A Tactile Palette to Translate Graphics for the Visually Impaired

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Abstract
Spatial haptic displays, such as electrostatic vibration (electrovibration) based friction displays, augment flat panels and surfaces with spatially arranged tactile content. Such devices can be useful for the visually impaired to translate visual images to tactile ones on demand. In this paper, we explore a tactile palette that consisted of a set of six perceptually distinct tactile stimuli corresponding to six distinct colors. Users with normal vision overlay colors from the palette on the visual image. The overlaid image is rendered on the tactile display using a "color to frequency" mapping algorithm. In this preliminary exploration, we evaluated the use of graphic-to-tactile translation in variety of cases on an electrovibration device.

Author Keywords
Tactile graphs, assistive devices, electrovibration, tactile touchscreens.

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces, Input devices and strategies, Haptic I/O.

Introduction
Graphs, plots, images play supplementary but important roles in our daily reading and attract attention, aid retention, enhance understanding and create context [4]. While these mediums are readily
available in textbooks, newspapers, magazines, and instructional materials for able readers, visually impaired communities have suffered due to dearth of techniques and technologies to convey rich spatially distributed visual content through substituted sensory modalities. This paper explores on displaying non-textual information on digital tablets and surfaces for impaired users.

A standard representation of graphics in visually impaired textbooks is Tactile Graphics that are raised and protruded versions of the print graphics, and optimized for the sense of touch [7]. Numerous universities, schools and organizations have reproduced textbooks and instructional materials for their students and subscribers by overlaying images with a palette of tactile features, such as lines, dots, textures, etc., and fabricating them with specialized printing tools. The resulted printed tactile graphics are expensive, once fabricated could not be altered, and require special storages for protection from breaking and wearing. In this paper, we present a novel approach of translating graphs, plots and other non-textual data into representable tactile graphics rendered on flat programmable tactile surfaces.

The paper is organized as follow: After presenting relevant background, we present a framework to convert graphical images to tactile images. We describe the construction of an electrovibration device and present a tactile palette to convert visual graphics into tactile graphics on our device. Finally, we conclude the paper with use cases of our approach.

**Related Work**
With advancements in technologies, assistive devices for the blind have also grown substantially and have improved educational and instructional methods. Perhaps the most popular reading aid for the visually impaired has been Braille that represents alphanumeric symbols as protruded pins on a 3-by-2 array of pins. Using the similar approach, Refreshable Braille displays are available to translate the digitized text to symbols on the fingerpad using a computing device attached to the display [12]. These displays have been further expanded to convey full-page

![Figure 1: Images are color coded to emphasize segments of charts with different tactile features. (a) bar charts, (b) maps, (c) pie charts, and (d) pictograms.](image_url)
programmable Braille-like characters to its users, such as Braille e-book.

An early pictorial aid for the blind was the Optacon (OPTics to TACTile CONversion) device [11] that yoked the input from an optical sensor to an matrix of vibrating pins on a user’s fingerpad, therefore enabling a user to read printed text and graphics. Similarly TVSS (Tactile to Vision Substitution System) displayed a camera feed to an array of 400 vibrating actuators on the user’s back [1]. Both of these vibrotactile devices were effective in displayed text and environmental information, however the use of these devices were limited due to low-bandwidth of mechanical stimulations, low-resolution of the stimulated site, high cost, and complexity in design. Other popular systems use ‘alternative text’ to convey detailed screen content through sound and other modalities [5].

Recently, friction-based haptic displays are introduced that produce on-demand, variable and broadband haptic content on flat surfaces [2, 10]. The benefits of using such technologies are that they could be assembled into compact form factor and operate with capacitive and resistive touch sensitive technologies available in the touch-screens of current mobile devices. These devices are not particularly applicable to display Braille-like content; however, non-textual information, such as spatial layout of environmental objects, symbols and shapes, could be identified by the impaired users [8, 13].

