TouchPen: Rich Interaction Technique for Audio-Tactile Charts by Means of Digital Pens

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Abstract. Audio-tactile charts have the potential to improve data analysis with tactile charts for blind people. Enhancing tactile charts with audio feedback can replace Braille labels and provide more structured information than pure tactile graphics. Current approaches lack especially in support of gestural interaction to develop useful interaction concepts for audio-tactile charts. Many approaches make use of non-standard hardware or are less mobile. That is why we investigated digital pens and their capability to increase data analysis with tactile charts. We compared two digital pens, in particular, the TipToi® pen and the Neo SmartPen M1. First, we evaluated the implementation and feasibility of five basic gestures. While the TipToi® is not suitable to support rich touch gestures, the Neo SmartPen showed in a pilot study good support of single-tap, double-tap as well as hold and line gestures. On that basis, we implemented the first prototype to demonstrate the potential of digital pens to support data analysis tasks with audio-tactile scatter-plots. Afterwards, we evaluated the prototype in a pilot study with one participant. The study shows high indications for the usefulness of the presented system. The usage of the digital pen can improve the readability of a tactile chart. Our system provides audio-feedback for given tactile scatterplots in an accessible and automatic way. As a result, blind users were able to produce and use audio-tactile charts on their own by using an Android application and the Neo SmartPen.

Keywords: Audio-tactile charts · Tactile scatterplot · Digital pen · Interactive touch graphics · Blind people · Pen interaction

1 Introduction

Analysing data is a main requirement in many professions. This task can be achieved by means of information visualisations that enable fast perception of relations within the data such as correlations, cluster, or min/max values. For blind and visually impaired people, tactile charts are suitable to get access to data and their insights independently. They consist of raised lines, symbols, and
textures which can be perceived via touch. Embossed graphics are static representations with limited resolution (typically 20 dpi). As a consequence, they can represent a limited amount of data. Additionally, braille reading skills are needed to understand tactile charts which many blind and visually impaired people do not have [6,15]. Several approaches aim to overcome these disadvantages by enriching tactile charts with audio feedback and supporting interactivity.

Audio-tactile charts are being widely used to enable dynamic audio feedback and interacting with tactile graphics. Audio feedback is able to support reading out precise values or comparing data, detecting relationships, or exploring tactile graphic elements. Additionally, it can be used instead of Braille labels which require much space [6]. Existing approaches for audio-tactile charts mostly support simple interaction techniques and lack rich interaction concepts. While many researchers focus on interactive information visualisations which are made for the visual sense, less research address analysis tasks for interactive, audio-tactile charts. Furthermore, hardware for audio-tactile graphics is very expensive, does not support rich interaction concepts, or is not suitable for mobile use. To address these lacks, we examined the potential of digital pens with respect to their suitability to develop low cost, mobile and usable interaction concepts for audio-tactile charts. In addition, we analysed interaction tasks that audio-tactile charts could cover and developed the first prototype to evaluate the usefulness of the proposed concept.

2 Technologies for Audio-Tactile Graphics

Besides audio-tactile charts, there is a wide range of approaches providing audio-haptic charts by simulating tactile feedback by use of vibration [6] or force feedback devices such as PHANToM [13]. However, the focus in this work lies on approaches that enrich pure tactile graphics with audio-feedback. These approaches differ in terms of mobility, costs, handling, provided information and interaction modes. Furthermore, the accessibility of the generation process of audio-tactile graphics needs to be focused. On the one side, several approaches focus on technologies that can be used for audio-tactile graphics, while other approaches focus more on rich interaction concepts to realise an effective data analysis with audio-tactile charts.

Touch sensitive devices such as IVEO [5] or Tactile Talking Tablet (TTT) [10,12] were commonly used. These approaches allow the tactile graphic to be placed on a specific tablet PC. Audio feedback is provided by a tap or a double-tap gesture directly on the graphic. Therefore, the tablet has to be connected with a computer. This kind of technologies allow static audio-feedback that has to be determined in advance. The mobility is limited and the technology does not provide rich interaction techniques.

