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Description:
Repository of designed patterns for combination of audio-output with tactile output

Audio-Tactile Design Pattern Repository

Repository of designed patterns for the combination of audio output with tactile output

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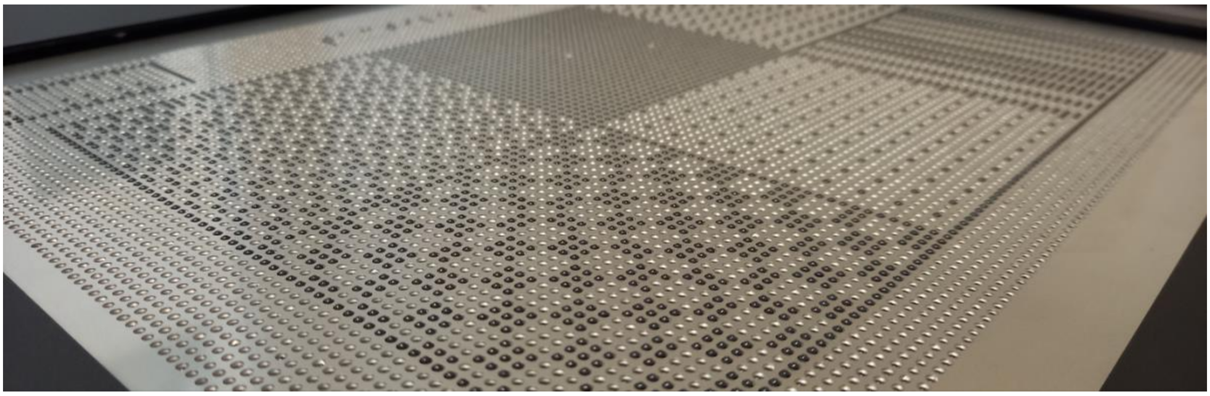

Figure 1- The Tactonom device V1. This technology combines pinpoint audio explanations with a pin-matrix tactile surface of more than 10.000 pins through camera-based fingertip recognition. On the current surface, we can view a set of six different tactile filling patterns.

Abstract

Enabling blind and visually impaired persons to perceive and interact with two-dimensional data is a complex challenge. Blind users cannot perceive graphical information in visual user interfaces, and current assistive technologies only allow linear text information access. Two-dimensional refreshable pin-matrix devices are an emerging technology capable of presenting two-dimensional data to blind persons through audio feedback and a tactile braille matrix display constituted by tactile pins that can be raised up and down. While hardware development for this technology has advanced, user interface development has not progressed likewise. There is a need to improve these devices' user interfaces to enable blind and visually impaired persons to access and use graphical information. One of the critical challenges of this technology is to design audio-tactile synthesis representations of patterns. Currently, there are no standards for creating audio-tactile patterns in 2d refreshable pin-matrix displays, and only a few tactile pattern repositories exist. In this work, we addressed and analysed audio-tactile patterns for 2d refreshable pin-matrix displays. These were split into two groups, filling patterns (used to fill areas) and plot line patterns (used to represent lines). Beyond presenting each group set, we implemented each pattern in the *Tactonom* device (Inventivio GmbH), analysed each pattern, and raised its advantages. Results concluded that using different audio-tactile patterns can substantially change the user's interaction with the device. Further investigation on

designing these patterns for other contexts, such as representing a train station floor plan or a mathematical chart line graph, is necessary to advance 2d refreshable braille pin-matrix displays.

1. Introduction

Access to graphical information is crucial for connecting blind and visually impaired (BVI) people with the rest of the world. Yet, adapting visual information, such as graphics, web pages, floor plans, and math graphs, to an accessible and usable format for people with BVI is challenging (Prescher, Bornschein, & Weber, Consistency of a Tactile Pattern Set, 2017). Even professional institutions that produce on-a-daily basis assistive materials have difficulties adapting graphical information to an accessible format (Prescher, Bornschein, & Weber, Production of Accessible Tactile Graphics, 2014).

People with BVI usually access digital information through screen readers. However, graphic content, such as line charts, is not accessible through this technology. An alternative is to use text descriptions, but these do not convey critical aspects that graphical representations do (Schwarz, Melfi, Scheiffele, & Stiefelhagen, 2022) (Zebehazy & Wilton, 2014). A standard solution is to use static tactile graphics representations that can be felt with the user's fingertips. However, this solution proved inefficient for more complex line charts since users would get overloaded with graphical elements (Aldrich & Sheppard, 2001).

An innovative alternative to tactile graphics representations and audio descriptions is 2d refreshable braille pin-matrix displays. This emerging technology enables BVI people to access complex 2d information through tactile and dynamic audio feedback. While this technology has received much attention in hardware aspects, software user interface aspects did not. Although some addressed and developed 2d pin-matrix displays' user interfaces, contributions are dispersed, and research gaps remain open (Ramôa, Classification of 2D refreshable tactile user interfaces, 2022). Such research is to define a set of suitable audio-tactile patterns for all application domains (mathematics plot charts, train station floor plans, school graphs, and others). In this work, we addressed the following research questions: Which characteristics should audio-tactile patterns include in 2d refreshable braille pin-matrix displays? What are the advantages of using audio and tactile feedback for representing filling patterns in 2d refreshable braille pin-matrix displays?

We investigated audio-tactile patterns for specific usage in 2d pin-matrix displays. Our analysis was split into two groups, filling patterns and line patterns. Although we only address here two types of patterns in this technology, there are more patterns to explore, such as control patterns or symbol patterns. In this work, we focused our analysis on filling and line patterns since we have been developing a user interface for representing train station floor plans and line charts, frequently using these patterns. The patterns were implemented in a 2d pin-matrix display, the Tactonom V1, from Inventivio GmbH. This technology combines pinpointed audio explanations with a pin-matrix tactile surface of more than 10.000 pins through camera-based fingertip recognition. We also presented our recommendations for audio-tactile filling patterns for this technology (tactile filling patterns recommendations are annexed to this document – appendix folder). Beyond 2d pin-matrix displays, our audio-tactile patterns suggestions are also scalable to 2d graphic readers. Such a device is the Tactonom Reader V1, From Inventivio GmbH. As the Tactonom, this device uses audio-tactile user interfaces. Still, instead of a pin-matrix tactile surface, the user places a tactile graphic (swell or braille-embossed paper) on the device. The audio patterns remain the same since both devices support sonification, and the tactile pattern recommendations can be applied in an SVG format and printed on swell or braille-embossed paper. Hence, our contributions applied to 2d pin-matrix displays and 2d graphic readers.

Our document is organised as follows: Section 2 discusses the related work. Section 3 describes the methodology of our analysis. Section 4 presents our recommendations and analysis of filling patterns. Section 5 presents our analysis and suggestions for line patterns. Section 5 presents the conclusions and new projections for future work.

2. Related Work

We reviewed the previous literature on the definition of audio-tactile pattern sets specifically for 2d braille pin-matrix displays.

Previous work addressed filling and line patterns in the context of creating accessible graphics for people with BVI (Prescher, Bornschein, & Weber, Production of Accessible Tactile Graphics, 2014). Results concluded that these patterns should be adaptable to other technologies; hence, using a vector graphic format was chosen in previous research. Lines and filling patterns are important since institutions often use these very often when producing tactile graphics. What was not done was to define the standards of these patterns for 2d pin-matrix braille displays, which can use tactile feedback and sonification patterns.

A user-centred approach for developing tactile filling patterns for tactile graphics and 2d tactile pin-matrix displays was developed (Prescher, Bornschein, & Weber, Consistency of a Tactile Pattern Set, 2017). Once again, the authors used the Scalable Vector Graphics format to define each pattern. Using evaluation with participants with BVI, a set of nine tactile patterns was defined. The research aim was to understand better the usage of these tactile patterns together on the same graphic. Results concluded that pre-defined standards by the Royal National Institute of Blind People pallet differ from the evaluation with the participants and present new and exciting results to the research community. Nevertheless, the related literature did not cover audio-filling patterns and line patterns. Further investigation o these alternatives is necessary to develop 2d pin-matrix devices and 2d graphic readers.

3. Methodology

In this paper, we have looked at the following categories of audio-tactile patterns for 2d pin-matrix devices:

- Filling patterns
- Line patterns

To better analyse the advantages and drawbacks, we implemented all the patterns presented in this document in the Tactonom V1 device from Inventivio GmbH. We split our analysis into audio and tactile modalities for each type of pattern. We did not address other kinds of patterns, such as symbol and control patterns, since we focused our analysis on three context domains, train station floor plans, excel sheets, and mathematical line charts. These domains represent high importance for people with BVI and were not highly covered by related work.

4. Filling Patterns

There are multiple ways of presenting digital graphical information to blind and visually impaired people through 2d refreshable pin-matrix displays.

