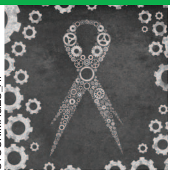

Tactile diagrams for the visually impaired

Richa Gupta, M. Balakrishnan, and P.V.M. Rao

In this information-driven era, the use of pictorial forms of communication has become widely popular, making the world increasingly inaccessible to visually impaired and blind individuals. Accessing print media has also been a challenge for this population. Braille, a standard writing system for perception through touch, and audio translations of written text have made books accessible to the visually impaired. However, both these formats fail to make pictures and graphics accessible to the blind.

Tactile modality has been found to be the closest to vision in terms of semantic and cognitive processing of pictorial information. As a result, the role of tactile modality has been explored to communicate graphical information. The unavailability of visual information in accessible formats suitable for tactile perception poses a big challenge for visually impaired and blind individuals in carrying out day-to-day activities.

The challenge is more critical in education. The U.S. National Science Foundation has acknowledged that people with visual impairments and blindness are underrepresented in the fields of math and science compared to the general workforce. Because these fields make extensive use of visual graphics, they are particularly challenging for individuals with impaired vision. The use of pictures and diagrams in educational material, and thus in learning science, technology, engineering, and mathematics (STEM) subjects, has been deemed essential. Therefore, it is widely believed that making graphical information accessible to blind people would significantly increase their educational and career opportunities.

Digital Object Identifier 10.1109/MPOT.2016.2614754
Date of publication: 10 January 2017

One significant approach has been to present visual information by creating diagrams suitable for tactile perception. These diagrams are called *tactile diagrams* or *tactile graphics* (*TGs*) (Fig. 1). This article presents an overview of the challenges in making pictorial information accessible to the blind and the efforts made to address these challenges by the Indian Institute of Technology (IIT) Delhi and other organizations.

Tactile diagrams

Tactile diagrams enable the perception of two-dimensional images through touch. They are embossed outline drawings that are uniquely designed to communicate visual information to individuals with visual impairment and blindness. Blind students can attempt to study subjects that are heavily dependent on graphics, such as geography, mathematics, and science, among others. Special educators and students with visual impairments are optimistic about the benefits of using tactile diagrams in learning graphic-intensive subjects. Despite the acceptance of tactile diagrams by students, the design and delivery of effective diagrams is a challenge.

The effectiveness of tactile diagrams has been questioned and doubted by many earlier researchers. For a long time, it was thought that a tactile version of graphics was bound to fail because it would be based on principles of vision and optics. Later, this thought changed as the definition of pictures evolved. It was argued by researchers that understanding pictures is inherent to humans and is not confined to perception by visual means. This opened up research opportunities in the area of picture perception through touch.

Empirical data presented by various researchers suggests that many properties of objects and surface can be registered by active touch. Additionally, active touch is similar to vision in experiments related to shape and texture perception. However, efficiency of tactile perception is lower than that of visual perception due to physiological differences between the two modalities. Tactile modality has a lower resolution and smaller field of view, which results in piecemeal information acquisition.

Observers use a set of exploratory procedures to gather information tactually. These procedures are dictated by the tactile attributes the observer chooses to process. Graphics that allow all types of exploratory procedures enable the harnessing of more information through touch. Yet, the perception of graphics through touch is much more difficult.

One of the factors that contribute to this difficulty is the limitation of raised outline drawings in conveying depth information. Many tactile pictures involve perspective and foreshortening effects in object representation, and one might expect a difficulty in perception because of the purely visual nature of the concept of perspective itself. However, some recent studies requiring congenitally blind subjects to draw objects from different viewpoints have conveyed an understanding of perspective in blind people. This has compelled the research community to revisit the previously cited thought on perception of perspective drawings by touch. It has been suggested that visual experience is not necessary to understand some important aspects of linear perspective and viewpoint effects. Researchers have also stated that, with prior instruction about the nature of the drawing and viewpoint, perspective representations may be accessible to many blind users.

The design and presentation of visual information in tactile format requires an in-depth understanding of the limitations and strengths of touch.

