A Concept for Re-Useable Interactive Tactile Reliefs

Andreas Reichinger, Anton Fuhrmann, and Stefan Maierhofer,
and Werner Purgathofer

VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH,
Donau-City-Str. 1, 1220 Wien, Austria
http://www.vrvis.at/projects/ambavis
http://www.ambavis.eu

Abstract. We introduce a concept for a relief-printer, a novel production method for tactile reliefs, that allows to reproduce bas-reliefs of several centimeters height difference. In contrast to available methods, this printer will have a much smaller preparation time, and does not consume material nor produce waste, since it is based on a re-usable medium, suitable for temporary printouts. Second, we sketch a concept for the autonomous, interactive exploration of tactile reliefs, in the form of a gesture-controlled audio guide, based on recent depth cameras. Especially the combination of both approaches promises rapid tactile accessibility to 2.5D spatial information in a home or education setting, to on-line resources, or as a kiosk installation in museums.

Keywords: (e)Accessibility · Design for All · Blind People · Assistive Technology · HCI and Non Classical Interfaces · Tactile Models · 2.5D Reproduction · Interactive Audio Guide

1 Introduction and Related Work

Tactile models are an important tool for blind and visually impaired people to perceive images and objects that are otherwise incomprehensible for them. 3D tactile models (e.g. [8,10]) and 2.5D reliefs (e.g. [5,7]) offer even more possibilities than the more classic raised line drawings and tactile diagrams [2], as depth, 3D shape and surface textures are directly perceivable. However, such tools are more difficult to produce, require complex production machinery, consume material and are therefore more expensive. Further, production time is comparatively long, and once a model is no longer used, it still exists and needs to be stored, or, if no storage space is available, it has to be disposed of.

This is acceptable for permanent exhibitions, where models are presented over a long period and need to be especially durable. It is less acceptable for temporary exhibitions or when a large number of objects need to be made accessible. And, in a home setting, where a user wants to consume a lot of different materials, but only one at a time, it might be completely out of the scope.

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Therefore, we developed a concept and a first prototype of a novel temporary production method, a relief printer, that does not waste any material, creates the output in a comparatively small amount of time and still in a sufficient quality and size. With such a method, on demand production of touch reliefs will become possible, at home, but also in a museum or school setting.

The second point we target in this work, is the interactive exploration of such reliefs. Touch tools are difficult to understand without proper guidance. Introductory texts to the tactile piece together with the required background information and a description of the depicted objects are important, but often not sufficient. Typically, a blind person is guided by a trained guide who is prepared to answer questions to specific regions, or who can guide the hand to desired locations. But such a guide may not always be present, or a visually impaired person may want to explore the relief in a more autonomous way.

We sketch a concept of a touch-sensitive audio guide, capable of giving location specific information during tactile exploration. This is similar in spirit to a number of already established technologies: The Talking Tactile Tablet [6] operates with raised line graphics on top of a touch-sensitive device; Tooteko [1] is based on NFC tags integrated in 3D models and read by a wearable NFC reader; Talking pen devices[1] sense barely visible printed patterns with an integrated camera; Digital Touch Replicas [12] have touch sensors integrated in haptic exhibits; And, most recently, the colored tactile reliefs of *3DPhotoWorks*[2] feature infrared sensors, embedded at strategic points throughout the tactile art.

In contrast, our proposed method is based on recently developed depth cameras. It does not require sensors to be integrated into the models (as in [1,12] and 3DPhotoWorks) but operates with a depth camera placed over the object and observing the hands. In contrast to the Talking Tactile Tablet [6], it works on arbitrarily formed objects, and not only on thin sheets, and in contrast to talking pen devices it does not require printed patterns, that might be difficult to achieve on curved surfaces. This makes it especially suitable to operate on the introduced relief printer, where sensors cannot be placed inside the medium.

2 Conventional Production Methods

Typical production methods for tactile material include swelling paper [2] or Braille embossers in graphics mode[3]. The "Stiftplatte" [9], follows the same idea, but in an interactive form: It uses a technology similar to a Braille display, but arranged in a two-dimensional dense array, as an interactive computer interface. These methods have in common, that there is only a tiny amount of height variation, and therefore no real 3D surfaces are possible. Computer-aided

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[1] Multiple vendors offer talking pens, like the TalkingPEN (`http://www.talkingpen.co.uk`), Livescribe (`http://www.edlivescribe.com`) or Ravensburger tiptoi® (`http://www.tiptoi.com`).

