These title letters on this particular print were about 9mm tall, and the numbers labeled on the axes were about 4mm.

Multiple Quadrant Print (Prototype #3)

We tested the feasibility of making larger visualizations by combining prints using a small hardboard holder (Figure 5). This prototype included a graph of the cosine function in two quadrants. With minimal assistance, P3 was able to determine the Braille quadrant numbers, and place them into the correct position in the hardboard graph holder, with the first quadrant to the right of the second quadrant. Upon placing them into the hardboard holder, P3 was able to navigate to both the positive and negative sides of the two-quadrant graph, and seamlessly transition from one quadrant to the next when reading the function. She was able to read the Braille axis markings that were printed in quadrant 2 rather than quadrant 1, so the axes lined up flush with the edges of both prints. Her only trouble came when trying to determine some of the Braille numbers that were being impeded by the print of the function. A greater difference in height between the Braille and the function may solve this problem in the future.

Multi-line Plot (Prototype #5)

In the plot of two data sets (Figure 1) line 1 was printed at the standard height (5mm), while line two was printed slightly (2mm) higher. P3 was able to independently trace both line graphs from the point of their origin at the y-axis. She was able to follow line 1 until it intersected with line 2, however she became confused when trying to recapture line 1 after the intersection. Lines 1 and 2 have similar slopes after they intersect which may have added to the confusion. P3 suggested either raising height of the second line even further or experimenting with different textures, such as printing one line as continuous while dashing the other.

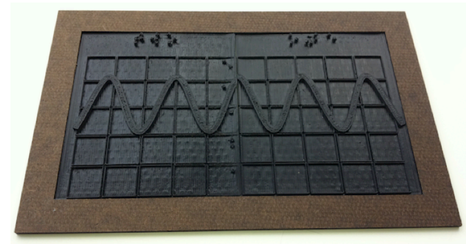


Figure 5. 3D printed prototype of Y = cos(X*3) +3, with 2mm difference between grid and data. Visualization has two printed pieces held together with a frame.

Lessons Learned

We found alphanumeric characters to be more difficult to distinguish than Braille dots. The subtleties of alphanumeric characters may become more obvious at the tactile level as the letters get larger, as we saw with P3 reading the “Y =” title. However, our prints have limited space, so it may not be possible to use larger letters.

In general, the main advantage of 3D printers over previous technology is the ability to manufacture different heights and different textures. As voiced by all three of our participants in different scenarios, both height and texture are the main features which help to distinguish some of the finer details which may appear distinct from a visual perspective, but can appear similar at a tactile level.

Group 2: Additional Interviews

We further explored the design and potential of VizTouch through interviews with individuals who had less math experience than Group 1, and were 25 and 65 years old. Table 2 highlights demographic information about these participants. P4 and P5 worked together, and were interviewed at the same time, while P6 and P7 were interviewed separately. P7 is fully sighted and assesses the abilities of individuals with vision impairments for help place them in the workforce. In this round, participants were asked to interact with the visualizations, share their impressions, and describe how they would use software to generate customized tactile graphics.

Participant	P4	P5	P6
Gender	Female	Male	Female
Degree of Vision Loss	Low Vision	Blind	Extremely Low Vision
Age of Vision Loss	Decline to State	Birth	Birth
Braille Use	Minimal	Frequent	Minimal
Profession	Office Manager	Technologist	Technologist

Table 2. Demographic information for participants with limited vision in Group 2.

Comparison of VizTouch Output to Other Tactile Graphics

All participants saw significant benefits to VizTouch over other tactile graphic solutions they had interacted with before. P6 preferred the feel of the VizTouch output to the Braille embossers she has interacted with because she liked feeling a smooth path instead of a line of dots. P5 complained that braille embossers are very loud, and should not be in an office. We have not compared sound levels between the two, but frequently run our MakerBot while we are working. P7 once created a tactile graphic by hand for a presentation and said it was tedious and took hours.

Issues for Adoption

When we initially presented the idea of customized tactile graphics to P4 and P5, P4 thought it was an interesting idea, but something she wouldn't use in her job. She explained that she doesn't she need to read graphs because the information is often verbalized (in the surrounding text) or she can get a sighted person to summarize it for her. She does use a screen magnifier, but feels that graphs are more useful for quick reference, and she doesn't always study or reference them. However, after we demonstrated the possibilities offered by VizTouch, P4 admitted that having access to VizTouch would be "ideal for situations where it is hard to do it all in your head".

