Towards Rapid Fabrication of Custom Tactile Surface Indicators for Indoor Navigation

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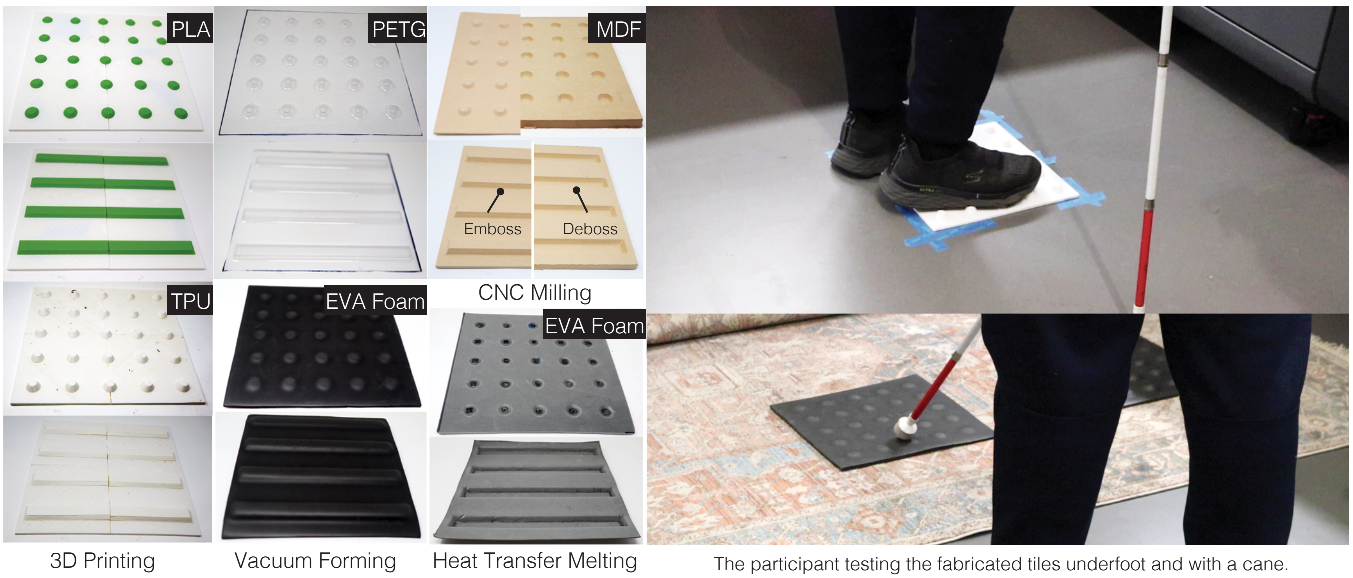

Figure 1: Samples of tactile surface indicators (TSIs) created via rapid prototyping methods (left) such as 3D printing, vacuum forming, CNC milling, and heat transfer melting—(right) which were evaluated through a qualitative study with a blind cane user to validate their tactile saliency as well as an O&M specialist.

Abstract

Tactile surface indicators (TSIs) provide ground-based tactile cues to help pedestrians who are blind or low-vision safely and independently navigate different environments. For example, TSIs can serve as warnings for hazards (*e.g.,* edge of a subway platforms) and directional guides (*e.g.,* a route through a mall). In this exploratory work, we examine how digital fabrication technologies such as 3D printing, CNC milling, vacuum forming, and heat transfer melting can enable the production of custom TSIs. To compare different fabrication approaches, we designed and evaluated a series of prototypes with varied surface materials and design features (*e.g.,* bump height). We then solicited feedback on our ideas and fabricated TSIS via two initial qualitative evaluations: one with a blind cane user and another with an Orientation and Mobility (O&M) specialist. Our initial findings demonstrate that digital fabrication processes—primarily 3D printing and CNC milling—can produce salient and useful TSIs, and indicate interest in our approach and how highly customized, rapidly fabricable TSIs could support navigation in reconfigurable indoor spaces.

CCS Concepts

• **Human-centered computing** → **Accessibility**.

