CapMaps

Capacitive Sensing 3D Printed Audio-Tactile Maps

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Abstract. Tactile maps can be useful tools for blind people for navigation and orientation tasks. Apart from static maps, there are techniques to augment tactile maps with audio content. They can be used to interact with the map content, to offer extra information and to reduce the tactile complexity of a map. Studies show that audio-tactile maps can be more efficient and satisfying for the user than pure tactile maps without audio feedback. A major challenge of audio-tactile maps is the linkage of tactile elements with audio content and interactivity. This paper introduces a novel approach to link 3D printed tactile maps with mobile devices, such as smartphones and tablets, in a flexible way to enable interactivity and audio-support. By integrating conductive filaments into the printed maps it seamlessly integrates into the 3D printing process. This allows to automatically recognize the tactile map by a single press at its corner. Additionally, the arrangement of the tactile map on the mobile device is flexible and detected automatically which eases the use of these maps. The practicability of this approach is shown by a dedicated feasibility study.

Keywords: Tactile maps · Audio-tactile · Blind · Orientation · Worldwide · Accessibility · Tangible user interfaces · 3D printing · Touch screen · Capacitive sensing

1 Introduction

Tactile maps can be useful tools for blind people for navigation and orientation tasks. In the latter case, tactile maps can be used to inform about an area beforehand. Alternatively, the consultation of tactile maps in situ may contribute to orientation for blind people. In this context, portability of the map is of particular importance.

In the past, the construction of tactile maps has been a manual task which drastically limited their availability. Today, physical representations of electronic tactile maps can be produced by a number of different techniques. Thermoforming refers to a process of generating a negative template and to deforming thermoplastic foils by heating them and sucking them towards this template with low pressure. This allows reproduction of continuous graphics (cartographic line and area features) with multiple height levels which can be used to topologically group elements. This technology is rather expensive, and the creation of the templates is laborious. Hence, it is uncommon to use this technique for personal use. Tactile embossers punch a series of dots into

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printer paper. Some embossers are able to vary the strength of punches, which result in different sizes of dots. In combination with halftone techniques, this in principle allows simulation of a smaller number of height levels. Currently, embossers are the optimal choice to print Braille letters. However, the graphical abilities of embossers are limited, since continuous graphics have to be approximated by dots. Additionally, in contrast to thermoforming, the simulation of multiple consecutive height levels is not expedient. Another process enables printing of black and white graphics on chemically treated paper (microcapsular paper/swell paper) by ordinary printers. Subsequently, the printed sheet is heated by a thermal enhancer (also fuser) which elevates black parts of the printed graphics. This technique makes it possible to print complex graphics with continuous elements. However, because only the black parts are elevated by heating, only one height level can be reproduced. Thin lines as well as large black areas can be problematic, because the elevation of these parts can be skewed which may alter the intended tactile sensation. 3D printers are still uncommon, but recently there have been an increasing number of publications which also consider this printing technique. The most common 3D printing technique for the consumer market is Fused Decomposition Modelling (FDM), which is based on the disposition of molten thermoplastic polymers (filaments) which are positioned by a mechanical printing head. Braille letters can also be printed with this technology, but due to its limited printing speed, there are more adequate technologies for this task. On the contrary, its graphical abilities make it possible to print graphics as continuous elements. Even low-cost 3D printers already technically allow numerous high levels with resolutions up to 20 microns (0.02 mm) height difference. This additional level of freedom enables structuration of map features into multiple topological areas which might be used to support their readability. Another advantage is that multiple filaments with different immanent characteristics can be printed into a single, monolithic map, which is utilized in this paper.

Besides static maps, there are techniques to augment tactile maps with audio content. They can be used to interact with the map content, to offer extra information and to reduce the tactile complexity of printed maps. This is particularly important to consider physiological constraints of blind users' tactile sense and to limit the cognitive load whilst reading the map. Such audio-tactile maps can be more efficient and satisfying for the user than pure tactile maps without audio feedback [1]. A major challenge of audio-tactile maps is the linkage of tactile elements with audio content and interactivity. This paper introduces a novel approach to link 3D printed tactile maps with mobile devices, such as smartphones and tablets, in a flexible way to enable interactivity and audio support. By integrating conductive filaments into the printed maps it seamlessly integrates into the 3D printing process.