The design and presentation of visual information in tactile format requires an in-depth understanding of the limitations and strengths of touch. Researchers have attempted to compare the performance of blind and sighted participants in tactile perception tasks. Results show that the perception of graphics through touch is more challenging as compared to the perception of graphics though vision. As stated previously, tactile touch has a limited field of view and a lower spatial and temporal resolution. This hinders the observer from receiving a global view of the graphic. Information acquisition through touch is piecemeal and sequential and needs to be congenitally integrated to be perceived semantically. This adds to the cognitive load of the blind observer, which makes tactile perception difficult and slower.

Additionally, understanding TGs is a challenge when diagrams are directly converted from print to tactual format. Due to the lower resolution of tactile modality, a directly converted diagram may seem cluttered

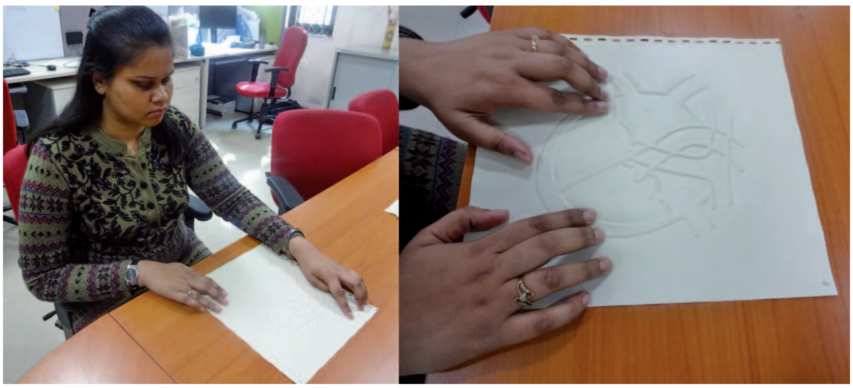

FIG1 A user exploring a tactile diagram.

and difficult to interpret. Reportedly, tactile diagrams were perceived with higher efficiency when they were specially designed with the limitations and strengths of tactile modality. The graphics have to be simplified, decluttered, and scaled to appropriate sizes to allow for better exploration.

Researchers have investigated various parameters and attributes that can help in improving the efficiency of information communication. It has been emphasized that the translation of information from visual to tactile cannot be direct. Various organizations have developed and evolved tactile design guidelines to aid in the design of TGs. These guidelines have evolved with feedback and trials with blind users as well as empirical data provided by behavioral and neurobiological studies done with visually impaired and blind subjects. Other than defining specific design parameters such as minimum perceptible line widths, gaps, and texture density, the guidelines also help tactile designers in the translation of semantic information from visual to tactile form.

Various realization techniques have been explored with different base materials. The techniques offer varying levels of resolution, cost effectiveness, and perceptual advantages. Techniques used to realize TGs include:

- ad hoc methods, such as craft, parchment paper drawings
- embossed drawings using braille embossers
- printing on microcapsule paper, which swells when heated
- thermoforming using drawing molds
- inkjet printing
- digital devices, such as refreshable displays.

All of these techniques produce raised line drawings. Though these techniques have been used to realize and present physical TGs, there are several issues associated with them. The key constraints in dissemination in developing countries like India have been the lack of skilled designers as well as the high cost of production (swell paper).

Need for skilled tactile designers

Researchers have emphasized that the design of tactile diagrams cannot be a mere translation of information from a visual to a tactile format. The contextual and semantic information being communicated, whether though diagrams for the sighted or through tactile diagrams, should be ideally the same. This is somewhat addressed by the tactile design guidelines developed by rehabilitation organizations like the Blind Association of North America and the Royal National Institute of Blind People.

Since most tactile designers are sighted individuals, the need to understand the specifics of the strengths and weaknesses of tactile modality is essential for creating effective tactile resources. Understanding user needs is the key to good design. Despite the aid provided by tactile design guidelines, there is a demand for skilled tactile designers who have an in-depth understanding of user preferences. Tactile guidelines provide a basic design framework for designers to transfer information from visual to tactile formats, but they fall short at addressing content-specific design issues. For example, guidelines assist in making decisions regarding the size, scale, orientation, decomposition of information (if required), texture palettes, labelling, and keys but do not infrom about how to represent different views of an object so that it is perceived as one three-dimensional (3-D) object. Skilled tactile designers are limited in number, and this amplifies the challenge of providing quality tactile resources to the large number of blind individuals.