Participants P4-P7 all work in accessibility-related jobs, yet none of them have access to tools to make tactile graphics. They have busy schedule and don't have extra time to learn how to use new technology, so they need to be able to produce usable visualizations with minimal input. While they have limited time to learn how to use this technology, they are willing to schedule their time around one hour print times and don't need most visualizations immediately.

DISCUSSION AND LESSONS LEARNED

Our investigations of VizTouch provided insights into the physical design of tactile graphs, such as how to differentiate between data and background information (grids), axis labels, and visualization size. We also saw how this software fulfills a need that isn't currently being met low vision and blind individuals since most people still don't have access to customized tactile graphics.

Despite our small sample, we saw differences in how these graphs were interpreted by individuals with different math backgrounds and braille ability. Data oriented professionals might have a greater appreciation for prints of complex, real world data sets, such as our unemployment example (Figure 4). In contrast, prints of simple functions, (Figure 2), might be more relevant for students learning mathematic concepts.

VizTouch allows a user to choose between Braille and alphanumeric labels. Participants who knew Braille were able to read the Braille letters, but the alphanumeric characters were difficult to read by touch. Labels and background had low contrast, so they were difficult for individuals with low vision to see, an issue that may be addressed by printing in multiple colors.

Practical Applications of VizTouch

Our interviews identified several practical applications of the current VizTouch prototype.

Accessible Curriculum

VizTouch can be used in the instruction of mathematics for individuals with visual impairments. With 3D printers currently available as consumer level devices, VizTouch can be useful for both classroom and homeschool teachers. VizTouch could be used to help teachers plot their own graphs, or make accessible textbooks. Our participants who had vision impairments as children shared stories about their difficulty learning math, and hypothesized that access to more tactile visualizations would have helped them in several subjects.

Applications for the home or office

P4 and P5 suggested using VizTouch to make tactile visualizations of graphs in a slide presentation. P6 found math difficult in school, and does not interact with many graphs or charts at work. However, she does like information to be presented tactilely and was very interested in using a 3D printer to create her own tactile visualizations to use as a portable reference.

Helping People Understand Personal Data

P7 performs surveys and assessments on people with limited vision, and currently explains data verbally. He felt that the ability to create tactile visualizations would help his clients better understand their own performance data, and how their abilities have changed over time.

Making Online News Articles Accessible

Currently, many professionals who work with mathematical data are constrained in how they can interact with this data when it appears in the news media. P1, who does extensive work with economic data, mentioned that she has trouble accessing graphs that appear in financial news articles. Screen readers such as JAWS [7], do not handle graphs embedded in articles on the web. We envision authors making their work more accessible with VizTouch by publishing the equations or raw data for an article's graphs. Blind and low vision individuals could use this information to create their own tactile version of the graphics.

LIMITATIONS AND FUTURE WORK

Future work includes further investigation of the design of tactile visualizations, faster and more complex printing, and testing VizTouch with individuals with vision impairments.

Our current prototype is limited by manufacturing constraints that we believe will be eliminated as affordable 3D printing technology improves. Our current work was limited by the 3.5x3.5" build platform on the MakerBot. However, our initial efforts to combining several prints to represent larger visualizations worked well. Our current prototype takes an hour to print a single quadrant, which may prevent its use in applications (such as just-in-time visualizations). However, it still enables many individuals graph access they wouldn't have otherwise. Despite this limitation, our participants still saw value in the current solution, and had ideas for how they could plan around it.

VizTouch currently doesn't give the user much control over the visualization's appearance. We believe a benefit of VizTouch is that the user doesn't have to curate the data, but acknowledge that some users may prefer having this control. Currently, users are not able to precisely identify parts of the graph (i.e. distinguishing between 1.8 and 1.6) if the scale is in integer units. In future work we will investigate the limits of information density, and how we can further take advantage of the Z-axis.

In this investigation, participants only interacted with the output from VizTouch, and not the software. In future work we will evaluate how blind and low vision individuals use our VizTouch software, and conduct a longitudinal study of its' impact.