One user interface element that exists in graphical information is **filling** patterns. Filling patterns are commonly used to distinguish areas or sections in GUI (graphical user interfaces) and 2d information. These patterns can go from a simple colour filling (Figure 1) to a visual shape texture (Figure 2). Beyond enhancing the distinction between areas, filling patterns are also used to give more detail to 2d information, such as decorative images.

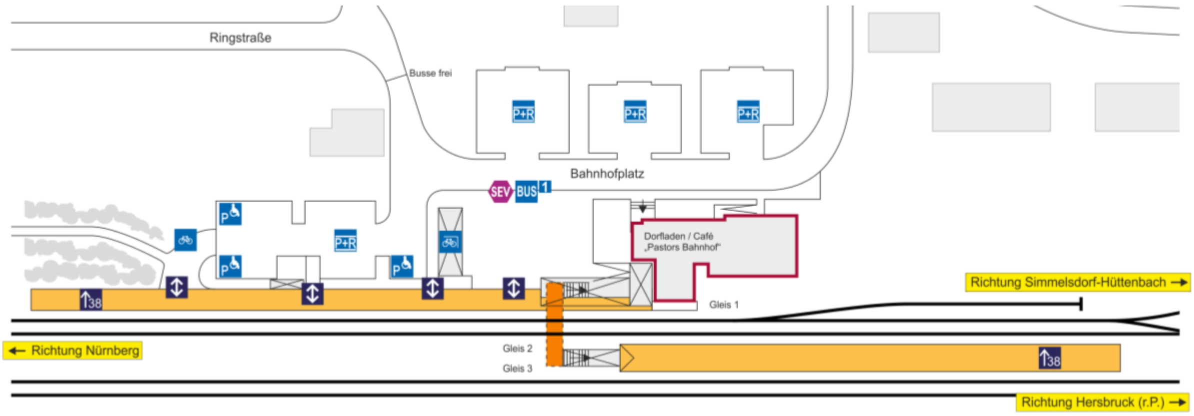

Figure 2- "Neunkirchen am Sand" Train Station floor plan – Bavaria train station database (BEG). Colour-filling patterns are used to distinguish different elements of the train station map. Light Orange is used for platforms, dark orange for tunnels, light grey for buildings and dark grey for tree areas. Texture-filling patterns are also used in small rectangular regions with the shape of crosses to represent staircases or shelters.

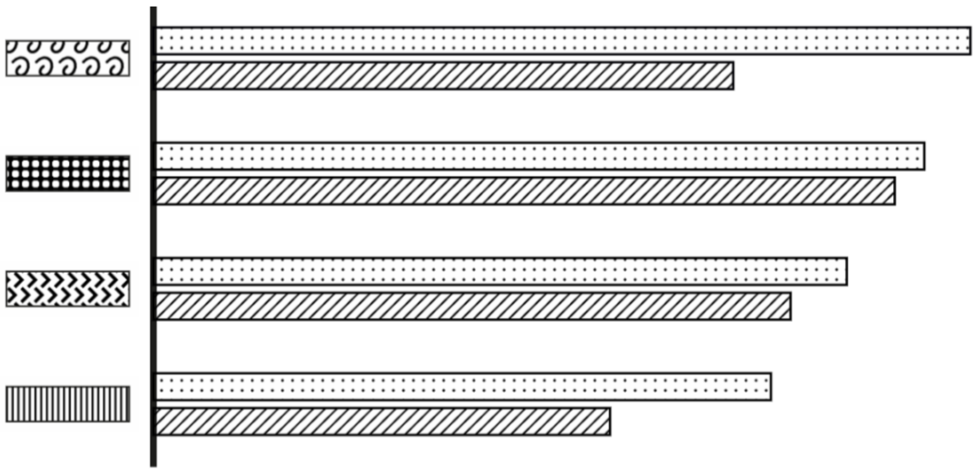

Figure 3 – Bar Plot Graph – created with Inkscape. Visual shape-textures are used to distinguish the different bar elements. Colour is often not used for graphics that need to be printed in black and white, so tactile textures are used instead.

For blind and visually impaired people, an alternative to visual filling patterns must be designed. This alternative should give extra detail to 2d information and allow people with BVI to distinguish between different areas in 2d graphics. Two types of filling patterns are used to design accessible 2d data, tactile filling patterns and audio filling patterns.

Tactile Filling patterns:

According to ISO 24508:2019, *Ergonomics – Accessible design – Guidelines for designing tactile symbols and characters*, a tactile pattern is composed of convex-type dots, lines or planes, or a combination of these perceived by touch.

An essential characteristic of tactile patterns is tactile legibility, the ease with which tactile symbols or characters can be identified by touch (ISO 24508:2019 definition of tactile legibility). There are filling patterns that are easy to identify by vision (high visual legibility) but are hard to locate by touch (low tactile legibility). Further characteristics and obstacles on tactile patterns for the blind and visually impaired will be present in the document.

As discussed in the related work section, previous work designed a consistent set of tactile patterns for tactile graphics on swell paper, tactile matrix embossers, and 2d refreshable pin-matrix displays (Prescher, Bornschein, & Weber, Consistency of a Tactile Pattern Set, 2017). Similar to this work, a set of tactile patterns for tactile graphic readers and 2d refreshable pin-matrix displays was designed at Inventivio GmbH. Following a user-centred design methodology, blind and visually impaired participants were involved in the design process of these tactile patterns from the beginning. The participants helped filter out tactile patterns that are not distinguishable enough and hence not suitable for presenting 2d information to blind and visually impaired people.

The proposed tactile patterns were defined in an SVG-based format. This enables the use of the SVG pattern in SVG objects that are then printed on swell paper used in the Tactonom Reader device. The Tactonom device (2d refreshable pin-matrix display) supports SVG files viewer. The software is based on the Apache™ Batik SVG Toolkit, which creates bridges from SVG elements(content) to an internal structure that is then used to map these elements in the pin-matrix surface. These bridges are customisable per type of SVG element and for specific tactile patterns, which makes it possible to adjust tactile patterns to be more recognisable in pin-matrix tactile views (higher tactile legibility).

Tactile filling patterns were split into three groups:

- point patterns (TacFillingPointPatterns.svg)
- symbol patterns (TacFillingSymbolPatterns.svg)
- line patterns (TacFillingLinePatterns.svg)
- mesh patterns (TacFillingMeshPatterns.svg)

Point patterns use small dots to fill areas. An example is presented in Figure 3.

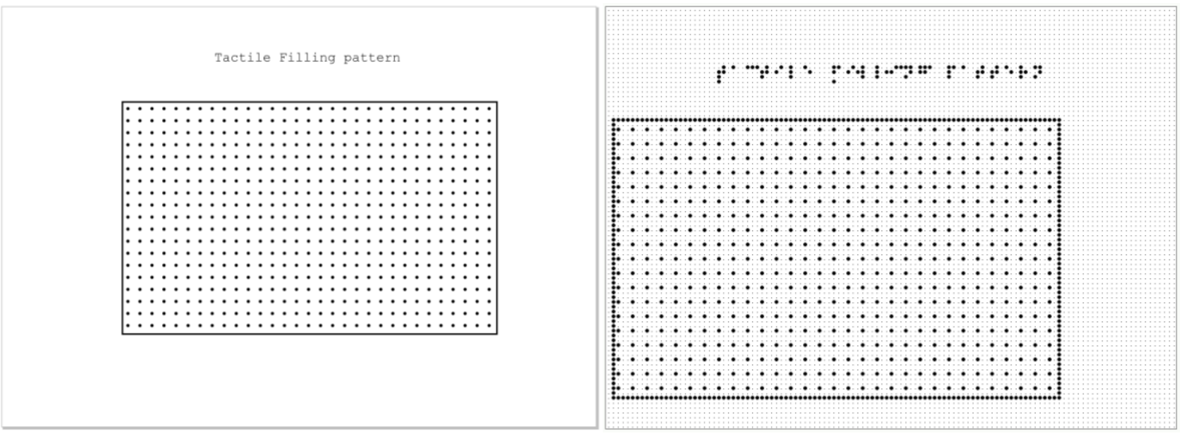

Figure 4 – Tactile filling pattern dots [dot diameter=2.2mm; distance between dots=6.2mm] – The pattern fills a rectangle object. On the left, we have the SVG format view. The Tactonom pin-matrix software simulation view of the same point-filling pattern is on the right. The picture on the Tactonom simulation has 119 pins (width) per 89 pins (height).

The points are equally distant from each other. This distance is an essential parameter for this pattern since, if not adjusted correctly, the pattern fails to convey that it is a distinctive area. Increasing the distance between dots increases the probability of points being perceived as individual elements and not as a whole. It also depends on how big the area contains the tactile filling pattern.

