Playing with geometry: a Multimodal Android App for Blind Children

Maria Claudia Buzzi/Marina Buzzi
CNR-IIT
Via Moruzzi 1, 56124 Pisa
{claudia.buzzi,marina.buzzi}@iit.cnr.it

Barbara Leporini
CNR-ISTI
Via Moruzzi 1, 56124 Pisa
{barbara.leporini}@isti.cnr.it

Caterina Senette
CNR-IIT
Via Moruzzi 1, 56124 Pisa
{caterina.senette}@iit.cnr.it

ABSTRACT
Geometry is a traditionally difficult subject to teach to visually impaired subjects. This paper investigates tools to help blind children learn geometry. An accessible vibro-tactile-based android application has been designed to allow children to make freehand drawings and play with geometry, recognizing common geometric shapes or topological configurations. An initial usability test of the application, performed by a blind researcher, has revealed some limitations of the proposed approach that could soon be overcome thanks to current technological innovation in the mobile world.

Categories and Subject Descriptors
H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6) - *Haptic I/O*. K.4.2 Social Issues - *Assistive technologies for persons with disabilities - Handicapped persons/special needs*.

General Terms
Performance, Design, Experimentation, Human Factors

Keywords
Blind, visual impairment, software, geometry, multimodal interaction

1. INTRODUCTION
Geometry is very important in the progress of learning and reasoning in children. Literature shows that the development of children in primary schools largely depends on the perception of space [8, 11, 12]. Therefore, it is very important to encourage and support geometry in curriculum activities for children with visual impairments. For a blind child it is usually very difficult to deal with space and its laws, so teachers and educators often neglect geometry among school subjects, considering it an impossible challenge. Nevertheless, this can be addressed by creating teaching support tools and providing educators with the knowledge and strategies for teaching geometry to visually impaired students [13]. When research offers cheap accessible multimodal systems (as alternatives to expensive hand-made systems) to facilitate a blind student's learning process, this challenge will be easier to overcome.

For visually impaired people, the best way to receive environmental information about shapes and 3D objects is touch. As Kennedy suggested, manipulation of objects in space also provides background for understanding algebra, trigonometry, calculus, and many topics in higher mathematics that require spatial thinking [12]. However, a tactile approach to learning concepts such as shapes and distances can only be used with items that are small enough to be explored with the hands. Many environments, surfaces and objects that belong to so-called *macro-space* require abstraction skills and mental models that are acquired differently by blind subjects compared to sighted persons; furthermore, differences exist among blind people, depending on how early the subject was exposed to such concepts [13].

Considering the importance of early involvement of blind students in multimodal approaches to learning geometry, we present our contribution of a free learning game application accessible to blind children. We focus on children age 6-11 years since in this age range most spatial abilities (topology at 18 months, concept of single shapes at 5 years, vertical and straight lines at 7-8 years) should be mastered [16]. Blind children can present a slight developmental lag for different reasons including the lack of intensive experience with drawing [10].

The work presented herein is a feasibility study on the possibility of conveying spatial information to blind students through haptic feedback provided by the new generation of mobile devices. We created an Android application consisting of two main functions: 1) freehand drawings; 2) games to train the child with geometric shapes, or with topology and geometry mixed up (guess-game). We selected vibration as the primary feedback to allow the child to recognize the shapes after exploration. The application is entirely accessible; all the elements on the screen, including the labels of shapes and distractors, are announced via a text-to-speech (TTS) system, triggered by a single or double touch depending on identification purposes or selection modality. The child can easily locate on the screen the best candidate label to associate with the shape explored.

2. RELATED WORK
There is limited availability of accessible math (including physics and geometry) tools and resources for blind children. Previous studies involving software to support mathematics and geometry learning proved that haptic technology can improve accessibility of mathematics and science software for visually impaired people [19, 20, 22]. For instance in [19], a haptic device prototype (PHANToM) is described that enables a blind student to feel the shape of the graphical representation of the mathematical function under study. Similarly, in [22] the authors propose a system to support accessibility of graphical data (i.e., graphs and tables) for blind and visually impaired people, discussing the disparity between human haptic perception and the sensation simulated by force feedback devices. In [7] several experiments were conducted involving sighted and blind people to investigate object recognition and correct identification of size and orientation (angle). Results highlighted the differences in perception by blind and sighted people and showed that a haptic interface has considerable potential