2 Related Work

Accessible audio-tactile maps with physical map representatives for blind people have been addressed with different technologies. Integrated approaches use dedicated hardware to develop highly interactive applications for audio-tactile maps. Zeng et al. introduce multiple approaches which produce interactive tactile maps which can immediately adapt their appearance on the tactile display (e.g., [4, 5]). Schmitz & Ertl [6] use a tactile display for detailed building plans and outdoor maps which are enriched by text-to-speech (TTS) messages. A major strength of these approaches is the immediate adaptivity of the tactile rendition on the tactile display. However, this technology is very expensive and its portability is limited to desktop usage.

Hybrid approaches use physical tactile maps in combination with computers or mobile devices. The have to store a virtual representation (or at least parts of it) from the physical map which is used to augment the user interaction with the map. These approaches have to solve two additional tasks: (i) the recognition (identification) of the currently used map and (ii) the layout (arrangement) issue to accommodate the physical map with the virtual map data. An approach named Touchplates [7] uses acrylic overlays including visual tags, which can be recognized by tabletops such as Microsoft surface table. It was able to recognize these maps automatically and to determine their arrangement. Its key technology (infrared based diffused illumination) used to recognize the optical markers is built in touch tables which are not portable. Graf [8] carried our experiments with embossed tactile maps and makes several suggestions for linking physical maps with their virtual representatives which are partly used in the following approaches.

The approach Talking Tactile Tablet (TTT) [9] consisted of a frame with a touch sensitive surface which was connected to a computer by a USB interface. Special tactile sheets had to be exactly mounted into this frame which is aligned to three calibration points. In order to recognize the mounted sheet, the user had to touch several points on the tactile sheets. A subsequent approach [10] was to able produce US maps for the TTT automatically by local Braille embossers or third party companies. Wang et al. [11] introduced a prototype system using a touchpad and a computer display to support the exploration of street networks which has been evaluated by blindfolded people. Automatically generated maps could be printed by thermal enhancers and embossers and placed on the touchpad. These tactile maps are were recognized automatically and had to be placed exactly on the touchpad. A common issue of these techniques is the limited portability.

Portability of tactile maps may be advantageous for the spatial understanding of blind users for unfamiliar urban environments [12]. In contrast to the previous approaches the maps by Sennette et al. [13] were applicable to portable devices, such as tablet and smartphones. Using the popular OpenStreetMap database, the map data was edited and enriched by multimedia content, whilst the tactile maps were generated by a thermal enhancer. To use these maps, they had to be aligned exactly with the display's border on the mobile device, the map contents had to be preloaded, since they weren't recognized automatically. Finally, another portable approach [14] based on automatically recognizing 3D printed tactile maps, including multiple height levels by standard smartphones' built-in cameras. Barcodes attached to the upper and lower border of the tactile map encoded the geographic coordinates of the map's area, which allow the application to download the corresponding map data. An optical finger detection analyzed the user's map exploration by their fingers. This approach automatically recognized the map and had weaker constraints to the arrangement of the tactile map. However, this approach only supported one-handed exploration of the map and was sensitive to bad lighting conditions. In the following, this paper introduces a novel approach which automatically recognizes the tactile map by a single press at its corner. Additionally, the arrangement of the tactile map on the mobile device is flexible and detected automatically.

3 Approach

Most of the current mobile devices integrate capacitive touch screens, which enable to detect user interaction with the device's display. They localize interaction with the display by load changes caused by touch of a human finger. The touch sensor may be applied onto the display and touched directly by the user (surface capacitance) or be placed underneath an insulating surface (projected capacitance). This indirect technology allows even detection of the proximity of fingers (even through thin materials) and is the most common technology for mobile devices. Usually ten fingers can be detected concurrently. Conductive materials can be used to pass capacitive coupling, which is exploited by tangible user interfaces such as Sketch-a-TUI [15]. This approach allows to sketching conductive wires by a special ink dispenser and thus, to add interactivity to objects placed on capacitive touch screens. These wires have recently also been used [16] with conductive filament which can be deposited at exact positions and 3D printed along with normal (isolating) filament. In this paper we extend this concept to form a capacitive code. By encoding combinations of concurrent touch points in predefined spatially arrangements, both the identification and the arrangement issue (see Sect. 2) can be solved. To do so, a touch of the user on the one side of the 3D printed capacitive code is forked into multiple locations on the display's surface, inducing the detection of multiple concurrent touches. Software analyzes concurrent touches and classifies them into normal touches and specific codes. Thus, the 3D printed tactile map is able to transmit information to the surface by a single touch.