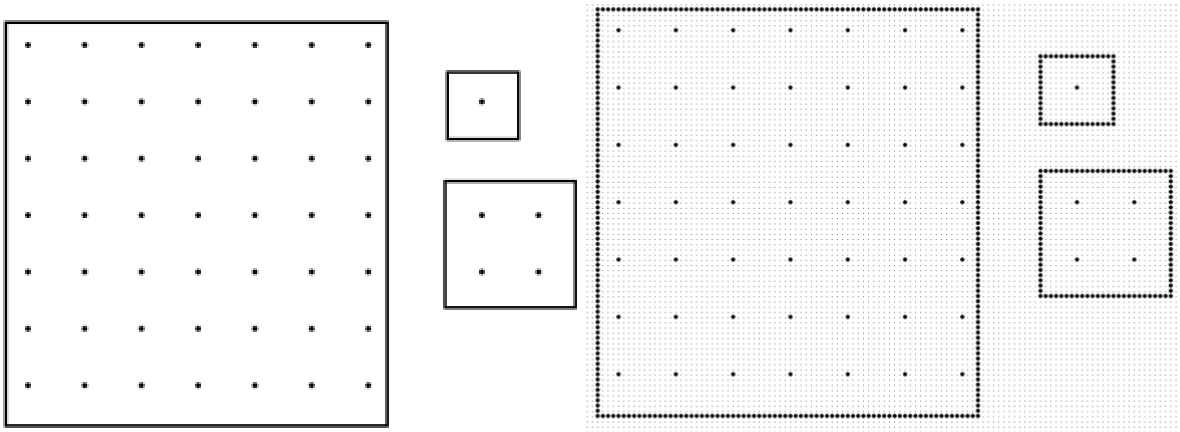

Figure 5 – Tactile Point Filling Pattern [dot diameter=2.2mm; distance between dots=20.0mm] – Left represents the SVG swell paper view, and the right image is the tactonom pin-matrix. The pattern applied to the smaller objects was not perceived as a pattern but as a tactile key point by two blind workers at Inventivio GmbH.

On the other hand, if the distance between points is smaller, the dots will not be perceived as individual elements but as a whole pattern. On the swell paper, this creates a sensation of height that can be used to highlight a specific area on the tactile graphic. For smaller distances, the Tactonom pin-matrix representation size is not enough to represent all points and distances, and it covers the area with all pins instead (Figure 5). With the zoom feature, the Tactonom adjusts its rendering to represent the pattern, making it possible to understand its shape and size better.

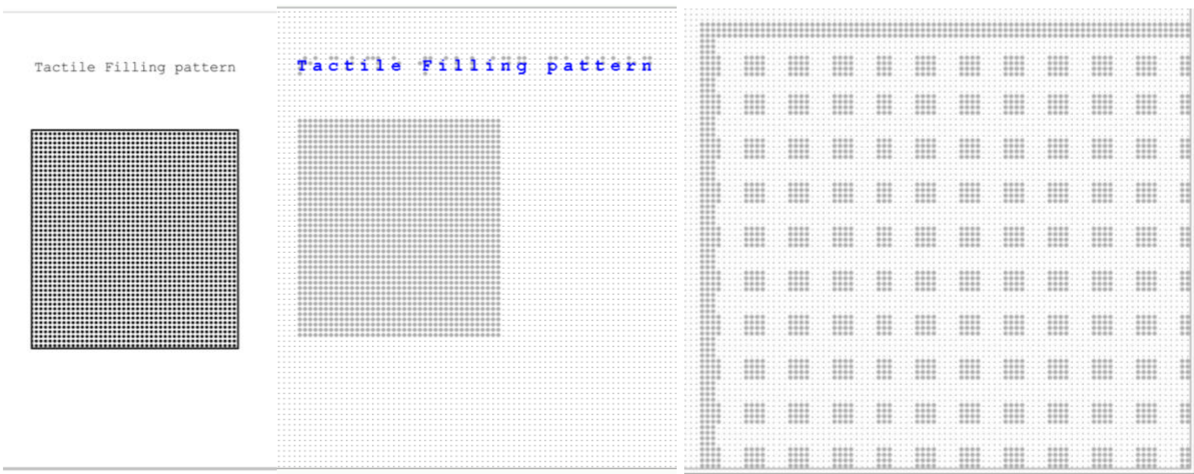

Figure 6 – Tactile Point Filling Pattern [dot diameter=2.2mm; distance between dots=3.0mm] – Left represents the SVG swell paper view, and the middle and right images represent the tactonom pin-matrix cell. The image on the right is a zoomed view of the Tactonom software simulation, where the pattern dots and distance are in scale. For this pattern, the Tactonom software raises all pins of the rectangle. When rendering a filling pattern, the distance between pins on the Tactonom (1.5mm) is considered.

Beyond the distance between points, the size of the points also plays an important role in tactile legibility and how the user perceives the pattern. If the dots are too small (smaller than 0.5 mm), they will not be detected by the heat processors (swell form machines), hence not having a tactile representation on the swell paper (microcapsule paper). On the Tactonom pin-matrix cell, if points are too small but the distance between points is still the same, this will have no impact on the final view (Figure 6).

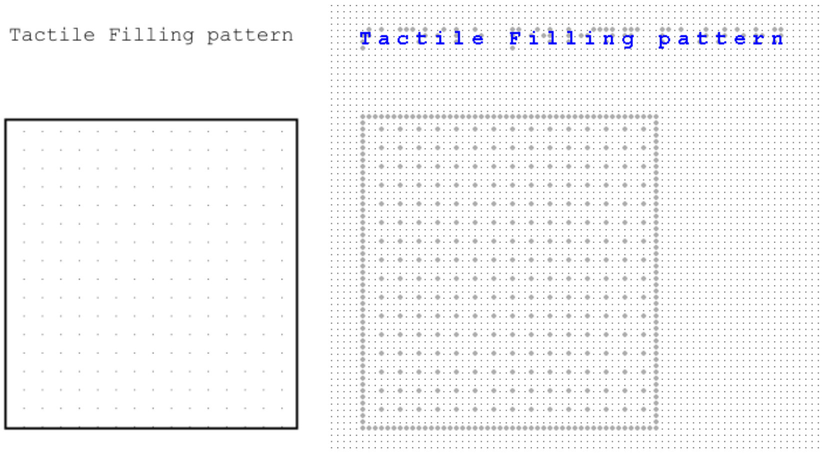

Figure 7 – Tactile filling pattern point [dot diameter=0.5mm and distance between points=6.2mm] – On swell paper, the pattern points are tiny and would not be turned to tactile by the heating processor. To visually perceive the points in the swell paper view, it might be necessary to zoom in on the figure. On the Tactonom view (right side), each pattern point is mapped to one pin coordinate.

With bigger points, tactile perceptiveness (recognising the existence of something - ISO/EIC 29138-1:2018) is higher and gets more users' attention. When combined with a smaller space between points, it becomes denser and taller in swell paper graphics for the blind user. This filling pattern can highlight important areas since the user will perceive this area as higher than the others. Nevertheless, if points are too big without a smaller distance between them, these will be perceived as tactile key points rather than as a whole pattern.

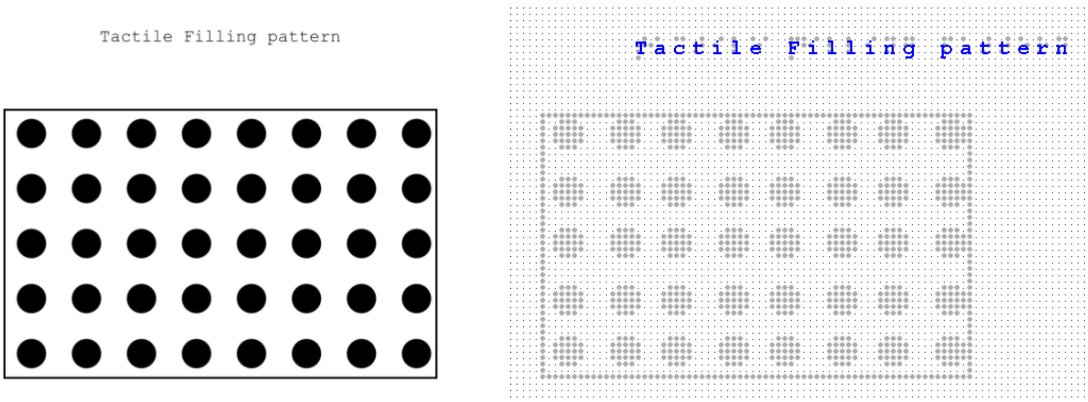

Figure 8 – Tactile filling pattern point [dot diameter=16mm and distance between points=30mm] – Swell paper view on the left and Tactonom pin-matrix picture on the right. In both views, due to its large size, each point in this pattern is perceived as a key point rather than a whole pattern.

