Haptic Guidance to Support Design Education and Collaboration for Blind and Visually Impaired People

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PantoGuide: A Haptic and Audio Guidance System To Support Tactile Graphics Exploration

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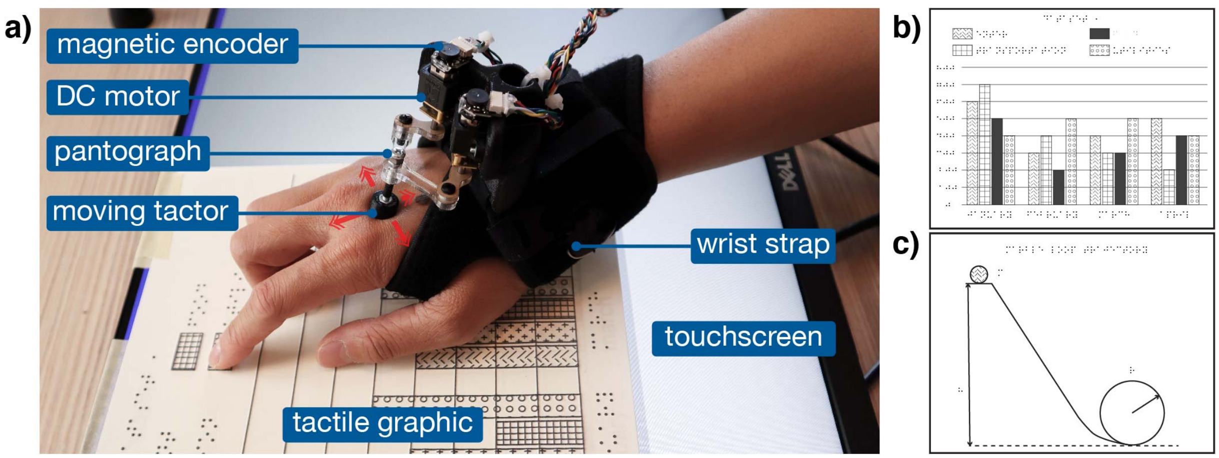

Figure 1: a) PantoGuide is a system that provides haptic and audio guidance cues to a user while exploring a tactile graphic. The device has a tactor in contact with the user that moves in a 2D plane (red arrows) to provide skin-stretch feedback. We demonstrate its use in two applications: b) providing point-to-point directional guidance cues when a user explores different elements of a tactile bar chart, and c) providing continuous guidance on the trajectory of a moving marble

ABSTRACT

The ability to effectively read and interpret tactile graphics and charts is an essential part of a tactile learner's path to literacy, but is a skill that requires instruction and training. Many teachers of the visual impaired (TVIs) report that blind and visually impaired students have trouble interpreting graphics independently without individual instruction. We present PantoGuide, a low-cost system that provides audio and haptic guidance, via skin-stretch feedback to the dorsum of a user's hand while the user explores a tactile graphic overlaid on a touchscreen. This system allows programming of haptic guidance patterns and cues for tactile graphics that can be experienced by students learning remotely or that can be reviewed by a student independently. We propose two teaching scenarios (synchronous and asynchronous) and two guidance interactions (point-to-point and continuous) that the device can support – and demonstrate their use in a set of applications we co-design with one co-author who is blind and a tactile graphics user.

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CCS CONCEPTS

• **Human-centered computing → Accessibility systems and tools.**

KEYWORDS

haptics, guidance, tactile graphics, wearable, skin-stretch feedback

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1 INTRODUCTION

People who are blind or visually impaired (BVI) frequently rely on alternative text and tactile media to access graphical content. Recent studies have found that BVI students struggle to work with tactile graphics [3, 13, 18]. In a survey of BVI students in mainstream classrooms, students often reported receiving insufficient instruction on how to use and interpret graphics [29]. Teachers of students with visual impairments (TVIs) have also noted that their students are not always able to use the graphics independently and rely on individualized instruction [28].

Tactile graphics are not immediately meaningful to a student without prior instruction and training. TVIs need to help students develop interpretation competency [29]. Teachers report an important aspect of tactile literacy is encouraging students to adopt a systematic approach to exploring and reading a graphic [19]. This process requires one-on-one instruction to provide feedback by moving a student's hand, tracing along paths, or offering individualized verbal encouragement and guidance [6, 14, 17].