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for blind computer users. In [20] authors present the results of an investigation of the potential benefits of incorporating haptic feedback (through the Logitech Wingman Force Feedback Mouse™) into software to be used in high school physics curricula. Blind students experienced the electric field concept via force feedback devices while a screen reader provided information about texts and user interface (UIs) components. Results indicated that haptic feedback was a useful tool for conveying information on how a dynamic system works, as well as for presenting non-text content such as data plots for blind computer users. Using the same haptic mouse, in [6] the author introduces the Touch Tiles project, which aimed to create a multimodal interface for a geometry software program for visually impaired children. Results of a test with three children and one adult suggest that the identification of shapes with force feedback settings were 80% to 100% easier than the ones without.

Another interesting field of research involves visual aid systems using sound to convey spatial information and to display images by differences in frequency pitch and loudness. In [17] both interaction approaches, tactile and sonic, are investigated in the same system, "From Dots to Shapes" (FDTS) in order to provide a support in special education for teaching basic planar geometry. The auditory platform is composed of three classic games for blind and visually impaired pupils, adapted to work on a concept of Euclidean geometry. Authors tested their system with blind adults, who were able to understand this sort of auditory coding technique.

Concerning apps for mobile devices, in Gorlewicz at al. [9] the authors conducted a pilot study investigating user comprehension of grids of points and graphical entities using vibratory touchscreens and audible sounds. Results showed that each student could successfully find and locate 100% of displayed points on a grid. Another research group [2, 3] presented an experimental prototype, entitled EVIAC (EValuation of VIbration Accessibility), allowing visually impaired users to access simple contour-based images using vibrating touch screen technology. Results show that the accessibility method based on a vibrating touch screen seems feasible for accessing simple contour-based images but blindfolded testers performed better.

3. GEOMETRY AND FREEHAND DRAWING FOR BLIND PEOPLE

As explained by Anne Sfard [18], one big challenge in teaching geometry is the difference in space levels: *(i)* Micro-space (the minimum work environment) *(ii)* Meso-space (the schoolroom or the domestic environment). *(iii)* Macro-space (cities, rural spaces, etc.). The correct understanding of all these levels allows the transfer of big spaces to small maps and vice-versa. Considering that space levels could be a great challenge even for sighted children [5], in this study we focus on micro- and meso-space.

In "*Tactile Pictures: Ideas For Lessons*" by M. A. Heller [10] a set of exercises is proposed for teaching geometry to blind and sighted children depending on the degree of early exposure to drawing skills, including: *(i)* Drawing common geometric shapes *(ii)* Understanding straight lines *(iii)* Understanding the difference between standing upright and having one's body tilted *(iv)* Freehand drawing and art activities used as a reward for both sighted and blind children.

Visual exploration of shapes and objects can be replaced by touch, but at a cost in terms of serialization vs parallelism, and slowness of task completion. Freehand drawing is a challenging task for a blind person. A blind child usually draws using a special paper and pencils that can track grooves of different textures on the paper. Despite this, freehand drawing or figuring out an existing drawing (illustration) is very difficult because the user perceives only individual sections of it, lacking the ability to understand the overall meaning of what has been drawn [13]. Some blind children have reported preferring to draw with a sighted person, to listen to the verbal description of what (s)he is drawing and thus not miss information on how the drawing is progressing [14].

4. ANDROID APP DESIGN

To deploy our application, we tested three different Android devices observing differences in the strength of the vibration motors. Some haptic effects are very pronounced on one device, and barely perceptible on another. We selected a Tablet device (Acer Iconia Tab) with Android 4.0 O.S. (Ice Cream Sandwich, optimized for Tablets). The application has been developed with Android Studio.

4.1 Freehand Drawing

The UI for freehand drawing (see Fig. 1) was conceived to respond to two different user-interaction modalities ('draw' and 'sense'), providing the user to with immediate feedback on the line tracked on the screen and also giving him/her the possibility of perceiving the drawn object a posteriori. The two modes -*draw* and *sense* - are activated by a double tap on the device screen. When one mode is active, the other mode is implicitly disabled. To improve the application's usability, a TTS informs the user about current active mode.