Other tablet-based approaches make use of standard tablets which were overlaid by tactile representations. Touchplates [8] uses acrylic plastic overlays on a tabletop or a tablet with infrared-based diffused illumination that recognizes visual markers to get the orientation and position of the overlay. This technology allows multi-touch interaction whereby touches on non-transparent overlays
cannot be recognized. Other approaches do not need specific technologies such as infrared sensors to recognise overlays. For instance, the recognition and calibration of overlays can also be done by the means of capacitive codes which are embedded within the overlays by use of conductive filament [7]. TPad allows overlaying standard tablets with embossed, tactile graphics [11] by easily loading SVG-files into a specific app. These approaches lack in supporting rich interaction gestures because it must be possible to distinguish between intended user input and tactile graphic exploration. Authors of TPad reported that common multi-touch gestures were disabled for this reason. In most cases, double-tap was implemented as a selection gesture instead of a single tap to prevent unintended touches. Just one approach provides gestural interaction such as hold or lasso-gesture [2] which was applied for tactile maps and not for charts. Besides static tactile representations, dynamic, touch-sensitive pin-matrix devices also support audio feedback that was applied by Zeng et al. in several projects mostly in the context of tactile maps [16,17]. Pin-matrix devices, for instance, made by Metec\(^1\) support 10 point multi-touch interaction as well as additional hardware buttons for Braille input and further features. Additionally, speech output is supported. Users can interact with refreshable, tactile graphics in real-time whereby just 10 dpi resolution, and just one dot height is provided. These devices cost several thousand euros per piece and are limited in mobility and resolution.

More hardware-independent approaches which aim to augment pure tactile graphics with audio feedback, make use of computer vision or image processing techniques to recognize the intended interaction on the sheet. Baker et al. [1] placed QR-Codes directly on the graphic that can be read by a developed app to replace Braille labels in graphics. As a disadvantage, the blind user has to scan QR-Codes with the camera of the smartphone which is not practicable for fluid interaction concepts and challenging especially for blind users. Another approach comes from Fusco et al. [4] who developed a machine-vision based system that tracks the finger of blind users to enable point-and-click interaction.

Digital pens were rarely examined for practical usage together with tactile charts in the past. Just Landau et al. [9] use a digital pen that reads out printed Anoto patterns with an infrared sensor. The authors used the pen in the context of tactile maps and did not make any user studies to evaluate the usefulness of the application. Additionally, the producer does not provide an open SDK for this product anymore. In contrast, Wall et al. [14] combined a graphic tablet with simple, physical, circular overlays that can be explored by means of a digital pen. In this application, the user has to press a button on the pen to get audio feedback about the current position on the circular overlay, which makes it difficult to hold the pen steady. Beyond that, we are not aware of any approaches that use digital pens for tactile graphics in the same way we want to implement.

All in all, we identified the following disadvantages of current approaches: (1) Lack of support of rich gestures (2) Lack of ability for mobile use (3) No use of pure tactile graphic (4) Creation of audio-tactile graphic is not accessible for

\(^1\) https://www.metec-ag.de/en/produkte-graphik-display.php, Retrieved on 04 April, 2020.
blind users (5) Lack of distinguishing between intended input and output (6) Requirement of specialized and expensive hardware (7) No support of simultaneous exploration and interaction with the graphic (8) No flexible usage (e.g. limitations of size or position of the tactile graphic) (9) No support of direct user input on the tactile graphic. For sure, some of these lacks were supported partly by several approaches that were discussed above. Requirements for audio-tactile graphics strongly depend on specific graphic types and goals of the analysis. Because tactile charts are useful for effective data analysis for blind and visually impaired people [3], interacting with data to address specific analysis tasks should be provided. This is the first step for the development of interaction concepts as they have already been examined for visual information visualizations. To achieve this goal, we investigated how digital pens can support exploring and analysing tactile charts and which gestural interaction can be supported. Afterwards, we propose a first interaction concept for tactile scatterplots.

3 Digital Pens for Audio-Tactile Charts

Digital pens are inexpensive, mobile, and allow fluid, direct interaction. They can be used one-handed. A main requirement for the envisaged usage is the possibility to get audio feedback dependent on user input. It should be possible to manage and identify several sheets as well as the position on the sheet. Furthermore, the creation of customised applications should be supported. Based on these requirements, we compare two digital pens that are able to interpret dot patterns.

3.1 Comparison of Digital Pens

The TipToi® is a standalone product from Ravensburger which was developed for children’s books. Second, the Neo Smartpen M1 was developed to digitalise handwritten content. The TipToi® is cheaper (about 20€) than the Neo Smartpen (about 150€) and can be used without additional hardware (apart from a computer to transfer the required files to the pen) because a micro-controller, as well as a speaker, are integrated. Furthermore, they differ in their operating principle: The TipToi® works with an Anoto pattern and does not come with an official SDK to generate an object identifier (OID) or script files for the pen. Instead, an unofficial tool was developed by the community². Neo SmartPen provides a SDK for different operating systems as well as documentation. While the TipToi® assigns a single identifier to interaction objects (OID) that can be encoded with Anoto pattern, Neo SmartPen uses the NCode pattern which is organised in a coordinate system so that the position on the paper can be determined by the pen. Neo SmartPen is not able to provide feedback without additional hardware. The possibility to connect the pen with other devices such as smartphones leads to the advantage that all feedback modalities and features of these devices could be used (e.g. vibration, TTS). Blind users can utilize their own devices which are familiar to them. Neo SmartPen is equipped with additional sensors to measure e.g. pressure, tilt, and rotation.