Keywords

Tactile surface indicators, detectable warning surfaces, digital fabrication, 3D printing, blind and low vision

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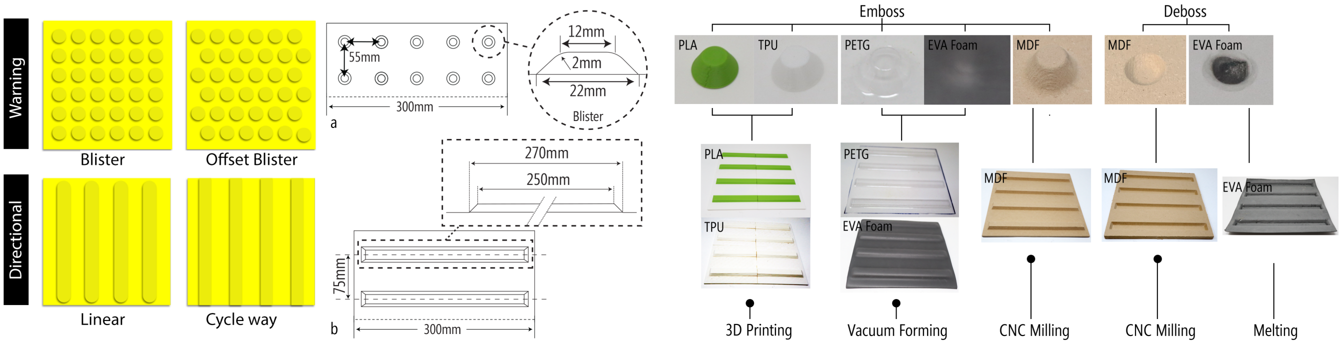

Figure 2: The standard tactile surface indicator designs for the warning (truncated domes) and directional guides (rectangular bars). Diagram showing the dimensions and spacing of the bars and blister designs (middle). Detailed prototypes (left to right): 3D printing, vacuum forming, CNC milling, and melting and varied design elements—embossed and debossed features (right).

1 Introduction

Tactile surface indicators (TSIs) serve as warnings, directional guides, and markers to entrances and intersections to help blind or low-vision (BLV) people navigate the environment safely and effectively [9, 17, 25]. TSIs commonly consist of a series of raised blisters or bars arranged in a repeating pattern and are installed on the ground at specific locations like curbs, train platforms, and elevator entrances [25]. Cane users can use orientation and mobility (O&M) techniques, such as shorelining, to identify and follow an edge to guide their path [4, 23]. However, even with proper O&M training, BLV people face challenges in navigating indoor spaces due to a lack of tactile landmarks, especially in open spaces. Furthermore, the fabrication and installation of tactile surface indicators into an environment are costly, labor-intensive, and permanent [17]. This limits the ability to adapt and rearrange TSIs in places that often change layouts like conference halls, building atriums, and supermarkets [21, 24].

In this work, we begin to explore a vision for customizable and reconfigurable TSIs that would be suited for spaces that are continuously rearranged for new layouts and pedestrian flows. We examine how emerging fabrication techniques—3D printing, CNC milling, vacuum forming, and heat transfer melting—can be used to produce tactile surface indicators adapted for existing environments and rearranged for multi-purpose spaces like conference halls and arenas. While prior work has explored ways of using digital fabrication processes to integrate electronics into tactile navigation tiles [20] or focused on new geometries for 3D printed tiles [22], we analyze several digital fabrication processes, surface materials, geometries, and patterns. We also examine the tactile saliency (how detectable the TSIs are underfoot and with a cane) of the prototypes through two qualitative studies with a blind participant and an O&M specialist, and discuss the possibilities of using digital fabrication techniques to make new TSIs that can better adapt to dynamic indoor environments.

In summary, this poster paper contributes a preliminary exploration of fabrication techniques suited to rapidly prototyping custom and reconfigurable TSIs towards expanding TSI deployments in evolving or changing indoor environments.

2 Related Work

Researchers have explored various ways of providing tactile and multi-modal feedback to support non-visual navigation for BLV people, including integrating robotics, computer vision, and haptics into assistive devices [2, 5, 11, 12, 19]. For example, Slade *et al.* proposed an augmented white cane that uses sonar, lidar, and accelerometer data to provide multi-modal sensory feedback like voice instructions and haptics [19]. However, these devices are not widely available, require additional training, and, critically, shift the burden to the user who has to equip themselves with more technology. An alternative approach is to instrument the environment instead of the user to provide navigation assistance [1, 6, 7, 10, 13]. For instance, Amemiya *et al.* embedded RFID tags into the floor that guide BLV pedestrians by triggering haptic feedback as they walk by the tags [1]. Recently, researchers also investigated using fabrication techniques to support the creation of custom TSIs [22]. For example, Swaminathan *et al.* used vacuum forming to design a TSI tile with an embedded pressure sensor and IoT device that could provide tactile directional information and trigger prerecorded audio messages [20]. We share the vision to augment the environment but focus on how digital fabrication tools could improve access to the already-known role of tactile surface indicators and allow for further adaptation and customization. We build on prior work to explore additional fabrication methods and dimensions, including surface materials, feature types, and pattern design.