**Graph-to-Tactile Translation Framework**

The purpose of the present work is to develop a procedure to translate two-dimensional educational material, such as plots, graphs, flow charts and other pictorial content, to tactile representations that i) can be displayed on the flat panel of a handheld device on demand, ii) can be understood by abled and visually impaired users, and iii) can be uploaded, saved and shared among users. We present a framework for abled users to generate tactile graphics, by highlighting critical regions on the graphs, and a palette of perceptually distinct tactile features. In this section, we describe the construction of a friction-based haptic display, translation of imagery to tactile content, and an authoring method to generate tactile content.

**Electrovibration Device construction**

The device we selected to develop and test the translation scheme is an electrovibration based friction display, similar to the one used in [2]. The device includes a flat conductor covered by an insulation layer. When the alternate voltage is applied to the conductor, it creates an electrostatic coupling, which moves the charge in the insulation layer depending on the polarity of the voltage. Once a finger is placed on the insulation layer and dragged, then the capacitive coupling between the conductor and the fingerpad results into lateral forces, resembles the frictional forces acting on the fingerpad (see description of the operational principal in [2]). The perception of frictional forces varies with the voltage amplitude, frequency of the alternating voltage, its polarity, and shape of the waveform, thus allowing wide range of tactile content rendered on the touchscreen.

Our device uses a 3M microtouch touchscreen (model: SCT3250), its finger tracking driver (model EXII), an LCD display (Tontec AT090TN12), a custom high voltage driver, and in-house software interface, all connected through a HP laptop running Windows 8. The
basic interface was developed on python using pyQT and the waveform generator was implemented on puredata (https://puredata.info/). The 3M touchscreen was placed on top of the visual screen, and fixed on an acrylic housing containing drivers and additional circuitry (see Fig. 3). The high voltage driver takes input from a waveform generator via an audio line and scales the waveform to ±100 V using a simple transistor based amplifier (current rating 6.25 mA). In order to utilize 3M touchscreen as both the finger tracker and the haptic display, the high voltage was passed through a metallic ring held by users while sliding their finger on the touchscreen. Depending on the location of the fingerpad on the touchscreen, the software triggers tactile waveform passing through the audio line of the laptop. The size of the touch area expose to users is 8 in by 4.5 in.

Visual Graphs and Tactile Mapping
Visual images are spatial distribution of visual primitives arranged by a predefined rule. Bar charts, maps, pie charts, scatter plots, flow charts and dissection images are most common graphical representations found in textbooks and newspapers. In order to further highlight the graphical content and characterize it into groups, these images are adorned with color codes that are easily differentiated by an abled user. To convey the imagery (visual) information to the visually impaired, these visual features and colors must be differentiated through the tactile sense. Previous work on electrovibration devices has demonstrated that primitive shapes could be identified by the visually impaired ([8, 13]), and spatial features, such as edges, protrusions and bumps, also could be rendered on flat surfaces [9]. In this paper, we proposed a direct color to tactile mapping, and propose a palette to translate colors from images to distinct tactile stimulations.

In computer graphics, color palettes are coded as three byte representations, such as R (red), G (green) and B (blue). Each color is also represented by a corresponding hue, saturation and value (h,s,v). Hue corresponds to the true colors of the spectrum and value is equivalent to the luminosity of the color. In electrovibration devices, frequency and amplitude of the applied voltage are the two commonly controlled variables. The dynamic range of the electrovibration device is from roughly 30 Hz to 500 Hz along the frequency dimension, and from the detection threshold level to the full voltage range (dielectric breakdown voltage of the insulation layer) along the amplitude [2]. In our method, we associate the color value to the amplitude, and color hue to the frequency of sinusoidal waveform.