Tactile learners face additional challenges in improving tactile literacy due to a lack of self-directed learning opportunities, as many educational resources for BVI students rely upon the presence of a skilled instructor. Several online educational resources exist to enable universal access to education (e.g. Coursera) but these also often neglect the needs of tactile learners. COVID-19 has recently highlighted the importance of supporting remote education. Thus, there is a need for learning tools that promote tactile literacy, even without the presence of a skilled instructor [8]. Moreover, BVI students in traditional classrooms report that they often receive their tactile graphics late [6], resulting in a disconnect between the instruction material presented to them and their sighted peers.

Prior work has explored methods for BVI users to obtain spatially relevant feedback about tactile graphics through audio augmented interfaces [2, 6, 9–11, 21]. These systems include audio annotation in addition to Braille labels. While audio is an effective tool for communicating details on-demand and contextual annotations, it is less effective for guidance especially when trying to move a user's attention to specific areas of interest [26, 27]. Haptic feedback has been used as an alternative to provide directional signals, using a combination of tactile cues (e.g. skin-stretch, vibration) [7, 16, 20, 22–24] and/or kinesthetic feedback (e.g. force) [1, 12, 14]. However, these methods have not been used to facilitate guidance on an existing tactile graphic for the purpose of teaching and training but rather have been used as an alternate means to access digital content, usually through larger devices that require use of one or more hands.

In efforts to address several of these challenges, we see the potential for a tool that provides contextual audio and haptic feedback to guide a BVI student who is exploring a tactile graphic. To investigate this, we introduce PantoGuide, a wrist-worn device that provides haptic guidance cues to the dorsal (back) side of the user's hand while the user explores a tactile graphic mounted onto a touch screen for additional audio feedback (Fig. 1A). The device has a tactor that stretches the user's skin (skin-stretch) to convey directional cues. While there are many types of haptic feedback, skin-stretch has been used in devices to provide precise directional guidance [5, 15, 24, 25]. Moreover, skin stretch feedback, unlike graspable and hand-held haptic devices, does not interfere with a user's typical exploratory procedures.

We discuss the technical implementation of PantoGuide and demonstrate its use in a set of applications that we closely co-designed with our blind co-author. The system showcases the potential for haptic and audio cues to support tactile graphics training.

2 INTERACTION METHODS

We closely designed our system with co-author Gene Kim, an engineering college student who is blind and is an expert tactile graphics reader who uses tactile graphics regularly for work (at least once per week). Our co-designer reflected on his own tactile graphics exploration strategies to identify scenarios where guidance from a teacher had been helpful. These were in agreement with much of the literature that surveys BVI students and teachers on their use of tactile graphics and teaching strategies [14, 17]. We used these tactile graphics and scenarios as a basis to explore the design space of audio-haptic guidance cues through skin-stretch feedback. After these discussions and review, we created a preliminary set of applications and delivered the PantoGuide prototype to our co-designer. Due to COVID-19, we worked remotely to set up the system, iterate on changes, and collect feedback.

2.0.1 Teaching Scenarios. From literature and our co-design discussions, we envision two different teaching contexts where guidance could be used: 1) synchronous instruction and 2) asynchronous instruction.

In the ***synchronous scenario***, guidance could facilitate remote instruction of one or multiple students. A TVI could be teaching remotely while teleoperating a guidance tool that provides feedback as the student explores the tactile graphic – mirroring a one-on-one, in-person teaching scenario. This scenario also applies to a teacher with multiple students, enabling the teacher to provide instruction to all students simultaneously via a guidance tool.

In the ***asynchronous scenario***, the tactile graphic guidance could be pre-recorded allowing the student to review the tactile graphic and annotations at any time and at the speed the student desires. In this scenario, the guidance could provide more self-directed learning opportunities for tactile learners to review material independently.

2.0.2 Guidance Strategies. Through reflections with our co-author about tactile graphics where teacher guidance was helpful for facilitating understanding, we identified two guidance strategies: 1) point-to-point and 2) continuous.

With ***point-to-point*** guidance, the device starts from an initial resting position – which is located in the center of its reachable workspace. From there, it can move in a direction to give guidance cues (such as the cardinal and intercardinal directions). This allows the user to be guided to and from landmarks around the graphic in order to better understand the content as well as guide the user to areas of particular interest.