TG designers are faced with challenges like the conversion of information into tactile format while making sure that the semantic meaning of the diagram remains intact. Also, simplification, decluttering, and the division of one diagram into parts cannot be completed without input from a teacher. This stands true in the case of tactile perception research as well. Input from teachers and special educators can help in studying design and drawing of inferences from collected data. More collaboration must be formed between educational and research organizations.

The automation of the TG design process

In an attempt to address the shortage of skilled designers, researchers have tried to automate the process of information translation from visual to tactile-suitable formats. Though there have been significant efforts to improvise the design and production processes for creating better quality tactile diagrams, the effort to automate these processes is in a very nascent stage. The desire for such automation can be understood in the context of countries like India, where there is a need to convert thousands of existing textbooks into a couple of dozen languages if the goals of universal education is to be attempted.

The widespread acceptance of tactile diagrams has created a need for automated design and production processes that require little or no training. Few notable works have come from the field of computer science that attempt to develop decision-making frameworks and software applications for converting a scanned visual diagram into versions that are suitable to be made into raised line drawings. Accessible software tools with built-in design guideline frameworks for making tactile diagrams have also been proposed. Such tools can help educators and students make tactile diagrams themselves with minimal training. However, a commercially successful automation tool is yet to be seen.

Looking for a low-cost realization technique

Rehabilitation and educational organizations for the blind have reiterated the need to develop efficient mass-production techniques to provide effective resources to the large numbers of blind and visually impaired students so that they match the pace of the current ever-changing, information-oriented world. Since a large percentage of the blind population resides in developing nations, there is a

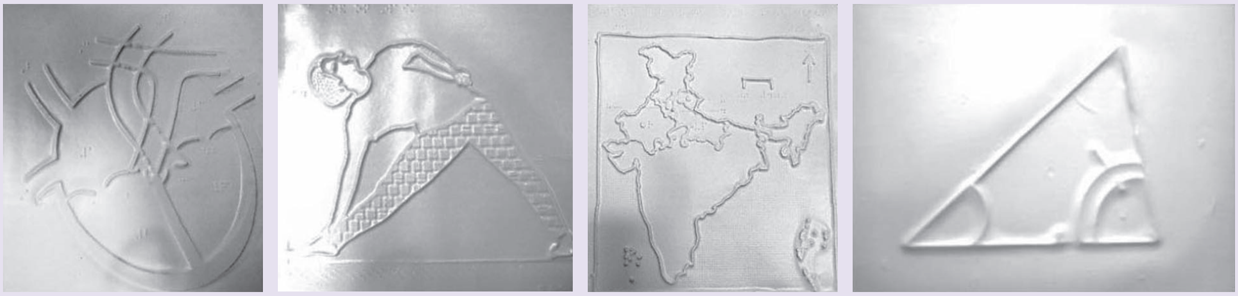

FIG2 Examples of tactile diagrams made using the production process developed at Assistech Lab.

need to develop cost-effective mass-production techniques for greater penetration. There is also broad consensus for developing affordable tactile diagram production processes to provide good education to young minds who are at a disadvantage due to the unavailability of tactile material.

Assistech Lab work

Assistech Lab at IIT Delhi has been working to address the aforementioned issues. A Center of Excellence in Tactile Graphics (CoETG), supported by Ministry of Electronics and Information Technology (MeitY), Government of India, has been set up with the objective of

- identifying and developing techniques/technologies for the production of affordable TGs
- producing and testing tactile material from multiple domains
- developing a software tool chain for automating the design of tactile diagrams from diagrams essentially produced for sighted students.

The CoETG team consists of skilled tactile designers and seeks regular consultation from special educators in the diagram design process. The lab also conducts workshops and trainings for special educators and members of the rehabilitation community that teaches them the processes used in the design and realization of quality tactile diagrams.