[2] 3DPhotoWorks (`http://www.3dphotoworks.com`) recently created tactile reliefs for the exhibition "Sight Unseen" at the Canadian Museum of Human Rights.

[3] e.g. ViewPlus Braille Printers, `http://www.viewplus.com`.

production of tactile reliefs, with at least a few centimeters of height variation, is typically performed using subtractive or additive methods [8].

Models created with *subtractive* methods like CNC-milling have a high stability and can be created with a high surface quality. The process produces a large amount of dust, and therefore, a dedicated working place (i.e., a workshop) is required. In addition, a lot of material, energy and operating time is required.

On the other hand, *additive* production methods (widely known under the term 3D printing) offer a much cleaner way of production, suitable to be performed in an office setting. With most processes, no material is wasted, since only the amount of material is used that actually makes up the final output, but, material is still irretrievably used. Production times and costs depend strongly on the method, but are similar or even higher than with subtractive methods, and most methods create unwanted surface artifacts, like steps or ridges that are inherent to the method of material deposition. Further, some methods have a quite small build room, making it difficult to print reliefs of sufficient size.

3 Relief Printer Concept

Our idea is inspired by the concept of Ward Fleming's Pin-Art toy [3] (cf. Fig. 2b), which became famous in the 1980s. A large number of pins are arranged in a two-dimensional regular lattice. The pins may be shifted parallel to each other, and their heads form the relief surface of any object that has been pushed into the back of the toy. The relief can be viewed, as long as it is handled carefully to not move the pins by inertia or gravity. If no longer used, the pins can be shifted back, and the toy can be re-used for the next object to be depicted.

The relief printer concept extends this idea by three facets:

1. It is necessary to temporarily fixate the pins in their shifted position, in order to allow the relief to be touched and to be handled without the embossed surface being destroyed.
2. The pins need to be arranged much more closely in order to achieve a higher spatial resolution that is adequate for the resolution of human finger tips.
3. The pins shall be automatically shifted by a computer-controlled machine (the printer), which will allow the cost-efficient, fast, physical realization of digital 3D data.

Since the printing mechanics will be the most complex and expensive part, our concept is to separate the printing mechanics (i.e., the relief *printer*) from the pin array (i.e., the relief *medium*). In this way, multiple low-cost relief media can be used with the same relief printer, similar to a conventional document printer that may be used to print on multiple sheets of paper.

The workflow may be as follows (cf. Fig. 1): a) The medium is reset by moving the pins into their home position. b1) The medium is inserted into the printer, the printer shifts the pins according to a digital model. d) The medium is set to a locked position in which the pins are fixed to withstand touching. h) Once it is no longer used the medium may be set back to the write position, the pins

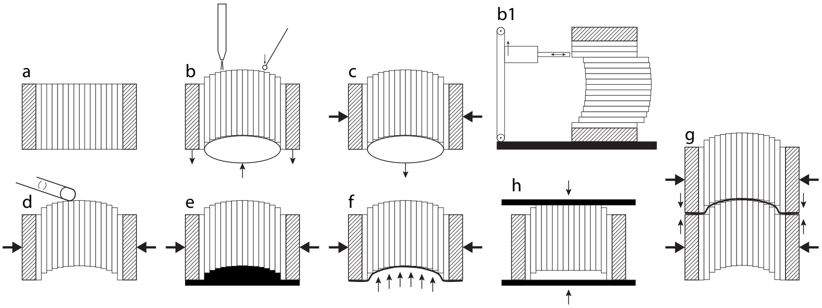

Fig. 1. Life cycle and usage possibilities of the relief printer medium (see text)

pushed back and the cycle starts again. b) Alternatively, it can be used to cast an existing object with different tools or compressed air.

Multiple reliefs may be used simultaneously when printed in advance, or one relief may be touched while the other is being printed. It may even be possible to use the medium as a casting mold e), as die for a press g), or as die for thermoforming of plastic sheets f) to create durable reliefs without the need to create a master form as with conventional methods.

4 Relief Medium Prototype

The goal of the present work is not a market-ready device, but, as a first phase, a working prototype of the relief medium. Only after a successful evaluation of its usefulness, and a thorough study of its properties, the printer may be developed in a following phase.

In a recent work [4] a real-time changeable relief with 30×30 square pins arranged in an orthogonal lattice with a total of 900 actuators was presented. The pins have a side length of 9.525 mm and an inter-pin spacing of 3.175 mm, giving 12.7 mm per pin, which is way too large for our purpose.

