An End-to-End Pipeline to Generate Augmented Tactile Maps from Floor Plans

Michelle Quach[1][0009-0008-8478-5189], James M. Coughlan[2][0000-0003-2775-4083],
Dragan Ahmetovic[3][0000-0001-5745-1230], Matteo Manzoni[3][0009-0002-1946-5919],
Sergio Mascetti[3][0000-0002-8416-4023], and Roberto Manduchi[1][0009-0007-9999-6360]

[1] Dept. of Computer Science and Engineering, UC Santa Cruz, CA 95064, USA
`mitquach@ucsc.edu, manduchi@ucsc.edu`
[2] Smith-Kettlewell Eye Research Institute, San Francisco, CA, USA
`coughlan@ski.org`
[3] Department of Computer Science, Università degli Studi di Milano, Milan, Italy
`dragan.ahmetovic@unimi.it`, `matteo.manzoni@unimi.it`,
`sergio.mascetti@unimi.it`

Abstract. This paper presents an end-to-end pipeline for transforming indoor floor plans into accessible tactile maps enriched with audio annotations. The approach integrates SIM (Semantic Interior Mapology), which allows authors to trace floor plans and assign semantic labels to relevant spatial features (e.g., rooms, corridors, restrooms, and stairs), with CamIO, a camera-based web application that delivers spoken feedback when users point to interactive regions (hotspots) on a tactile graphic. A pilot study with two blind participants and a follow-up study with five additional participants showed that users could successfully complete room-finding and route-tracing tasks and appreciated the system's support for spatial understanding. Usability evaluation yielded a mean SUS score of 77, indicating good usability, while NASA-TLX results showed a relatively low perceived workload, supporting the effectiveness of the proposed solution. Results also highlighted areas for improvement, including lower latency and clearer interaction around doors and small hotspots.

Keywords: tactile maps · audio augmentation · indoor accessibility · floor plans

1 Introduction

Tactile Maps (TMs) are often used by people who are Blind or have Low Vision (BLV) to access information about an environment and to orient themselves within it [2]. However, TMs need to be specifically designed to properly convey the environment layout tactually. This can be time-consuming and requires unique expertise. Additionally, TMs can contain only a limited amount of information due to the low spatial resolution of tactile sensing. Braille can supplement tactile elements with textual information, but space limitations typically restrict labels to short abbreviations, and many BLV people cannot read braille [15].

Several semi-automated TM creation systems have been proposed. For example, TMAP [11] is an online tool that allows to specify a urban area (*e.g.*, a city block), and generate a TM using OpenStreetMaps data. SIM (Semantic Interior Mapology) [13] similarly allows one to create indoor environment TMs from floor plans. Various techniques exist to augment tactile exploration with additional information provided through various feedback modalities, and in particular speech [4, 10, 12, 17]. For example, CamIO [1] is a web app that identifies touch interactions on a TM using a video camera and produces verbal feedback based on text annotations associated with the touched map location.

In this work, we propose a new end-to-end pipeline to generate SIM TMs and the associated CamIO map annotations, which can then be used to augment the produced TMs. Specifically, while authoring SIM maps, users assign names and attributes to spaces such as rooms, corridors, and hallways, which are then used to automatically generate CamIO annotations.

We conducted a pilot study with two blind participants who explored two TMs produced with SIM and augmented through CamIO. A follow-up study was then conducted with an additional five participants who received training on one TM and explored three additional TMs. The studies show that participants were able to complete the proposed tasks and found the system useful for understanding the spatial layout of the rooms, while also providing insights for further improvements to the system.

2 State of the Art

Tactile graphics and TMs can serve as spatial learning tools across a wide range of applications, including learning basic geometric primitives, exploring the shapes of stylized objects, examining geographic maps, and becoming familiar with the layout of a building prior to visiting it. Traditionally, TMs are created individually by expert designers [5]. In order to reduce the authoring cost and expand the availability of TMs, various mechanisms for automatic map production have been proposed. For outdoor maps, spatial information can be sourced from geographical information systems (GIS) such as OpenStreetMap [14, 6, 11]. For indoor spaces, existing floor plans can be converted to a format that is amenable to printing on swell paper or embossing [9]. For example, SIM[4] [13] is a web app that allows one to quickly trace an existing floor plan image (Figure 2a), generating a TM image which can then be printed (Figure 2c).