3 Tactile Surface Indicator Prototypes

Despite the evolution of TSIs since they were invented in Japan in 1967, there are some fundamental design elements that remain unchanged. Principally, TSIs should be detectable underfoot and with a white cane, be easy to walk on, be visually salient for people with residual vision, and allow for a seamless continuation across adjoining tiles [3, 25]. Surface indicators have two primary functions: to warn about potential hazards and to provide directional guidance to reach a target destination [8]. While there is no unified design for TSIs, generally, truncated domes serve as warnings and elongated rectangular bars are used to indicate directional guides

(Figure 2). Several other design dimensions (*e.g.,* surface material, pattern design), however, remain open for experimentation.

Specifically, we varied several design dimensions—surface stability, material contrast, feature height, and feature geometry. There are two key material specifications for designing and making TSIs: surface stability and material contrast. Intuitively, surface indicators need to stay reliable for users to stand or walk on [3]. Previous work analyzing how users perceived TSIs shows that contrast is critical for distinguishing indicators from other floor surfaces [16]. For example, Kobayashi *et al.* demonstrated that pedestrians could adequately detect and use surfaces of different elasticities (softness) for navigation [14]. Furthermore, contrasting surface materials preserved cultural and aesthetic context in places like historic landmarks [15]. This suggests that surface stability and material contrast can be considered design dimensions for exploring new digital fabrication techniques. Besides surface materials, TSI form design, such as the shape, height, and pattern of the raised features, impacts the function, feel, and look to pedestrians [25]. We selected the common arrangement for truncated domes and the linear arrangement for the rectangular bars, but varied the feature height and adopted embossed and debossed patterns. Embossed features protrude upwards from a surface, resulting in a positive form and quicker production with additive methods. Conversely, debossed features are carved into a material to form a negative impression, which is better suited for subtractive manufacturing methods.

We created a series of prototypes to examine various TSI design dimensions afforded by four digital fabrication techniques—3D printing, CNC milling, vacuum forming, and heat transfer melting—that are well-suited to three-dimensional forms for a variety of TSI tile designs and materials (Figure 2). We used an *Ultimaker 3 Extended* 3D printer with polylactic acid (PLA) filament and thermoset polyurethane (TPU) to create rigid and soft TSI prototypes in four smaller parts that could be joined together to form a full-sized TSI. The CNC milling was done using a *Shopbot PRSalpha* with two-step milling operation for each tile: first, a roughing pass using a 6mm flat end mill to carve out the material, and then, a finishing pass using a 6mm ball-nose bit to smooth over the MDF TSI. Vacuum forming was done on a *Formech NewForm 16:16 former* with rigid polyethylene terephthalate glycol (PETG) and a soft ethyl-vinyl acetate (EVA) foam that was pulled over a CNC'ed positive of the TSI. Alternatively, researchers have also developed CNC heating elements to shape, form, and sculpt thermoset materials [18]. To emulate these machines, we applied high heat using a torch to a metal ball transfer and manually pressed it into soft foams using a TSI design template to leave a debossed impression on the surface.

In total, we created 20 prototype tactile surface indicators using 3D printing (two rigid and six soft tiles), CNC milling (four rigid tiles), vacuum forming (two rigid and four soft tiles), and heat transfer melting (two soft tiles) with feature heights of 5mm, 7.5mm and 10mm (shown in Figures 1 and 2).

4 Evaluation

We performed a two-stage evaluation of the prototypes: (1) an initial qualitative study with a Blind participant to validate TSI utility and salience; and (2) an interview with an O&M specialist to identify challenges and opportunities for digital fabricated TSIs.

4.1 Preliminary Qualitative Study

To solicit reactions and evaluate how different design dimensions impacted the perceived feelings of the TSIs (both to a cane and foot), we conducted a qualitative study with one Blind participant (Male, age 29). The participant used a white cane and reported moderate familiarity with using tactile surface indicators, although they have not previously received formal mobility and orientation training.

Procedure The study was composed of three sections where we examined: (i) height differences of tactile features in soft surfaces, (ii) material surfaces and surface contrast, and (iii) emboss/deboss features. Each section of the study involved an obstacle avoidance task to determine the saliency of the prototypes, followed by a debrief session where the participant described their experience with the tiles. The first section compared the soft 3D-printed and vacuum-formed tiles with varying heights. In the second section, we tested one rigid and one soft tile created with 3D printing and vacuum-formed tile, respectively. We also evaluated the importance of surface contrast by placing each set of tiles on a hard concrete floor and a soft rugged floor. In the last section, the embossed and debossed features using blister and bar-based tiles were created with CNC milling and heat transfer melting. Finally, we discussed with the participant about their experience with navigation aids and TSIs to identify opportunities to improve their designs.