A set of best usable tactile filling point patterns was defined based on preliminary interactions with visually impaired and blind workers at Inventivio on tactile filling point patterns with different dot sizes and distances between dots. It is also recommended to use a dot distance between 1 to 5 mm and a dot diameter between 0.8 mm to 2.0 mm. The following list of tactile filling point patterns is suggested:

- Point pattern with dot diameter of 0.8mm and offset distance of 1.5mm. (Punkt-0_8-1_5)
- Point pattern with dot diameter of 0.8mm and offset distance of 5mm. (Punkt-0_8-5)
- Point pattern with dot diameter of 1mm and offset distance of 3mm. (Punkt-1-3)
- Point pattern with dot diameter of 2mm and offset distance of 5mm. (Punkt-2-5)

Symbol patterns are very similar to point patterns, but instead of using dots to fill areas, these are characterised by using small symbols with an equidistant distance between each other. The most used symbols are triangles (Figure 8), squares (Figure 9), and corners (Figure 10). Different symbol patterns are also presented (Figure 11), although users do not perceive these as well as the triangle, symbol and square patterns.

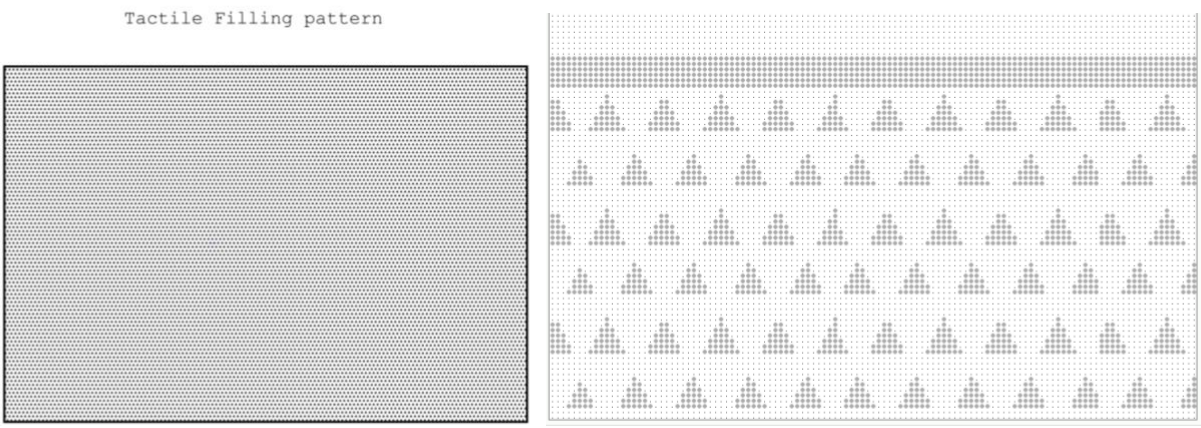

Figure 9 – Tactile filling pattern triangles [triangle size=1.2mm and distance between triangles=2.2mm] – Swell paper view on the left and Tactonom pin-matrix zoomed-in view on the right.

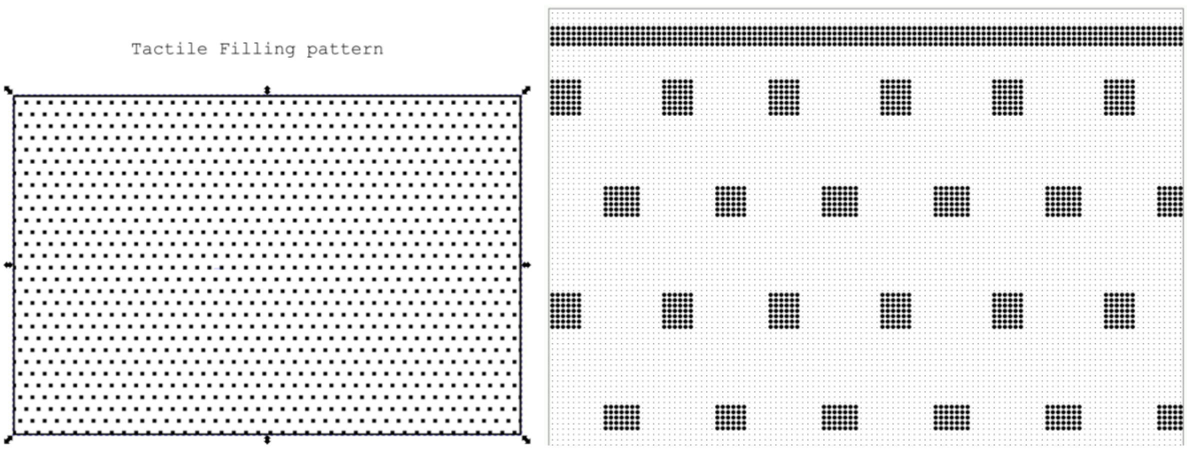

Figure 10 – Tactile filling pattern squares [square size=2.0mm and distance between squares=6.0mm] – The swell paper view on the left and the Tactonom pin-matrix zoomed-in view on the right.

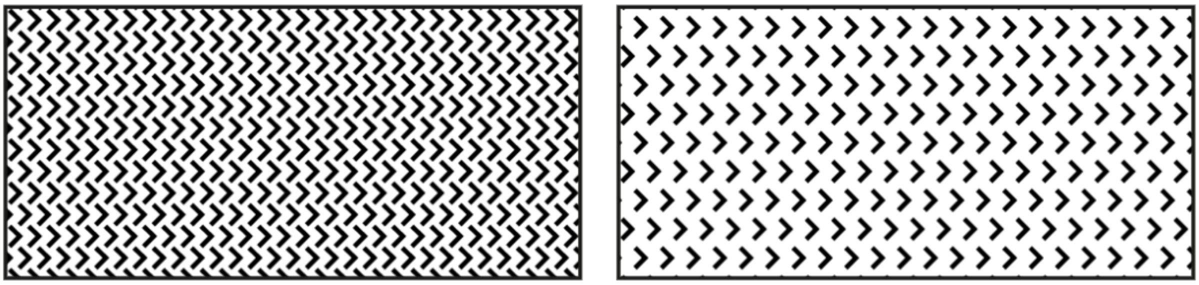

Figure 11 - Tactile filling pattern corners view on SVG. Both patterns have corner symbols of the same size, 5.0mm in height and 3.5mm in width. The left pattern uses a smaller spacing between the corners (x-spacing= 4mm and y-spacing=4.5mm), while the pattern on the right uses a larger spacing (x-spacing=5.5mm and y-spacing=6.5mm).

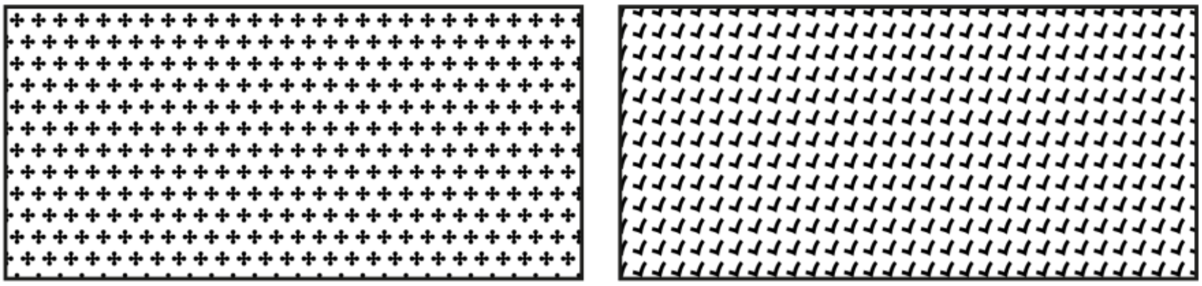

Figure 12- Tactile symbol filling patterns rendered of SVG. On the left is a cross pattern, also used in (Prescher, Bornschein, & Weber, Consistency of a Tactile Pattern Set, 2017), and on the right side is a correct-mark symbol pattern. Both symbols have a width size of 3.2mm and an equidistant spacing of 4.5mm on both axes.

Some recommendation rules on filling point patterns are also suggested for symbol filling patterns. The spacing distance between symbols will influence how the user perceives the pattern as a whole or as multiple individual elements. The shorter the spacing distance is, the more difficult it is to tell the individual symbols apart, and the higher the pattern is perceived.

Based on preliminary interaction with multiple tactile filling patterns in one graphic, triangles and squares symbol patterns are very similar to point filling patterns. It is recommended that these are not used simultaneously on the same graphic unless different spacing distance and symbol size is used. For example, a point-filling pattern with 0.8mm symbol size and 5mm spacing size with a triangle-filling pattern with 1.0mm symbol size and 2.0mm spacing size. For the Tactonom device, the symbol patterns difference is more minor due to the resolution limitation, which does not allow the rendering of very small-sized symbols.