CoETG has developed a cost-effective mass-production technique for making tactile diagrams that uses widely available 3-D printing technology. The process uses 3-D printing to make master diagrams, which are then used as molds for making multiple copies using the thermoforming technique. The team has successfully completed the conversion of the National Council of Educational Research and Training (NCERT), India, math book for ninth grade into accessible format, and it will soon complete the NCERT ninth-grade science book. Other projects that have been successfully completed include a tactile atlas of India and a tactile yoga book. These projects (Fig. 2) have received positive feedback from both visually impaired users and rehabilitation organizations.

Along with designing TGs, CoETG is attempting to automate the design process of the conversion of information from a visual to a tactile format. An application called *Edutactile* is under development (Fig. 3). It uses tactile design guidelines as a foundation for the conversion of visual information into a tactile-suitable form as well as converting associated written text into Braille. This application has a context-based interface and allows the user to make diagrams such as mathematical graphs, organic chemistry molecular diagrams, and free-hand drawings with ease. Other domains of graphics will also be added.

Another tool under development relates to the automatic conversion of scanned textbook images to tactile diagrams. This involves first the extraction and recognition of text followed by the evulsion of geometric primitives like lines and circles. For more complex diagrams, especially in science text books, there is a need for a tool that can recognize distinct regions so that different tactile shading (instead of colors) can be assigned to them. This kind of automation would enable the visually impaired readers to scan diagrams and directly print them in tactile formats without worrying about any design or preprocessing issues. Finally, the

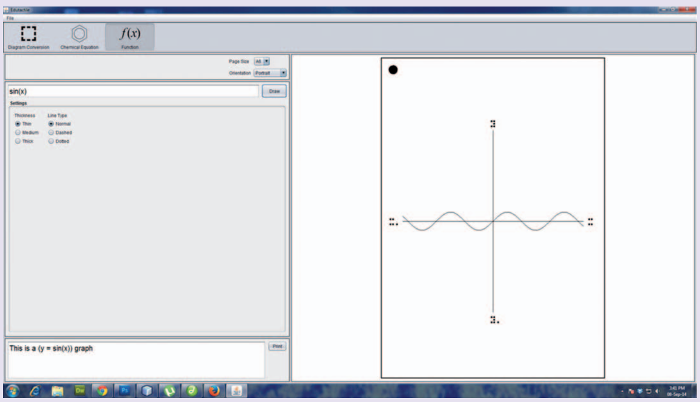

FIG3 A snapshot of the Eductatile application interface.