Results The participant successfully avoided the obstacles, identified the surface indicator across the trials, and shared valuable insights for the design variables. First, the differences in height for soft materials were perceptible with the participant's cane and feet. The participant felt that the 10mm features for the soft tiles had a more distinct "cushion" feel than other heights. They noted, however, that taller features, especially if made with rigid materials, might present challenges for people with mobility disabilities. For surface contrast, the participant did not feel differences between the flooring and tile surfaces. They suggested that this would be heavily influenced by the type of tip they had on their white cane and the footwear they wore. For the emboss/deboss comparison, the participant could identify the feature shapes of the embossed "ridges" but struggled to feel the debossed "grooves". These results indicate that more work is needed to validate how to properly contrast surfaces but that soft TSIs can effectively be differentiated from stiff TSIs. Lastly, this evaluation also suggested that embossed features are a better design option for TSIs, but the height should not present obstacles for others.

Following the tasks, the participant commented that O&M training teaches the strategic use of TSIs to maximize their utility as navigation aids. Consequently, the participant suggested further evaluations of the prototypes with O&M training instructors to gauge how they would use the various designs in their teaching. The participant agreed that these custom TSIs created with fabrication techniques would be potentially beneficial and observed that TSIs are most useful when navigation is strongly goal-oriented instead of exploratory. The participant used a shopping center as an example where TSIs could help them find the location of a desired store or a desired area within a store. This indicates that the custom TSIs could also adapt to evolving navigation goals or desired routes, not just changes in the environment.

4.2 O&M Specialist Interview

Following our session with the blind participant, we conducted a one-hour semi-structured interview with an Orientation and Mobility specialist to solicit feedback on the prototypes and to discuss how digital fabrication could be used to support O&M training and tactile landmarks. The participant has taught orientation and mobility training for over 25 years and specializes in training for clients who are Deaf-Blind.

The participant expressed concerns about the durability of soft prototypes, noting that they would likely degrade over time, making the tactile patterns less discernible. In contrast, they highlighted that CNC-machined and 3D-printed prototypes exhibited superior qualities for tactile surface indicators, particularly in terms of feature height, geometry, and surface stability. The specialist emphasized the robustness of these materials, noting that their tactile patterns would be easily detectable with both a cane and underfoot. They also discussed the significant challenges that BLV individuals face when navigating open indoor spaces, underscoring the critical role of tactile feedback for Deaf-Blind individuals who cannot rely on auditory cues. Additionally, the participant dismissed the importance of personalization in tactile surface indicators, as they are intended to serve a broad range of BLV users. They also pointed out that cost and labor present significant barriers to retrofitting existing buildings with these indicators, which are typically integrated during the initial construction phase. Finally, the participant stressed that the lack of engagement with the BLV community during design and construction often leads to designs that fail to meet the needs of BLV users adequately.

5 Discussion

Our preliminary work suggests that digital fabrication can successfully produce TSIs in various materials and designs to aid non-visual navigation. This points to the possibility of creating custom TSI alternatives that can be adapted to dynamic and changing indoor environments. Our evaluation also reinforces the need for tactile landmarks to be carefully considered and deployed in indoor spaces to aid non-visual navigation. Digital fabrication could be a promising approach to expand access to TSIs by making them easier to retrofit and deploy in multi-use spaces like convention centers and indoor plazas.

While our work shows potential for making custom TSIs, there are several limitations in our exploration. First, we did not evaluate the durability which could be done by performing repeated stress tests, wear-and-tear experiments, and in-the-wild deployment. Moreover, the limited sample size of our evaluation makes it difficult to generalize our findings to generate design guidelines for new TSIs generated with digital fabrication tools.

In the future, we plan to (i) engage more accessibility and O&M experts in the design process, (ii) develop novel software and hardware tools to support the design and installation of custom, dynamic TSIs, and (iii) integrate multi-modal feedback (e.g., tactile and auditory cues) into custom TSIs. For example, we will explore embedding sensing capabilities that detect human touch or feet stepping on a TSI to provide relevant navigation information. We will build a design tool that allows users to design new patterns, customize parameters, and fabricate their desired TSI. Finally, we envision that mobile fabrication machines can be developed to fabricate and deploy the custom TSIs in situ directly into the environment.

6 Conclusion

In this paper, we presented an exploration of four digital fabrication processes to make tactile surface indicators. Digital fabrication tools would allow for customizable designs and patterns that could be retrofitted and adapted to indoor environments. Our evaluation showed that our prototypes were tactilely salient and that more work is needed to understand how to best make use of the materials and designs enabled by digital fabrication techniques. We believe that this exploration sets up future work on how to deploy and customize tactile surface indicators for multi-use indoor spaces, thus expanding access to a critical tool for BLV users to safely and independently navigate the environment.

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