² https://github.com/entropia/tip-toi-reveng/wiki. Retrieved on 04 April, 2020.
3.2 Combining Individual Audio-Tactile Printouts with Dot Patterns

We first investigate the production of embossed graphics combined with dot patterns. Our goal is to develop an application that enables blind users to produce audio-tactile charts on their own. That is why we initially tried out printing patterns with a standard laser printer (Brother HL-5250DN). Both dot patterns were printed with a resolution of 1200 dpi and were readable by the pens. We noticed that the printed pattern was partially damaged when the pattern was touched repeatedly which decreases the recognition rate. Before embossing the graphic, the pattern must be printed on the sheet. On the reverse, the printing ink cannot reach the areas around tactile elements. Moreover, tactile printout and dot patterns have to be calibrated. When producing combined printouts for TipToi®, this has to be done manually by placing the graphic directly on the dot pattern which could be very hard especially for blind users. The Neo SmartPen requires an additional calibration step to find out where the coordinate system is placed on the sheet. Moreover, this step ensures hardware-independent printouts. To achieve this, we developed an accessible calibration process where the user just needs to identify a tactile initialisation point on the upper sheet’s corner.

To test the recognition of dot patterns in combination with tactile elements, we evaluated several textures and object sizes manually. Tactile elements decrease the recognition of both dot patterns. This applies especially to raised, filled areas. The lower the embossing height, the better the detection rate. Thin lines, small elements, and rough textures do not significantly influence the recognition rate. Overlapping elements are challenging especially for the Anoto pattern because here a single code is generated per object, which - in order to be recognized - is not allowed to overlap. We believe that the recognition rate can be increased through further printing tests and improved printing. Additionally, pre-printed sheets with NCode patterns can be provided.

3.3 A Pilot Study to Evaluate Touch Gestures with Digital Pens

In a second step, we evaluated the possibility to perform and recognize gestures. We focused on common gestures that are implemented for many touch devices: Single-tap, Double-tap, Hold-Down, and Line-drawing gestures. The Neo SmartPen offers the possibility to realise force-touch gestures by measuring the force with which the pen is pressed onto the sheet. It has been shown that the TipToi® is not suitable for the implementation of gestures, because of limitations in programming. The tap gesture was certainly recognizable with this pen. A circle gesture could also be recognized, whereby no distinction can be made between multiple circularly arranged taps and the continuous circular gesture.

To evaluate gestures with Neo SmartPen, we developed an Android App that receives sensor data from the pen in real-time. Together with a blind student, who is a good Braille reader and has experiences with tactile charts as well as the handling of pens, we evaluated the usability and comprehensibility of the
proposed gestures with the Neo SmartPen. We logged all captured sensor data and provided feedback about performed gestures for the experimenter during the whole study. The participant got audio feedback about the performed gesture. Furthermore, the participant had to use gestures to perform several tasks, e.g. tracing tactile lines, drawing lines with a specific length, lasso gestures to select elements, pointing in the middle of a circle.

Overall, the handling of the pen was not challenging for the participant. The force touch could not be recognised because the participant pressed the pen too strongly onto the sheet during the entire test. It is still unclear whether the sensor does not cover a broad enough range or whether blind people press the pen harder onto the sheet than sighted people. The hold-gesture was not only preferred, it was also often recognised instead of the force-touch, that is why we refrain from using both gestures in one application. The single-tap gesture was recognized most reliably. Apart from force-touch, the participant was able to perform all gestures easily and intuitively. Based on the study, the implementation of the gestures was adjusted again, as, for example, the threshold for the hold and double-tap was somewhat too short. Furthermore, by use of audio feedback, the participant was able to draw lines with a specific length along a tactile line and also without tactile support. The participant could frame several elements with a lasso gesture by making several small movements instead of one continuous movement. This requires further testing and implementation to reliably detect lasso gestures. The user study confirmed that the dot pattern could not be detected in purely embossed areas. This can be overcome by leaving small areas with unembossed surfaces for contact points with the pen. In our study it was unchallenging for the participant to point in the unembossed middle of a tactile circle.

The pilot study indicates that the Neo SmartPen is suitable to support interaction tasks with tactile elements. Furthermore, simple discrete and continuous gestures are applicable. Based on those findings, we developed a prototype to show the practical use of gestures in tactile scatterplots.