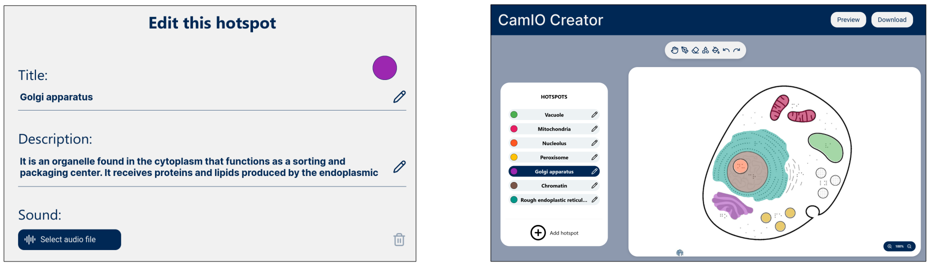
Various approaches have been proposed for augmenting tactile graphics and TMs to provide additional feedback based on where the user is touching [4, 10, 12, 17]. For instance, the T3 Tactile Tablet[5] is a proprietary tablet device that allows users to place a tactile graphic on its surface. The tablet's touchscreen detects where the user is touching, and the system plays audio feedback corresponding to that location. Other approaches, based on computer vision, detect where the user is pointing using webcams [12] or a smartphone camera [4, 17]. For

---

[4] SIM is publicly available at: https://sim.acad.ucsc.edu

[5] https://www.touchgraphics.com/store/p/t3-tactile-tablet

example, CamIO[6] [1] is a web-based application that runs on most desktop and mobile devices equipped with a web browser and a camera. It allows users to frame a previously annotated tactile graphic using their device's camera and receive verbal feedback on the elements they explore. The annotation process, supported by the CamIO-Creator web application (Figure 1), allows interactive elements (called hotspots) to be defined, providing their names and descriptions (Figure 1a), and the corresponding areas on the tactile graphics (Figure 1b).



Edit this hotspot

Title:
Golgi apparatus

Description:
It is an organelle found in the cytoplasm that functions as a sorting and packaging center. It receives proteins and lipids produced by the endoplasmic

Sound:

(a) Name and description of an element (b) Hotspots of the tactile graphics

Fig. 1: Annotation of a cell figure using CamIO-Creator[6].

In place of tactile graphics, some solutions use a Refreshable Tactile Display (RTD), representing content through an array of tactile pins that can be raised or lowered [16]. Touch-sensitive RTDs can support augmentation based on the touched location [18]. However, refreshable tactile displays are still not widespread; they are expensive and have limited resolution [18].

3 Methodology

3.1 CamIO Tactile Graphics Annotations

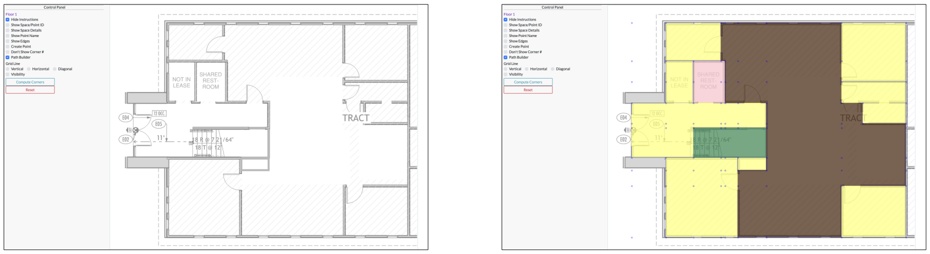
CamIO tactile graphics annotations, produced using CamIO-Creator (Figure 1), are saved in a *.camio* file, which is loaded into the CamIO web app for exploration. This file comprises three components: (1) a scan of the tactile graphic, used by CamIO to identify it in the camera feed; (2) a color map in which each hotspot area is annotated with a unique color (Figure 1b); and (3) the list of the hotspots, each with its name, description, and the color used to mark it in the color map. During exploration, CamIO continuously localizes the tactile graphic within the camera frame and detects the user's pointing gesture. Thus, the system naturally compensates for any shift in the position of the graphic, the camera, or the user's hand, without requiring explicit recalibration. When a pointing gesture is detected, CamIO determines the hotspot indicated (if any) through the color map and reads aloud the associated text. To ensure hotspots are clearly distinguishable, we empirically determined a minimum size of 1cm.