All of the presented symbol-filling patterns are listed in the *appendix* of this document.

Line patterns use straight parallel lines to fill areas. Line width and spacing affect tactile legibility and how the user perceives the pattern. If the lines are too thin with a small line spacing, the pattern is perceived as a more dense layer and feels higher for users (as with point and symbol filling patterns). Line-filling patterns can be split into three types, horizontal lines (Figure 12), vertical lines (Figure 13) and diagonal lines (Figure 14 and Figure 15).

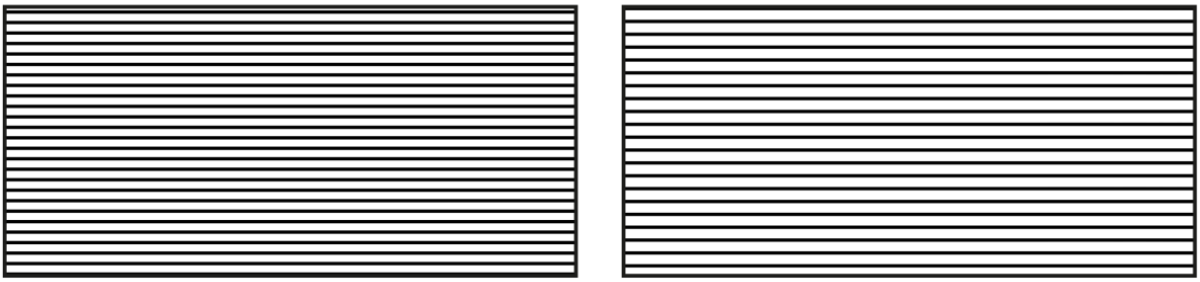

Figure 13 – Horizontal filling pattern. The left pattern uses a line spacing of 2.2mm, and the right pattern uses a line spacing of 2.8mm. Both patterns use a line width of 0.7mm.

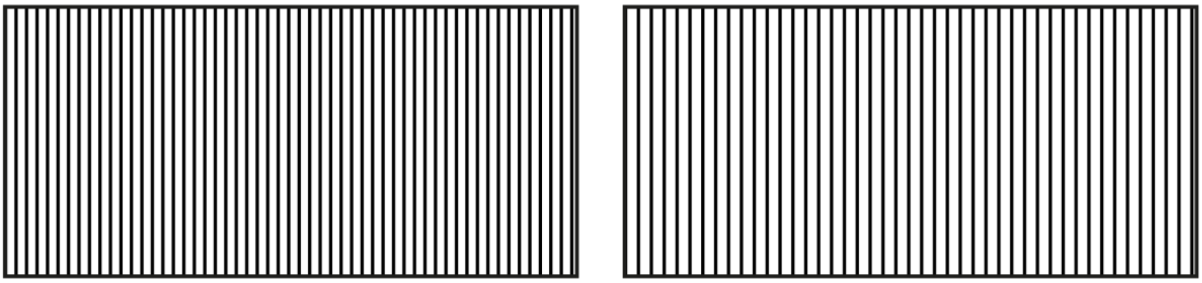

Figure 14 - Vertical filling pattern. The left pattern uses a line spacing of 2.2mm, and the right pattern uses a line spacing of 2.8mm. Both patterns use a line width of 0.7mm.

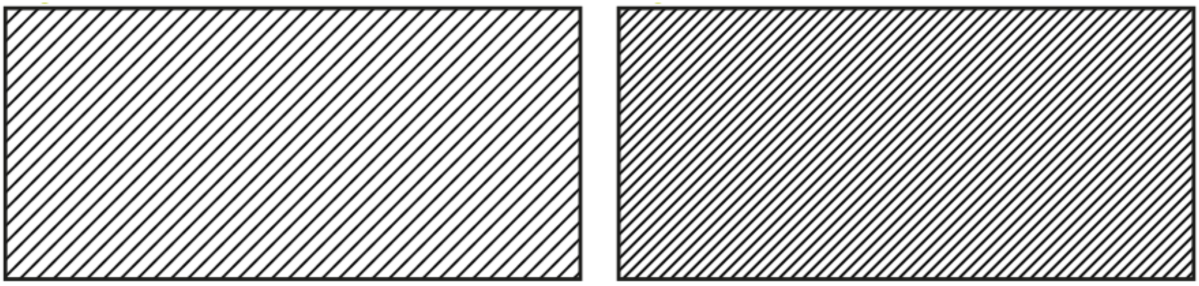

Figure 15 – Diagonal filling patterns. Both patterns use a line width of 0.6mm. The left pattern uses a line spacing of 2.5mm, and the right pattern uses a line spacing of 1.8mm.

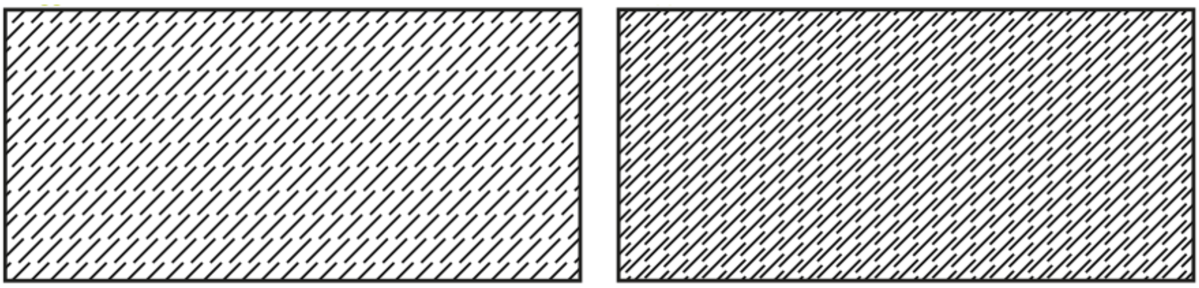

Figure 16 – Diagonal irregular filling patterns. The patterns use a line width of 0.6mm. The left pattern uses a minimal spacing of 1.7mm, and the right pattern uses a minimal spacing of 1.0mm.

It is recommended to use a line spacing between 1.0 to 4.0mm and a line width of 0.6mm to 0.8mm for tactile line-filling patterns in tactile graphics. As aforementioned, these recommendations came from preliminary interactions of blind workers with swell paper graphics.

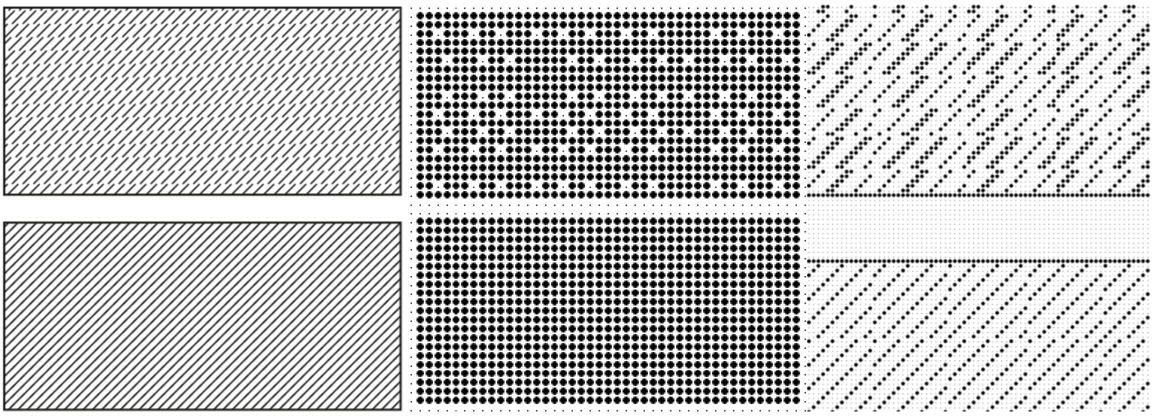

Figure 17 – Diagonal filling patterns comparison of swell paper view with Tactonom view. The left image represents two diagonal filling patterns rendered as a swell paper view. The middle image is the Tactonom view simulation of the same two patterns. The right image is a zoomed-in view of the central image. Both patterns use a line width of 0.6mm.

Rendering tactile line-filling patterns on 2d refreshable pin-matrix displays is challenging (Figure 16). If the line width and the line spacing size are small, the pattern will be represented in the 2d pin-matrix display as a complete pattern or close to that (all pins are raised). Only a zoomed-in version can render the pattern closely to its original representation (SVG file).