4 Audio-Tactile Scatterplots by Means of Digital Pens

Scatterplots are suitable for data analysis [3] and can be used to present a high amount of data. Distinguishing different symbols and the determination of precise values are challenging tasks when analysing data by means of tactile scatterplots. Especially overlying symbols are hard to distinguish. These lacks can be addressed by audio feedback. Therefore, we implemented a workflow that automates the generation of audio-tactile scatterplots which can be used with Neo SmartPen in combination with a smartphone (see Fig. 1). The structure of the SVG-file must follow a predefined structure in order to be interpreted automatically. This can be achieved by using a tool to automate the generation of tactile charts such as SVGPlott [3]. The SVG-file can be used to emboss the tactile chart. The implemented smartphone app reads the SVG-file and extracts areas, values and objects, implements gesture recognition, and automatically
generates feedback depending on the user’s input. Before the initialization, the SVG-file with the chart must be loaded into the app. Afterwards, the tactile initialization point in the diagram must be touched with the pen, so it can calculate an offset due to the printing inaccuracies.

We support the following tasks for information seeking inspired by the Audio Information Seeking Principles [18]: Gist, Navigate, Filter, and Detail-on-Demand. Every tactile element on the graphic provides audio feedback. Furthermore, we implemented two analysis modes: Speech and Sonification mode which can be switched by a tactile button. Sonification is suitable to provide an overview of the data while speech mode provides better support for detail-on-demand-tasks. In speech mode, single-taps provide properties of selected elements. In this way, the user is supported when exploring and understanding tactile graphic elements, such as axes, general content, or tactile symbols. A description of the chart will be provided by selecting the chart’s title. When tapping on a tactile symbol, audio feedback informs about values, corresponding data sets as well as the shape of the symbol. Double-tapping at any place stops current audio output. If another element is activated while speech output is still running, the latter is automatically stopped, whereas the hold-gesture selects elements for further analysis. We implemented a distance measurement for two selected points. In addition, a line-gesture on the axes specifies the start and end of a value range for filtering. The audio feedback for filtering provides category, the number of values which lie within the specified range, and its average and its outliers. Filtering in sonification mode along the axes is realised by mapping the amount of data within the specified range to pitches. The higher the pitch the
more data are located in the value range. When a single symbol is selected, the amount of data in the symbol’s immediate neighbourhood is sonified (we used a threshold of 2 cm). Performing a hold-gesture on a single data point extends this radius. This feature allows a better estimation of distributions and clusters.

5 Pilot Study on Audio-Tactile Scatterplots

The results can be strongly influenced by the partly poor recognition rate, which is why we first conducted a qualitative survey with one blind participant who took already part in the first pilot study. We asked seven questions addressing the detection of outliers, counting values within a specific range, reading out precise values, and distinguish point symbols for a pure tactile and an audio-tactile scatterplot. Both scatterplots represent three different point symbols and overlaying data points. Neither the handling of the pen nor carrying out gestures was challenging. The pen did not interrupt the exploration of the scatterplots. It was noticed that the holding of the pen has an influence on the detection rate, as the sensor must not be covered. The participant was able to connect the pen with the smartphone app and to load the scatterplot data. The participant reported that solving tasks was easier with the audio-tactile scatterplot than with the pure tactile one. Furthermore, it was stated that reading out values and symbol shapes especially for overlying symbols was improved by the use of audio feedback. However, users must first be familiar with the functions and handling in order to develop good analysis strategies. The participant suggested the following improvements. (1) Filtering data should be possible on all existing axes including doubled axes (2) Nevertheless, tactile markers should be available on the axes (3) Specifying ranges of values by drawing a line in the chart area can be helpful for the data analysis. Overall, we found some indications that the usage of Neo SmartPen for tactile scatterplots can improve data analysis.

6 Conclusion

By means of an analysis and a first pilot study, we showed that digital pens can be used to produce interactive, mobile, low-cost, audio-tactile applications. Further practical tests are necessary to improve the recognition rate of the pen on raised surfaces. The TipToi® is just useful for simple interaction tasks where the exploration of graphic elements should be supported (e.g. in form of guided tours through the graphic) or specifying precise values are demanded. In contrast, the Neo SmartPen has a high potential to support rich data analysis with tactile charts. Calculations on the data can be carried out in real-time and other output modalities of the smartphone can be used. Moreover, we showed a system that automates the generation of rich audio feedback on the basis of well-defined SVG-files. As a result, blind users were able to produce and use audio-tactile charts on their own by means of an Android application and the Neo SmartPen. More research and user studies are needed to examine further limitations and interaction concepts for audio-tactile graphics.
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