With ***continuous*** guidance, the device's cues are constantly being displayed to the user without any need to reset to a resting position. This can be used in a variety of scenarios, such as creating trajectory shapes, aiding in line following, and informing tactile exploration of movement patterns.

2.1 Application Demonstrations

To demonstrate these different interactions, two applications were developed – both focused on an asynchronous learning scenario (due to current COVID-19 related restrictions on in-person user testing).

The first utilizes a bar chart (Fig. 1B) and automatically guides the user through a systematic exploration of the graph using point-to-point feedback and audio. For example, when the user identifies the y-axis values, the system provides verbal instruction (e.g. "locate the x-axis") and provides haptic cues that stretch the skin in the desired direction.

The second application involves a tactile graphic of a marble rolling down an inclined plane and through a loop the loop (Fig. 1C). In this case, the haptic cues provide continuous feedback to trace the marble's trajectory on the user's hand. This feedback provides the user with an overview of the marble's motion as the user explores the graphic.

3 TECHNICAL IMPLEMENTATION

The haptic device consists of a pantograph (a mechanism commonly used for providing two-dimensional haptic feedback [4]) with a rounded tactor (1.1 cm in diameter) on the end effector, which comes into contact with the dorsum of the user's hand to provide skin-stretch cues. Two Pololu 6V 100:1 micro-metal DC gearmotors are controlled by a Teensy LC microcontroller through a DRV8835 motor driver. Rear shaft-mounted magnetic encoders (12 CPR) allow for relative angle measurements. The angle of each motor is controlled using independent Proportional-Integral-Derivative (PID) controllers, and inverse kinematics [4] are used to convert a desired xy position to motor angles. The movement of the device is limited to a semi-circular area (2 cm^2) within the reachable workspace of the pantograph with links of length 1.2 and 2.4 cm. The device connects over USB serial to an application that is run on a 24" multi-touch screen (Dell P2418HT) over which a tactile graphic is placed (Fig. 1A). To interact, the user can use two gestures: 1) one finger double tap for reading audio labels, and 2) two finger double tap for selection.

4 DESIGN RECOMMENDATIONS

Based on our initial user feedback with our co-designer (who tested the device and the applications), we present some design recommendations for future design iterations.

Point-to-point directional cues can provide useful guidance. Point-to-point feedback worked well in guiding the user to systematically explore the different bar chart elements (Fig. 1B). This was the preferred use scenario for our co-designer. He expressed interest in use of point-to-point feedback for more complex mathematical graphics. For example, in a polynomial curve where a student might need to understand different points in the curve such as the local maximum and minimum.

Continuous feedback can give an overview of the shape, but needs enough space to be understandable. The limited workspace, 2 cm^2 area, was not large enough to successfully convey complex motion trajectories. In the second application, continuous haptic guidance was used to communicate the trajectory of the marble (Fig. 1C). Our co-designer commented that motion guidance had been helpful during in-person instruction with a teacher to get trajectory overviews. However, with the current system, it was hard to distinguish complex motions such as the loop (Fig. 1C).

Haptic and audio cues need to be tightly coordinated. The haptic guidance cues helped complement the audio, because they prevented overloading the auditory channel. Our co-designer commented on how important it was for the two feedback modalities to be tightly coordinated so they're not competing for attention. When the haptic cue was not coordinated with the audio, our co-designer had trouble focusing on either one.

Guidance cues need to be more perceivable under high mental load. Our co-designer described how the guidance cues were less perceivable when moving his hands compared to the static case. He tried different tactor variations: a square surface with twice the surface area (1.9 cm^2) and a pointed tactor. The larger surface area greatly improved the guidance cue's perceivability, likely due to the increased amount of skin being stretched.

5 CONCLUSION & FUTURE WORK

Several technical improvements need to be made in future iterations of PantoGuide. In particular, we will improve the prototype to amplify the skin stretch feedback by increasing the size of the workspace, creating a higher friction tactor, and using stronger motors. We will also investigate authoring interfaces for teachers to annotate tactile graphics using both audio and haptic cues. Currently, we specifically program the different applications for each tactile graphic. An authoring interface could also allow a teacher to adjust the guidance level and cues depending on the student's tactile literacy skills. In sum, PantoGuide shows promise towards creating tools that support tactile literacy both through synchronous and asynchronous learning.

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