Lastly, **mesh** filling patterns use repetitive textures propagating in the two-dimensional axes to fill areas. The user cannot perceive individual elements in these patterns as in point or symbol-filling patterns. Results from preliminary interaction with blind workers generate four mesh filling patterns:

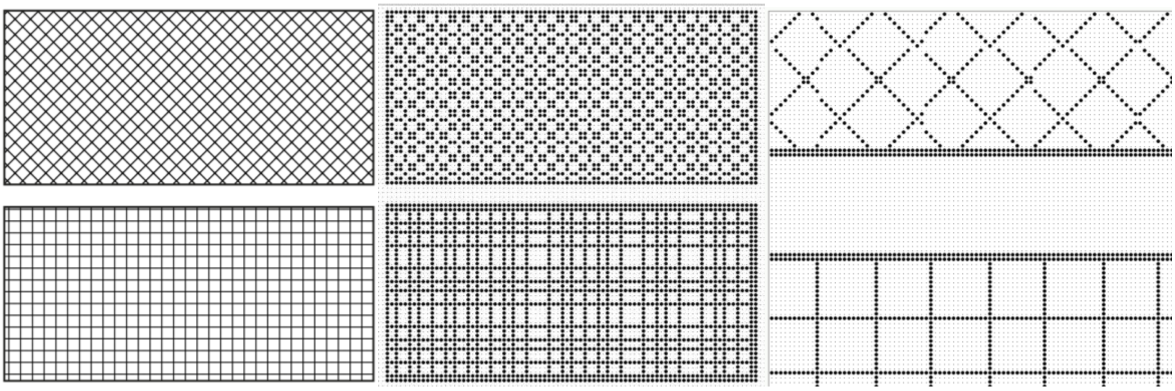

Figure 18 – Diagonal and chess mesh filling patterns. The left image is the swell paper representation of the diagonal (top), and the chess (bottom) mesh patterns. The middle picture is the Tactonom render of the same patterns. The right image is the zoomed-in version of the central image. Both patterns use a line width of 0.6mm. The diagonal mesh pattern size is 4.3mm in both axes, and the chess mesh pattern is 4.5mm in both axes.

Once again, rendering filling patterns on 2d refreshable pin-matrix devices is difficult. The zoomed-in version in figure 17 looks exactly like what the zoomed-in version of the original SVG format would look like. Nevertheless, the zoom-out view still has some flaws, especially in representing diagonal lines on both sides.

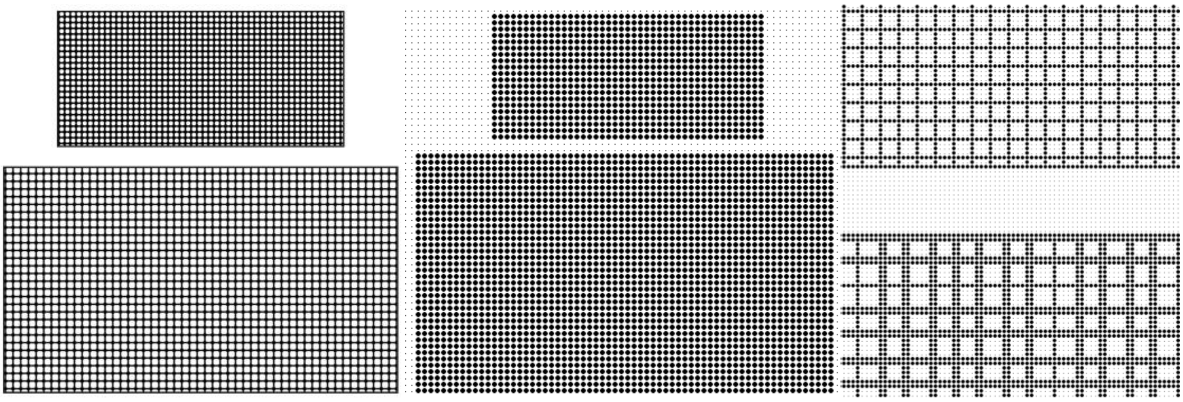

Figure 19 – Grid mesh filling patterns. The left image corresponds to the SVG format view of the grid patterns, the middle image the Tactonom view and the right image the zoomed-in view of the Tactonom. Both patterns are grid mesh filling patterns. The top pattern size is 3.3mm in both axes, and the bottom is 4.2mm in both axes. Both patterns use a line width of 0.9mm.

The zoomed-out 2d pin-matrix view on mesh filling patterns is totally filled (all pins are raised). Mesh patterns presented here occupy, on average more area than the other patterns (more black pixels than white pixels). As the 2d pin-matrix screen resolution is lower than swell paper precision, these patterns are differently rendered in the Tactonom view.

Tactile filling patterns are unsuitable for filling small areas (width or height smaller than 10mm). The tactile legibility in smaller areas is very low since the pattern can be mistaken for an object point or a key element instead. Even for line and mesh patterns, which do not use a set of individual and equidistant small symbols, the tactile information in smaller areas is not precise enough for users to perceive the pattern's contours information as vision is.

All the suggested lists of tactile filling patterns can be found in the *appendix* folder associated with this DELIVERABLE in an SVG file format, which is scalable to other assistive technologies, such as tactile graphic viewers and 2d refreshable pin-matrix displays.

Audio Filling patterns:

Tactile filling patterns work properly for swell paper and tactile graphics representation. However, the same cannot be said for 2d pin matrix device renderings. As these devices have a more limited resolution (almost all the same as braille) and screen size, the pattern's tactile legibility will not be the same for swell paper and when rendered on this technology. However, beyond tactile filling patterns, tactile graphic readers and 2d refreshable pin-matrix devices can also use audio feedback, hence audio filling patterns.

Audio-filling patterns are audio sounds mapped to elements (rectangles, circles, patterns and others) that represent an area. There are different audio patterns to use with different interaction user interfaces. Regarding audio feedback, this can be speech audio (Petit, Dufresne, Levesque, Hayward, & Trudeau, 2008) (either recorded speech or speech synthesis) and sound synthesis (context-dependent or independent). Regarding audio interaction, it can be action-orientated (users need to press a button or perform an action to get the feedback) or dynamic finger-oriented (the system plays audio as the user moves through elements). The goal of tactile filling patterns within an object is to help users understand the object's dimensions and discriminate it from other object areas. Audio-filling patterns have the same aim, to help blind users perceive the dimensions and boundaries and tell them apart from other objects in the same graphic. One of the essential features of filling patterns is categorising elements in 2d graphics.

It was developed for the Tactonom and the Tactonom Reader (a tactile graphic display also produced by Inventivio GmbH), two interaction methods to interact with two-dimensional graphics in an action-orientated and dynamic finger-orientated way.

The action-oriented method does not play sound if the user does not perform the intended action. While perceiving tactile elements with their hand, the user can point with their fingertip to one element and press a button with the other hand. Audio associated with the focused element is played when this action is performed.

Dynamic finger-oriented plays sound dynamically through interaction. Also called *Exploration*, the user explores the graphic elements with their fingertip. As the user reaches an element with audio information associated (with the fingertip), the Tactonom immediately plays the audio. If the user's fingertip moves to another element with audio associated, the Tactonom plays it.

Regarding audio patterns, the Tactonom plays speech audio and sounds with context to the elements of the graphic. Speech audio is speech synthesis and is generated using the Amazon AWS text-to-speech engine services. The speech synthesiser will change to the selected language depending on the chosen language. Speech is used for several applications, including menu navigation, error handling and fulfilling the tactile filling pattern aim. Speech is used both in action-oriented methodology and dynamic finger-oriented methodology.

Beyond speech, context sounds can be loaded in each element. At the moment, these sounds are not generated and are context-dependent, meaning that the Tactonom plays different sounds in different contexts. This also means that these are not scalable to other domains, where different sounds need to be selected and associated with each element in the graphic. An example is train station graphics, where the Tactonom uses nature sounds to describe different area elements, such as platform areas with people talking and the sound of trains arriving, or the main area with more people talking in the background and warnings about train status being played.

Tactile and audio filling patterns significantly differ when mapped to the Tactonom device. Some tactile patterns cannot be visual-accurately represented in 2d pin-matrix displays due to their limited resolution and screen size. However, should SVG-based tactile patterns be exactly visually rendered on 2d pin-matrix devices, or should these have a different rendering map that creates similar tactile legibility and perceptiveness? When caused in 2d pin-matrix displays, some tactile filling patterns lose their tactile legibility in the swell paper. The correct way would be to render these not thinking of the visual representation but the rendering that produces the most similar tactile legibility to their original format. Another issue is the zoomed-in views of tactile filling patterns in 2d refreshable pin-matrix displays. When zooming-in elements(such as circles, rectangles, and paths) on an SVG file, these are scaled up according to their size (width and height). SVG patterns are also scaled up when zoomed-in in the Tactonom (Figure 8, Figure 9, Figure 17, and Figure 16). However, when patterns are scaled up, their tactile legibility completely changes, which is not ideal since filling patterns on the previous view(before zoomed in) might not be recognised now, eliminating the function that filling patterns should have.