As shown in Fig.1, the canvas drawing area occupies most of the available space. On left and right sides there are two sets of buttons, for color selection (on the right) and navigation (on the left). Each button could be identified through a vocal feedback when the user moves his finger over the widget, while a long press activates the selection. The TTS announces each selected item in order to avoid accidental interactions. The UI's design enables the user to choose the color with which to draw from a palette. This sketch enrichment using colors could be useful in conveying information about the object drawn, in this way facilitating communication between sighted children and visually impaired children and encouraging the latter's inclusion.

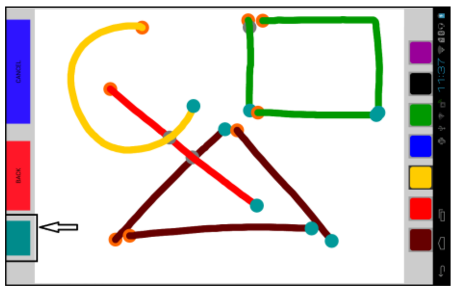

Fig. 1. UI for freehand drawing

To facilitate user orientation, we added a button equipped with TTS properties on the bottom left area of the UI (highlighted in Fig. 1 by the arrow). Localizing this button ensures the proper selected direction for exploration or drawing.

In the *draw* mode, the user draws by dragging their finger on the screen. During line tracking, the device triggers a vibration for the user's entire action. Whenever during the drawing a line intersects with another line, the user receives a brief sound as feedback. Furthermore, the intersection point is highlighted with a small circular region (in gray), to facilitate recognition of the intersection point even in the *sense* mode. The starting/end points of each line are highlighted in the drawing with other circular regions of a given color (orange for starting points and blue for endpoints); this allows their recognition in the *sense* mode since the strategy to respond to user interaction is based on the pixel's color.

In *sense* mode, the user interacts with the canvas by exploring the drawing by fingertip. The application responds to the position of the user's finger by extracting the pixel's value that fits these coordinates. Touching the drawn areas activates the tablet's vibration, while touching the white regions does not release any feedback. As previously mentioned, the intersection points between lines and the line's start/end points are identified using different sound effects.

4.2 Play with geometry: guess the shape

We developed a set of exercises accessible for blind pupils, following suggestions from the literature for a basic geometry program. The exercises do not teach new concepts which, by their nature, need to be experienced first by touching a 3D object or the traditional cardboard material representing geometrical shapes. Our intent is to create a software environment for going over previously mastered concepts, allowing blind children to test themselves by playing with geometry as sighted children usually do with thousands of apps designed for them.

The *Guess the Shape* section proposes random shapes as shown in Fig. 2. Straight lines can be horizontal, vertical or oblique. Any form is drawn on top of the screen. A small region at the bottom contains three text labels: one, randomly positioned, is the name of the proposed form and the others are distractors (randomly selected).

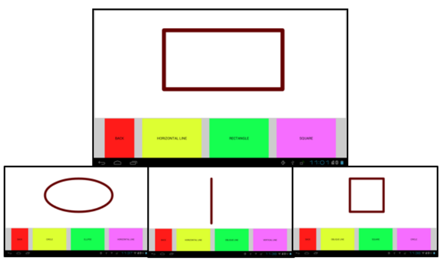

Fig. 2. UIs for *guessing the shape* section

The exercise requires the child to explore the figure with his/her fingertip and then choose the label representing the name of that form. The exploration causes a tablet vibration if the fingertip position falls under a pixel included in the drawing, while no feedback is provided if the fingertip touches a white pixel. To facilitate shape recognition we can use different strategies: the most effective might be to highlight the vertices of each shape since the user has a cue for guessing the type of shape: the number of vertices. Then (s)he can move around the screen to test a hypothesis. This is an effective exercise because it trains the child's spatial orientation. We can highlight the vertices of each shape by adding sound feedback to each of them, activated by user touch. In the case of geometrical shapes such as rectangle, square etc., other strategies are to depict each shape as a surface area and not as a perimeter, to help the user to define the region under test.

4.3 Topology Game

In the *topology game*, the software gives the child the opportunity to play with concepts such as *inside of*, *nearby*, etc. On the upper part of the UI (see Fig. 3) a simple shape (always the same) is drawn that could occupy different positions in relation to a straight line or to a circular line depending on the proposed topology. If the task requires locating the shape using terms such as *to the right of, to the left of, above, under*, the child has to identify a horizontal or vertical line and the position of the shape in relation to the line.