The medium as we envision it, trades resolution for speed. Tactile exploration takes time, and therefore build times of tens of minutes are still acceptable.

Literature using the *grating orientation task* suggest, that the sensor density at the finger tips is at least below 2 mm, and seems to be significantly smaller for blind Braille readers, e.g., 1.04 mm on average of 15 tested blind Braille readers for their self-reported dominant reading finger [11]. These tests however underestimate the actually perceivable resolution, since these are performed with a static, non-moving finger, touching top-down. A moving finger may detect even smaller features, and especially on steep edges, where the side walls of the pins can be felt, jagged lines may appear, which become less apparent with smaller pin sizes. The theoretical optimum is therefore definitely below 1 mm pin diameter, and is more or less dictated by the technical possibilities.

The need for a high resolution is especially visible in Fig. 2b, where we first tried to approximate a relief with the Pin-Art toy. The average pin distance of

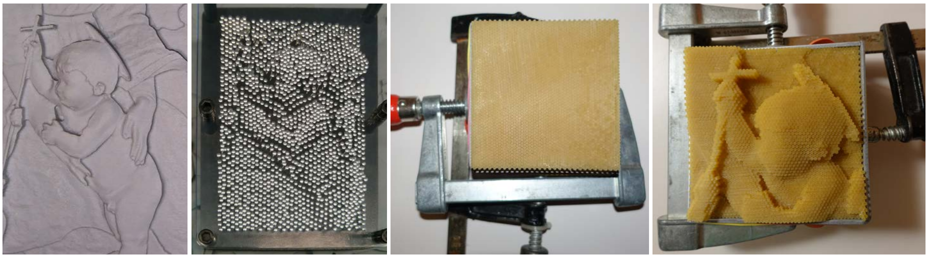

Fig. 2. Experiments with an earlier relief from our lab [7]. From left to right: a) Part of original relief; b) Embossed in Pin-Art toy; c) First prototype, 3038 pins, ∅ 1.75 mm, 89×88 mm, clamped tight and sanded flat; d) Relief embossed in our first prototype

3.27 mm renders the relief almost unrecognizable. This gets even more difficult, as each metal pin is mounted in a guiding hole in which it can wobble side to side. The guiding holes ensure that the pins slide easily and do not influence each other. In our application, this is however not a concern, as long as the printing device ensures the separation during pin movement, for which we already have a concept in mind. Moreover, the guiding holes restrict the achievable resolution, and the separated pins are prone to bend during tactile exploration.

Our solution is a tight arrangement of the pins as depicted in Fig. 2c and d. We use off-the-shelf uncooked cylindrical Spaghetti noodles[4] arranged in the natural hexagonal lattice, arising from the closest packing of circles. Therefore, this arrangement yields the highest attainable information density for a given pin diameter. Once built, the arrangement is stable as each pin is guided and supported by the surrounding pins, and may slide with small force.

However, the arrangement of the pins in an exact lattice is not easily achieved nor maintained. Similar to atoms in a crystal, random arrangement of the lightweight pins leads to lattice defects, e.g., vacant or dislocated pins, stacking faults or grain boundaries between regions of locally rotated lattices, which compromise the stability if the arrangement as some pins at the defects are no longer fully surrounded and are prone to falling out. We solved this by using a frame made from two L-shaped parts held together with rubber bands that exert a sufficient amount of pressure on the arrangement, and manual correction of lattice defects.

Our solution to fix the pins for tactile exploration (cf. Fig. 1d) is to increase the pressure on the frame. It distributes evenly in the lattice and increases the pressure between all pairs of pins, increasing the static friction until an almost hard surface is achieved. We use two clamps to increase the pressure. After sanding the pins to the same length, the same part of the existing relief was embossed (cf. Fig. 2d), with a noticeable increase in surface quality.

The first prototype already surpassed all expectations in a first evaluation with 7 blind and visually impaired persons. Most of them could get a sense of

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[4] Spaghetti noodles turned out to be a useful material, being very exact, hard, easy to acquire, low-cost and environmentally friendly, but are a bit brittle and sensitive to moisture and dirt. Further materials should be investigated in the future.

the depicted shape, but noted the much rougher surface than with the original relief, and the wish for a larger model.

5 Touch-Sensitive Audio Guide

As outlined in Sect. 1, we intend to develop a gesture-controlled audio guide, based on optical finger tracking, as no sensors can be integrated into the reconfigurable pin array. The idea is to place a depth camera over the relief, which performs a foreground separation from the static background (desk, relief,...), detects the hands and fingers, and classifies certain gestures. Possibilities are gestures in mid-air for selection of different interaction modes or a menu-like navigation, and gestures on the relief or surrounding objects or buttons like a touch gesture with a single finger in order to trigger location specific audio.