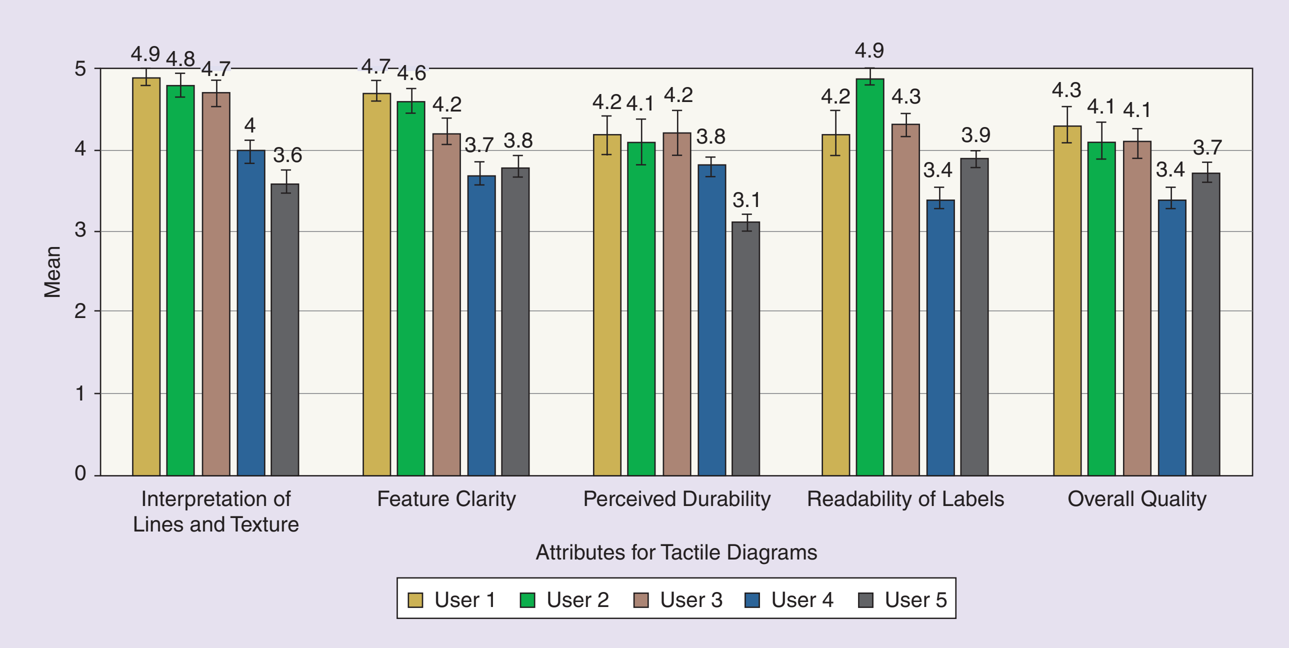

FIG4 The feedback from five users on the quality of tactile diagrams produced by Assistech Lab. The ratings are on a Likert scale of 1–5.

software translates text to Braille and creates a diagram in Scalable Vector Graphics format for tactile production. The first version of the software, though not yet fully automated, is still capable of enhancing the productivity of tactile designers.

Conclusion

Though the attempted research (Fig. 4) and innovation supports the development of tactile graphical aids in a big way, there are still several significant unaddressed issues in the design and realization of TGs that ensure the effective perception and comprehension by a blind individual. To promote the participation of blind students in education, the urgent need for accessible resources should be met. Various research and development institutions are working toward delivering quality and affordable TGs. These projects will ultimately help in the inclusion of blind and visually impaired individuals in education and present them with equal opportunities for growth.

Read more about it

- A. A. Kalia and P. Sinha, "Tactile picture recognition: Errors are in shape acquisition or object matching?" *Seeing and Perceiving*, vol. 25, no. 3–4, 2011.
- M. A. Heller, D. D. Brackett, E. Scroggs, H. Steffen, K. Heatherly, and S. Salik, "Tangible pictures: Viewpoint effects and linear perspective in visually impaired people," *Perception*, vol. 31, no. 6, pp. 747–769, 2002.
- B. Beck-Winchatz and M. A. Riccobono, "Advancing participation of blind students in science, technology, engineering, and math," *Adv. Space Res.*, vol. 42, no. 11, pp. 1855–1858, 2008.
- P. Edman, *Tactile Graphics*. New York: American Foundation for the Blind, 1992.
- J. A. Gardner, "Tactile graphics: An overview and resource guide," *Inform. Technol. Disabil.*, vol. 3, no. 4, 1996.
- L. Jäncke, A. Kleinschmidt, S. Mirzazade, N. J. Shah, and H. J. Freund, "The role of the inferior parietal cortex in linking the tactile perception and manual construction of object shapes," *Cerebral Cortex*, vol. 11, pp. 114–121, 2001.
- J. M. Loomis, R. L. Klatzky, and S. J. Lederman, "Similarity of tactual and visual picture recognition with limited field of view," *Perception*, vol. 20, no. 2, pp. 167–177, 1991.

About the authors

Richa Gupta is a Ph.D. scholar at the Indian Institute of Technology Delhi. She has a multidisciplinary background with education in mechanical engineering and industrial design. Her research interests are in the design of effective tactile diagrams by understanding tactile perception of pictorial information by the visually impaired and blind.

M. Balakrishnan is a professor in the Department of Computer Science and Engineering at the Indian Institute of Technology Delhi. For the last 30 years, he has been involved in teaching and research in the areas of digital systems design, electronic design automation, and embedded systems. More recently, the focus of his work has shifted to the development of affordable assistive devices for visually impaired. He is an IEEE Senior Member.

P.V.M. Rao is a professor in the Department of Mechanical Engineering at the Indian Institute of Technology Delhi. He has more than 25 years of teaching, research, and product development experience. His teaching and research interests include product design and manufacturing and the design of medical and assistive devices. He is an IEEE Member.