Further research on tactile filling patterns render on 2d pin-matrix devices is necessary. Meanwhile, audio-filling patterns maintain audio legibility since they are not scaled up or down as tactile filling patterns. Hence not changing in zoomed-in or zoomed-out views and maintaining their audio legibility through audio-tactile graphic readers and 2d refreshable pin-matrix devices. If the user does not move, he receives no tactile output. The interaction with audio should work like that too.

5. Line Patterns

Line patterns are used to represent lines of 2d documents and graphics. We have developed tactile line patterns in the context of an excel sheet application and a line chart viewer in the Tactonom device. As with the previous tactile patterns, the tactile line patterns presented here can also be implemented in the context of tactile graphics (swell and braille-embossed paper).

A standard excel sheet is constituted of cells. These cells are divided through lines. We developed a simple excel application where we can represent the following sheet (Figure 20) for the Tactonom device:

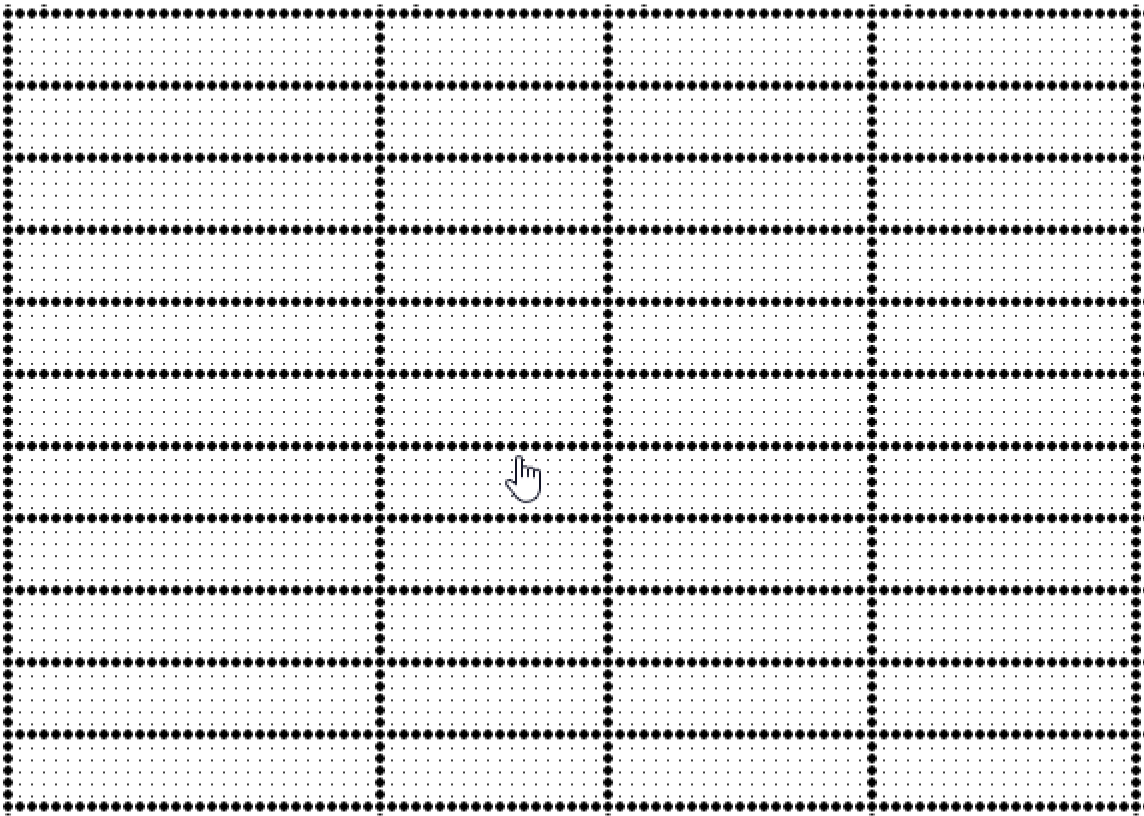

Figure 20 – An excel sheet application of the Tactonom device. Lines with a width equal to 1 pin are used to separate each cell.

We used lines with a width equal to 1 pin to separate each cell. The bigger this width, the less information we can represent on the screen since we still want the functionality to represent text or symbols inside each cell (Figure 21).

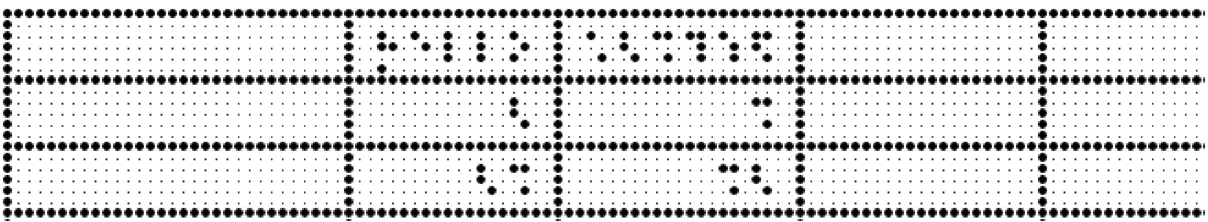

Figure 21 – The Tactonom excel sheet application. Each cell can eventually have text or symbol elements inside.

Instead of using just simple straight lines to separate each cell, we can use dashed lines. In the case of the excel sheet application, we used dashed lines to indicate a selection (Figure 22).

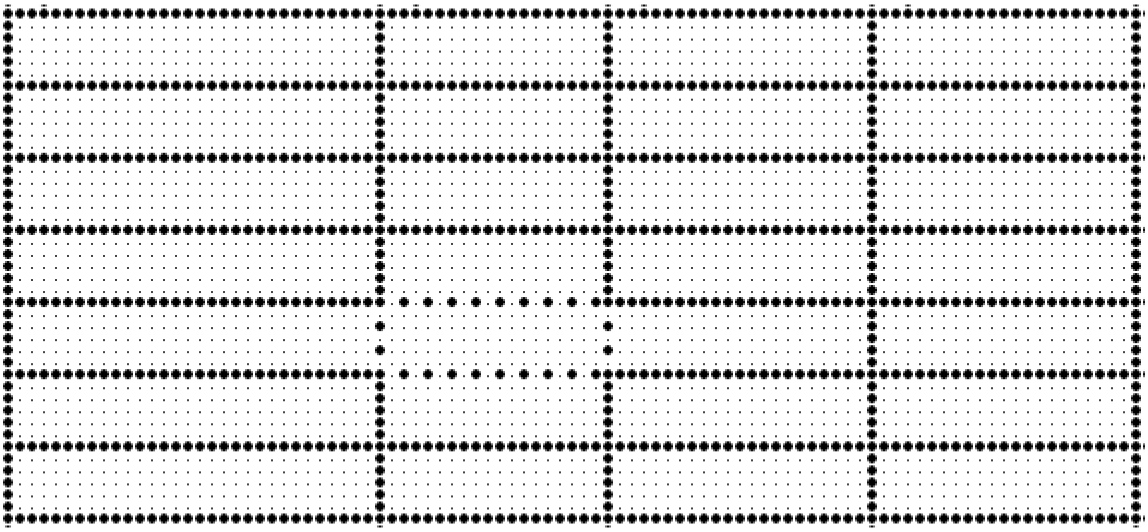

Figure 22- Tactonom excel sheet application. We can use dashed lines to indicate that one or more cells are selected.

The interesting detail in line patterns is which distance we should use between pins. For the dashed line in the Tactonom excel sheet, we use a space of 1 pin between each pin. One could argue that we can use more different distances, such as two or even three. However, the higher the distance, the higher the probability for the dashed line to be confused with a text or symbol element. In the specific domain of excel sheets, using dashed lines with text and symbol elements might not work together since the user is overloaded with the tactile modality (Figure 23). On the other side, if audio is used as an alternative for the text and tactile symbol, users will notice the dashed line patterns more perceivable.

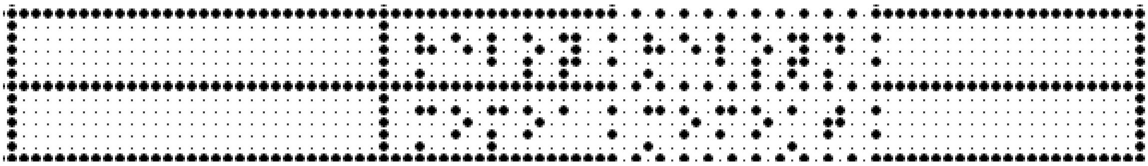

Figure 23- Tactonom excel sheet application. When using dashed lines, these can be confused with more minor elements, such as text or critical symbols.