The codes consist of both a conductive and a surrounding isolating part. The conductive part has a flat surface and a set of equidistant cylinders which contact the touch display. In this approach, distances between cylinders are used to encode information. In order to use it for audio-tactile maps, these capacitive codes are attached to the upper left edge of the tactile map (see Fig. 1) which also helps blind users to identify the orientation of the map. They are structured into four cylinders. The first both cylinders contacting the touch surface are located in a certain distance to each other and serve as identification as capacitive code. The remaining cylinders are located in multiples of this distance and encode the corresponding ID of the map. Since the

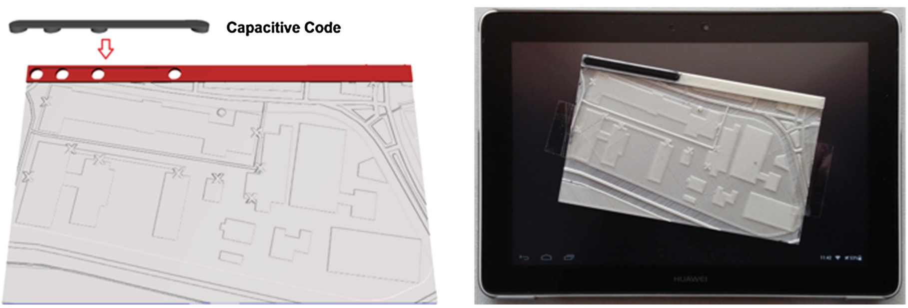

Fig. 1. Generated 3D model (left) with conductive element (dark grey) which bifurcates a touch on top to multiple concurrent touches on the touch display - Printed audio-tactile map with 10" tablet fixed by adhesive tape (right).

cylinders are arranged in a straight line alongside the map, the locations of touch points detected by the touch screen are used to compute its degree of skewing.

When the mobile application is started, it waits for the user to place a map on the display and to touch the identification bar at the upper left corner of the map. The map's orientation is determined by the sequence of touch points forked to the touch display. The recognized code allows the software to look up a table containing metadata about this map. Along with the map's ID, its geodetic data of the minimum and maximum coordinates and the physical map size is stored. By using the map's coordinates, the corresponding map contents can be obtained online with OpenStreetMap (OSM) [17] or by a cached version offline. In the latter case, additional annotations and multimedia content can be used in conjunction. Since touches are registered through the thin tactile map the user is able to explore it and to obtain audio information about map features. The user initiates commands by touch gestures (see Sect. 4).

4 Feasibility Study

To evaluate our approach, a feasibility study has been conducted. Using an existing approach [18], multiple tactile maps were generated and enriched by capacitive codes by using a free, open-source constructive solid modelling software OpenSCAD [19]. These maps were printed (see Fig. 1) by a dual-head 3D-printer (Velleman Vertex K8400) utilizing normal PLA (polylactic acid) and conductive filament (Trijexx Conductive). An Android application has been developed which is able to recognize the codes and uses the internal constant for pixel density the measure distances between points and the user interaction with the map. To encode the cylinders contacting the surface, a minimum distance of 5 mm between cylinders has been chosen. Both of the following two cylinders were able to be arranged in five different equidistant positions, which resulted in 25 combinations.

Because of the automatic recognition and detection of the arrangement, the users had to simply fix the map on the display by elastic straps or two short strips of adhesive tape. When the user touched the identification bar, the application first reported the scale of the map. When GPS coordinates were present, subsequently the distance and orientation of the map to the real world was reported. During the tactile exploration of the map, the users were able to obtain information about the map features a double tap (name of feature), a triple tap (type of feature) or a long press (names of surrounding map features).

5 Discussion and Future Work

This paper introduced a novel approach for 3D printing of tactile maps which can be recognized and augmented by audio descriptions through mobile devices. For the identification of the maps capacitive markers are used, which can be printed along with map content by our approach in a single turn. Compared to existing approaches of audio-tactile maps using microcapsular paper, this approach allows multiple height levels which can be used encode topological information into maps. CapMaps are recognized by mobile devices, such as tablets and smartphones which utilize capacitive touchscreens by a single touch on the map's corner. The maps do not have to be aligned in a specific way; their alignment is automatically detected by the capacitive markers.

This paper focused on the technical approach of linking physical tactile maps with tablets and smartphones. In our future work, we plan to carry out user studies about the impact and usability of the new possibilities of this approach for a dedicated paper. In particular, we investigate in which way the tactile maps of our portable approach have to be rendered, as well as how the interactive content should be ideally structured to support orientation and navigation tasks on site.

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