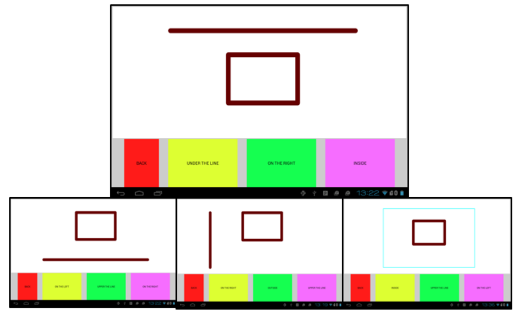

Fig. 3. UIs for *topology game* section

If the task is about concepts such as *inside/outside* the software uses a circular closed line representing a closed perimeter, and the child needs to locate the shape in relation to it. Each task is announced by the TTS and the child's response is performed by selecting the correct label by touching with a long press action, as in the *shape guessing* game.

4.4 User Interaction and Multimodality

The idea of this study was to understand whether the raised line on a sheet and vibration signal caused by the passage of a finger on the screen could be equivalent exploration methods.

A first usability test was carried out by a blind user (one of our research team who has been involved in each phase of the implementation). The test revealed some limitations, especially due to the technology used. A limitation of the tablet haptic technology is the lack of support for multi-touch interaction so the user has tested the application using only one finger. Literature has proved that multiple hand (one hand is used as a reference) and finger exploration results in improved haptic performance by the blind [15, 21]. Another limitation is that the haptic effect involves the entire device (it is the device that vibrates, not the finger) and is not perceived locally on the fingertip, making accuracy in identification still poor. Identification of a single horizontal or vertical line is fairly easy, but the recognition of forms, particularly the circle without edges, is not very accurate. Finally, we found some problems with the classic *onTouchEvent* handlers of Android that exhibit different behavior depending on the velocity of touch events. This effect is reduced if the user draws slowly and can be improved programmatically considering the notion of "touch slop" recently introduced in Android. [1]

A promising new technology that may overcome this limitation is offered by Tesla Touch [4]. As shown in Fig. 4, TeslaTouch technology is based on the principle of Electro-vibration discovered in 1953 that produces a dynamic friction between the finger and the panel's surface resulting in a haptic effect, programmatically variable, transmitted to the fingertip. "It can be easily combined with a wide range of touch sensing technologies and used to enhance a wide range of applications with rich tactile feedback" [4].

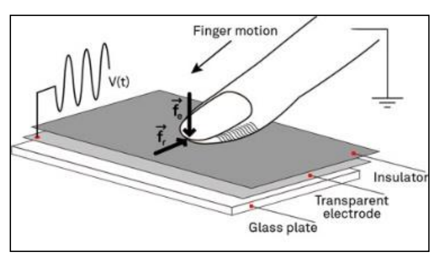

Fig. 4. Tesla Touch operating system [4]

5. CONCLUSION AND FUTURE WORK

The goal of our study is to propose software to help blind children learn geometry. The application herein described was conceived as a means to evaluate the effectiveness of conveying spatial information without the traditional tactile mode (Braille or raised lines on embossed paper), instead using haptic vibrational feedback generated in response to user interaction in mobile devices.

In this first phase of our study, we developed an Android application for training two main functions: freehand drawing and guessing basic geometric concepts such as shapes and simple topology configurations. Both functions are based on the ability to sense the drawing on the screen by dragging a fingertip over it. The touch and dragging inputs activate tablet vibration: differences in intensity and/or duration could convey different information. In addition, a system of short sounds provides the user with another type of information about the drawing such as vertices, starting/end points of individual drawn lines, and intersection of multiple lines, in order to facilitate understanding of the drawing and the identification of the geometrical shape. The first app prototype was tested by a blind person, revealing some technology limitations for purposes similar to those we considered in this work that we have critically discussed. Future work will continue in this direction, taking advantage of the rapid evolution of new mobile technology.

6. REFERENCES

[1] Android Developers . Community: https://developer.android.com

[2] Awada, A., Issa, Y. B., Ghannam, C., Tekli, J., and Chbeir, R. (2012). Towards Digital Image Accessibility for Blind Users via Vibrating Touch Screen: A Feasibility Test Protocol In Eighth International Conference, 547-554. IEEE.