Another application of tactile line patterns is representing and interacting with line charts (Figure 24).

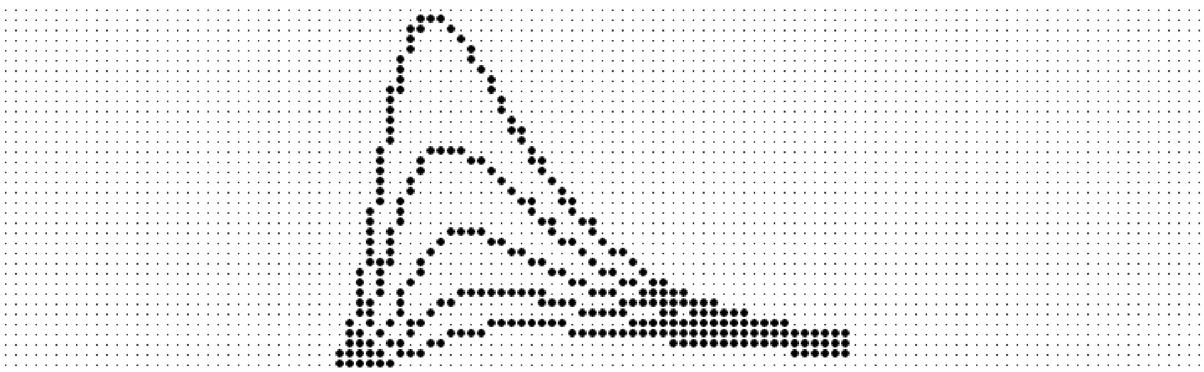

Figure 24 – Mathematical line chart application. Lines patterns are used to represent five mathematical functions.

We developed an application on the Tactonom device that enables users to interact with line charts. In this context domain, tactile line patterns are used to represent the lines of mathematical functions or graphs data. As in the previous domain, we can use dashed and not-dashed patterns. Dashed patterns can be used to distinguish between lines or even to classify one line as different from the others (Figure 25). In intersections points, using two different line patterns helps the user understand which direction each line follows (Figure 26). Beyond the 2d pin-matrix displays, we can use tactile line patterns in tactile graphics.

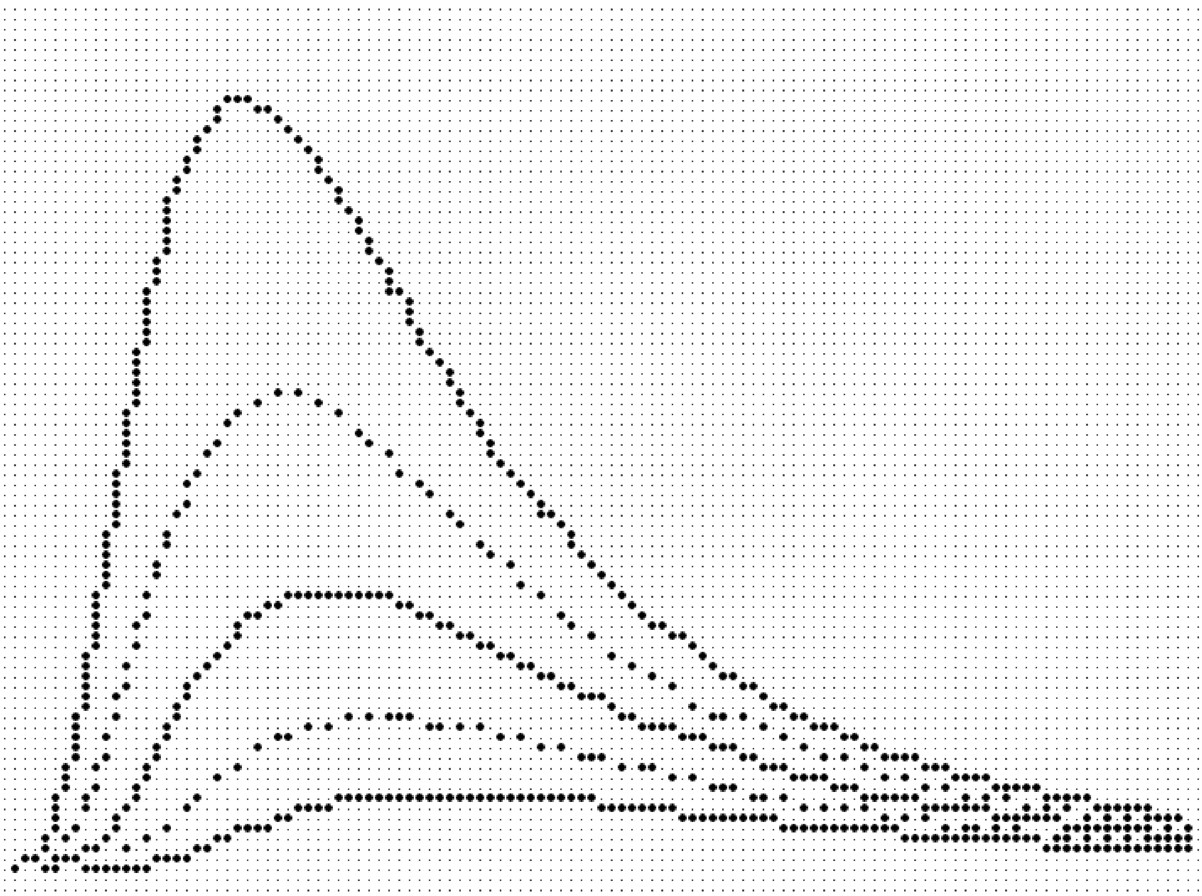

Figure 25 – Using different tactile line patterns (dashed and not dashed) to distinguish between lines.

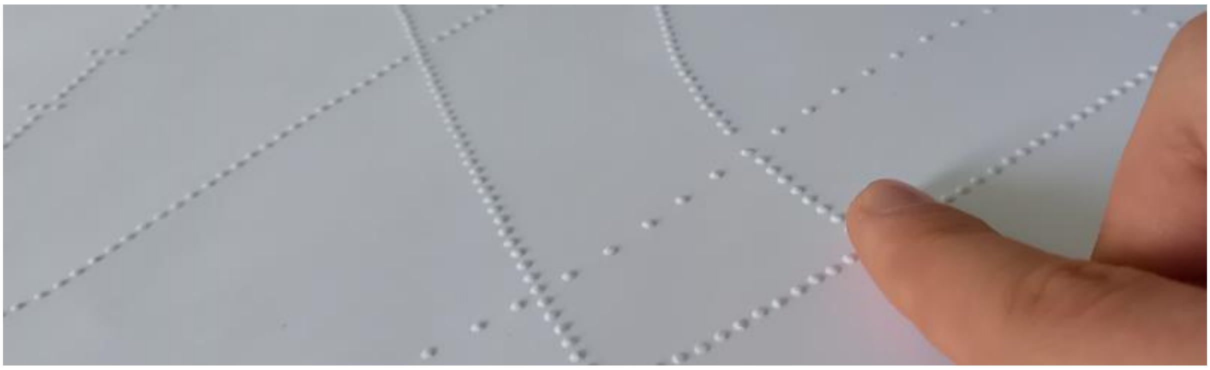

Figure 26 - Braille-embossed graphic with dashed and not dashed line patterns.

People with BVI cannot navigate in a straight line without any tactile feedback (Ramôa, Schmidt, & König, Developing Dynamic Audio Navigation UIs to Pinpoint Elements in Tactile Graphics, 2022). Because of this, we do not extend our line pattern analysis to the audio modality. We believe that sonification can increase the perception and help the user to follow the line, but tactile feedback is still beneficial for this task.

6. Conclusion

We have defined a set of tactile and audio patterns for 2d refreshable pin-matrix devices (such as the Tactonom V1) that also apply to 2d tactile graphic readers (such as the Tactonom Reader). The set of patterns in this work is split into filling patterns and line patterns. Filling patterns are used to fill areas in 2d documents and graphics, while line patterns represent lines.

We investigated the advantages of using specific patterns and others in different contexts. Although we have focused our implementation on specific context fields (mathematical line charts, excel sheets, and train station floor plans), our outcomes on patterns can be implemented into other areas, such as school graphs, complex PDF documents with figures, diagrams, web browsers, email service, etc.

As an emerging technology, it is expected that in the following years, 2d refreshable pin-matrix user interfaces development will increase. Topics such as audio-tactile synthesis, dynamic user interface design, high-precision fingertip gesture recognition, and audio-tactile pattern development for 2d pin-matrix devices will receive more attention. Although we have addressed several patterns in this work, further investigation and research are necessary to cover the full spectrum of audio-tactile patterns for 2d refreshable pin-matrix devices. For future work, it is expected to work on the development of these patterns for train station floor plans representations, including evaluation with users with BVI.

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