Tactile Palette and Authoring Methodology
Our visual sensory system is extremely good in differentiating hue and luminosity [6] of colors; however, the frequency and amplitude jnds (just noticeable differences) are scant in the tactile domain. Moreover, tactile and visual perceptions are not linearly correlated. In order to compensate for nonlinear dimensionality of the two sensory modalities, we introduce a palette of six true colors (violet, blue, green, yellow, orange and red; omitting indigo) to six clearly differentiable frequencies of electrovibrations. The frequency jnds in the 80-400 Hz range are 12-25% [2]. In order to clearly recognize the two stimuli, a rule of thumb is that they must be ~3 jnds apart (or three standard deviations apart on the cumulative psychometric function). Therefore we selected
frequencies that are roughly 75% apart, and the six frequencies corresponding to the six colors are: 30 Hz (red), 50 Hz (orange), 90 Hz (yellow), 160 Hz (green), 300 Hz (blue) and 500 Hz (violet).

The palette introduced in this paper has colors and corresponding tactile stimuli that are clearly differentiable by human users. By using the palette, enable users could select colors to different segments of the graphics, and our algorithm translates the visual image into tactile image for educational and entertaining media for visually impaired users. The method for generating tactile images from visual images is shown in Figure 2. First, the visual graph (1) is acquired by a designer who overlays pertinent parts of the graph with colors from the palette (2). Once the entire graph is overlaid by coded colors, then the designer saves the original image and the overlaid image as separate jpeg files (3). Both files are sent to the interface software and displayed through the hardware; the graphical image is shown on the LCD screen (4) and the tactile image is rendered using the graphic to tactile translation discussed above (5).

Normal sighted users see the image and the visually impaired user feels different parts of the images by sliding the hand on the electrovibration device.

USE CASES

In this section we present use cases of tactile palette to construct variety of tactile images. We also conducted a preliminary evaluation of tactile images on the flat surface using electrovibrations.

**Tactile Palette for Creating Bar Charts**

Bar Charts are used to represent distributions of data in various situations, and are common in mathematics and statistics textbooks. We designed a bar with two components, each assigned with a distinct color from the palette (red and blue in this case, see Fig. 1a). The length of the bar was 5 inches on the touchscreen. In a pilot evaluation, we determined if participants could, 1) differentiate the two segments of the bar, and 2) correctly determine the proportions of each segment.

Ten participants (5 males) took part in the experiments. All participants had normal or corrected to normal vision, and were blind folded during the experiment, as shown in Fig. 3. We constructed 20 bars in the stimulus set. Half of the bars had blue segment on the left with 10-100% proportion (in increments of 10%) and the other half had red segment on the left. Each participant completed a block of 20 trials. In a trial, participants scanned the touchscreen and uttered 1) the color of segment on the left and 2) the proportion of the segment corresponding to the total length of the bar. Before the experiment, participants were told the two colors and corresponding tactile cues.

Overall, participants were extremely good in differentiating the two segments of the bar associated with the two tactile cues (accuracy = 97.5%). The stimulus-response confusion matrix is shown in Fig. 3. The bright colors along the diagonal of the matrix indicate that participants were accurate enough in identifying the proportion of the segments.

**Redundant coding on tactile graphs**

Redundant coding is a technique often used to enhance the perception and processing of sensory information, specifically in identification tasks [3]. Complex plots, such as maps, could be augmented with tactile cues that vary in both the frequency (hue) and the intensity...
(value) of the color. This would allow users to quickly react to the change in tactile cues corresponding to different segments of the plot. We have also examined the use of the redundant amplitude cue to improve the understanding of tactile images; by coupling higher amplitude to larger size of the bar and higher values on scatter plots.

**Tactile textures for complex graphs**

Pie charts and dissection plots are complex, and may not be conveyed by colors provided in the tactile palette. Users can draw textures and complex color patterns using the palette, and our proposed method will render them as tactile textures, rather than pure tone stimulations. For example, the textures and patterns presented in Figure 1c have distinct perceptual features as of the plain colors were used.

**Graphs with innate distinct features**

Some graph types, such as pictograms (Fig. 1d) have innate distinct features with non-continuous data representation. In this case, the user could count the number of tactile stimulation points, rather than using a textural or redundant coding.

**Concluding Remark**

We present a method to convey graphics and non-textual content on flat programmable tactile surfaces, and propose use cases for generating educational media for blind users.

**References**