As this part is still work in progress, we comment on our already performed comparison of currently available depth camera sensors, and the selection of the *Intel RealSense F200* as the currently best suitable camera for our purpose.

5.1 Requirements on the Tracking Camera

The optimum would be an out-of-the-box solution for articulated finger tracking, on relief surfaces. The working area needs to be at least as large as the relief, plus some surrounding to still detect the full hand when interacting on the borders or outside touch areas. The users will mostly interact near the surface of the relief, but may also perform some gestures above the relief. The track-able working volume should therefore be at least 50×50 cm and 25 cm high, best observed from above or diagonally behind the relief to not disturb the user.

The sensors need to reliably distinguish the fingers from the relief surface, even if the relief is touched. They need to have a small enough error in the depth measurements, and low enough noise to allow reliable separation of the fingers from the background in order to detect touch events. In addition, the spatial resolution of the sensors needs to be high enough to be able to distinguish touch events between the different, often small areas in a tactile relief.

5.2 Camera Selection

Leap Motion, specifically designed for articulated hand tracking, only works mid-air, and not when the hand is on or near objects.

The *Microsoft Kinect for XBOX 360* and the re-packaged variants *Kinect for Windows*, *ASUS Xtion*, *Structure sensor*, and *PrimeSense Carmine 1.08* share the same hardware, and have a rather low effective depth resolution of probably 320×240 pixels or even lower[5], and a minimum distance from the camera of 80 cm. Together with the required 25 cm high working volume and its wide field-of-view this results in at least 3.5 mm per pixel at the relief distance, quite low

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[5] Andreas Reichinger, Kinect Pattern Uncovered. http://azttm.wordpress.com/2011/04/03/kinect-pattern-uncovered. Accessed March 2015.

for reliable finger detection, even in special *near modes* of newer models. The updated sensor of the *PrimeSense Carmine 1.09* might be better suited, but this device is no longer available after PrimeSense's acquisition by Apple.

Time-of-flight sensors like the *SoftKinetic DS325*, *Creative Senz3D*, *Kinect for Xbox One*, *Kinect for Windows V2*, and various sensors of *pmd Technologies* generally have a larger noise level in the depth measurements. Although this gets better in newer variants, we deem it still too large for our purpose.

Intel's RealSense product line has currently two depth sensors, with the *F200* as the near-field model (0.2–1.2 m), featuring full 640×480 resolution, lots of adjustment possibilities and a quite low noise level. In terms of quality and range, the *Intel RealSense F200* seems to be the most suitable device for our purpose on the current market, although the bundled finger tracking solution does not work on surfaces, and we will have to implement our own.

The former company *3Gear Systems* developed an articulated hand tracking software working with different depth cameras, even with the fingers on a planar surface like a desk. However, since their acquisition by *Oculus*, the software is no longer available. On the other hand, fully articulated hand tracking might not be necessary for our purpose, and we will concentrate on a simpler approach.

6 Conclusion and Future Work

We developed a concept and presented a first prototype of a novel relief printing method that allows to print temporary tactile reliefs in a relatively short amount of time into an erasable and re-usable relief medium, without wasting any material. This concept is complemented by a touch-sensitive audio guide based on finger tracking with a state-of-the-art depth camera. This may enable or improve the autonomous exploration of printed reliefs or other tactile models. It may help naming and differentiating different parts of the relief, and may enrich the exploration by valuable background information, or targeted guidance.

We believe, that the presented new relief production method can immensely drop the production costs for tactile materials in museums or schools. Institutions may not need to produce tactile materials in advance, but can print the reliefs on demand and may recycle them when no longer needed (e.g. reliefs for pupils for today's topic). It could be implemented as an interactive kiosk in a museum, or allow individuals to afford such a printing device. It can enhance home education for visually impaired people, or may even be useful for various 3D design and visualization studies in a broader context.

Although this work originated from research in the context of blind and visually impaired people, this work may be seen in a broader *design for all* context. Tactile Reliefs and the interactivity may be suitable for people with learning disorders or attention deficiencies, and may be interesting for everyone.

The next steps will be the realization of a larger relief medium with even thinner pins to further increase the resolution, the implementation of the gesture-based audio guide and a formal evaluation to plan further developments.

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