[3] Awada, A., Issa, Y. B., Tekli, J., and Chbeir, R.(2013, October). Evaluation of touch screen vibration accessibility for blind users. In Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility (48). ACM.

[4] Bau, O., Poupyrev, I., Israr, A., and Harrison, C. (2010, October). TeslaTouch: electrovibration for touch surfaces. In Proceedings of the 23nd annual ACM symposium on User interface software and technology (283-292). ACM.

[5] Berthelot, R., and Salin, M. H. (1998). The role of pupil's spatial knowledge in the elementary teaching of geometry. In C. Mammana and V. Villani (Eds.), Perspectives on the Teaching of Geometry for the 21st Century (pp. 71-78). Dordrecht: Kluwer Academic Publishers.

[6] Bussell, L. (2003). Touch tiles: Elementary geometry software with a haptic and auditory interface for visually impaired children. In *Proceedings of the EuroHaptics Conference*. (512-515).

[7] Colwell, C., Petrie, H., Kornbrot, D., Hardwick, A., and Furner, S. (1998, January). Haptic virtual reality for blind computer users. In Proceedings of the third international ACM conference on Assistive technologies (pp. 92-99). ACM.

[8] Dekker, R. (1989). Cognitive development of visually handicapped children. Intelligence test for visually impaired children aged, 6, 1-21.

[9] Gorlewicz, J.L.,Burgner J.,Withrow and J.T.,Webster,R.J. (2014) Initial Experience Using Vibratory Touchscreens to Display Graphical Math Concepts to Students with Visual Impairments. Journal of Special Education Technology (JSET)Volume 29, number 2 pp 17-26

[10] Heller, Morton A. and William Schiff, Editor. The psychology of touch. Psychology Press, 2013.

[11] Hobbs, J. R., and Narayanan, S. (2002). Spatial Representation and Reasoning [Electronic Version], 16. Retrieved 09.08.06.

[12] Kennedy, L. M., and Tipps, S. (1994). Guiding Children's Learning of Mathematics (7.ed.).Belmont, California: Wadsworth Publishing Company.

[13] Klingenberg, Oliv G. Conceptual understanding of shape and space by Braille-reading Norwegian students in elementary school. Journal of Visual Impairment and Blindness 106.8 (2012): 453.

[14] Klingenberg, Oliv G. "Geometry: Educational implications for children with visual impairment." Philosophy of Mathematics Education Journal 20.15 (2007): 15.

[15] Morash, V. S., Pensky, A. E. C., Tseng, S. T. and Miele, J. A. (2014). Effects of using multiple hands and fingers on haptic performance in individuals who are blind. Perception, 43(6), 569-588.

[16] Piaget, J., Inhelder, B., Szeminska, A., Jean, P., Barbel, I., and Alina, S. (2013). Child's conception of geometry. Routledge.

[17] Roth, P., Petrucci, L., and Pun, T. (2000, July). From dots to shapes: an auditory haptic game platform for teaching geometry to blind pupils. In Proceedings of International Conference on Computers Helping People with special Needs: ICCHP (17-21).

[18] Sfard, A. (2003). Balancing the unbalanceable: The NCTM Standards in Light of Theories of Learning Mathematics. In J. Kilpatrick, W. G. Martin and D. Schifter (Eds.), A research companion to principles and standards for school mathematics (pp. 353-392). Reston: VA: NCTM.

[19] Van Scoy, F. L., Kawai, T., Darrah, M., and Rash, C.: Haptic display of mathematical functions for teaching mathematics to students with vision disabilities. In Haptic Human-Computer Interaction Workshop, University of Glasgow. (2000).

[20] Wies, E. F., Gardner, J. A., O'Modhrain, M. S., Hasser, C. J., and Bulatov, V. L. (2000). Web-based touch display for accessible science education. Retrieved September 18, 2000.

[21] Wijntjes, M. W., van Lienen, T., Verstijnen, I. M., and Kappers, A. M. (2008). Look what I have felt: Unidentified haptic line drawings are identified after sketching. Acta psychologica, 128(2), 255-263.

[22] Yu, W., Ramloll, R., and Brewster, S. (2000). Haptic graphs for blind computer users. Retrieved December 18, 2002