CONCLUSION

We have developed VizTouch, software that makes it easy to generate tactile visualizations of data using rapid prototyping technology. Using VizTouch, a user performs a one-time software interaction that automatically generates files ready to be manufactured on a 3D printer. VizTouch provides an accessible and affordable option for individuals with limited or no vision to create customized tactile visualizations. We recruited 6 participants with vision impairments who were able to read visualizations generated with VizTouch and understand the data being represented. Our semi-structured interviews revealed that VizTouch could provide access to previously inaccessible education, employment, and entertainment content.

ACKNOWLEDGMENTS

We thank Jess Martin, Christopher Kidd, Robert McGuire, Lisa Anthony, and our participants for their help with this research. This project was funded by the DREU program, a project of CRA-W and the Coalition to Diversify Computing funded by the NSF Broadening Participation in Computing program (NSF CNS-0540631).

REFERENCES

1. Bolt, S. E., & Thurlow, M. L. Five of the most frequently allowed testing accommodations in state policy: Synthesis of research. *Remedial and Special Education, 25,* (2004), 141-152.
2. DeSimone, J. R., & Parmar, R. S. Issues and challenges for mathematics teachers in inclusion classrooms. *School Science and Mathematics*, 106, (2006) 338-348.
3. Ferrell, K. A., Buettel, M., Sebald, A. M., Pearson, R. *Mathematics research analysis.* Louisville KY: American Printing House for the Blind (2006).
4. Graphic Aid for Mathematics Kit. http://shop.aph.org
5. Index 4X4 PRO Braille Embosser and Booklet Maker with Acoustic Cabinet. http://www.enablemart.com
6. Inkscape. http://inkscape.org/
7. JAWS for Windows Screen Reading Software. http://www.freedomscientific.com
8. Jernigan Institute. The Braille Literacy Crisis in America: Facing the Truth, Reversing the Trend, Empowering the Blind. A Report to the Nation by the National Federation of the Blind. (2009).
9. Ladner, R.E., Ivory, M.Y., Rao, R., Burgstahler, S., Comden, D., Hahn, S., Renzelmann, M., Krisnandi, S., Ramasamy, M., Slabosky, B., Martin, A., Lacenski, A., Olsen, S., Croce, D., Automating Tactile Graphics Translation, In *Proc. ASSETS,* ACM Press (2005), 1-8.
10. Lederman, S.J., Campbell, J.I. Tangible Graphs for the Blind. *Human Factors Society 24,*1 (1982), 85-100.
11. MakerBot Industries. http://www.MakerBot.com/
12. Mereu, S., Kazman, R., Audio enhanced 3D interfaces for visually impaired users. *Proc. Conference on Human Factors in Computing Systems*, ACM Press (1996), 72-78.
13. McGookin, D., Robertson, E., Brewster, S. Clutching at Straws: using tangible interaction to provide non-visual access to graphs. In *Proc. Conference on Human Factors in Computing Systems*, ACM Press (2010), 1715-1724.
14. Nemeth Braille http://www.afb.org/braillebug/nemeth_braille.asp
15. OpenSCAD – The Programmers Solid 3D CAD Modeler. http://www.openscad.org/
16. Phantom Omni Haptic Device. http://www.sensable.com/haptic-phantom-omni.htm
17. Ponoko. http://www.ponoko.com/
18. Pstoedit. http://www.pstoedit.net/
19. Sánchez J., Flores, H. AudioMath: Blind children learning mathematics through audio. In *Proc. Proceedings of ICDVRAT*, (2005), 183-189.
20. Tiger Embossers, Audio Graphing Calculator http://www.viewplus.com/
21. Toennies, J. L., Burgner, J., Withrow, T. J., Webster, R. J. III. *Toward Haptic/Aural Touchscreen Display of Graphical Mathematics for the Education of Blind Students.* WorldHaptics, (2011), 373-378.
22. Universal Laser Systems. http://www.ulsinc.com/
23. Veusz: A Scientific Plotting Package. http://home.gna.org/veusz/
24. Yu, W., Ramloll, R., Brewster, S., Lee, R. Haptic Graphs for Blind Computer Users. In *Proc. First International Workshop on Haptic Human-Computer Interaction 2002*, Springer-Verlag (2001), 1-6.