---

[6] CamIO is publicly available at: https://develop.ewlab.di.unimi.it/camio

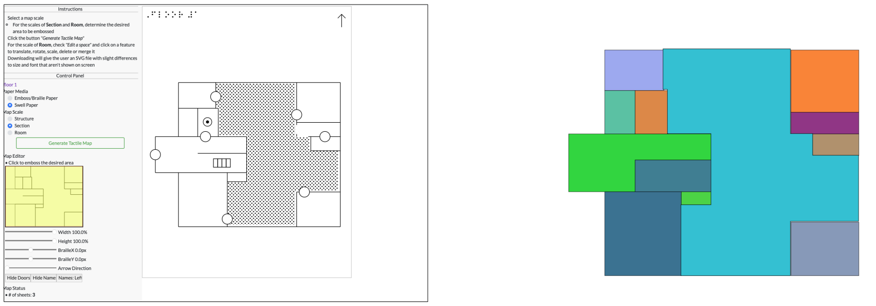
3.2 Generating Tactile Maps and CamIO Annotations with SIM

SIM represents maps using a planar *primal* graph and its *dual* multigraph. The vertices of the planar graph represent wall junctions in the floor plans, while edges are walls. Openings (doors) are represented as attributes of the graph edges. The faces of this planar graph represent *spaces* (typically, rooms or hallways), and form the vertices of the dual multigraph, which can be annotated with space type and space ID. The edges of this multigraph are the walls separating adjacent spaces. Thus, the primal graph can be used to draw the map, while its dual is useful to create traversable routes between spaces. As an example, the floor plan in Figure 2a is traced as shown in Figure 2b. Different colors indicate different space types (rooms, hallways, staircases, bathrooms). From the primal graph, SIM automatically generates a TM at the desired scale (Fig. 2c). In the current version, the TM shows walls as lines, hallway surfaces with a regular texture, and uses specific symbols for space types such as bathrooms, staircases, or elevators. Doors are displayed as circles when there is enough space, otherwise as gaps in the wall.



(a) A floor plan loaded in SIM

(b) Spaces obtained by tracing the floor plan



(c) Automatically generated tactile map

(d) Color image annotation for CamIO

Fig. 2: Creation of a TM and CamIO annotation from a floorplan using SIM[4].

CamIO annotations are generated using information from the dual graph (Fig. 2d). The CamIO color map is created where each space (vertex of the dual graph) represents a hotspot. Likewise, information about each hotspot (listed in a JSON file) is sourced directly from the space annotations in the dual graph. Note that doors and openings do not have an associated hotspot, as users can easily perceive their presence via the corresponding tactile symbol.

4 Results

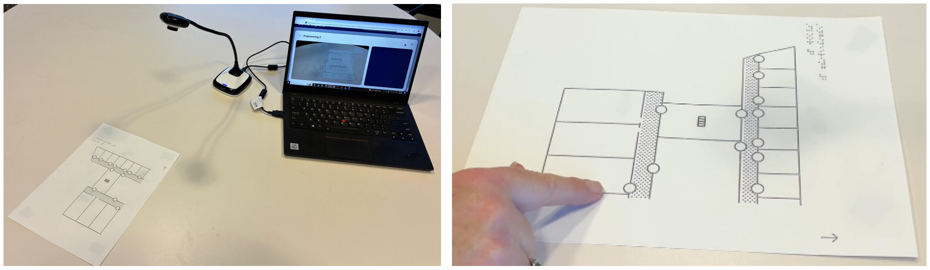
4.1 Study Design

A pilot study was conducted with two participants (**P1** and **P2**, Table 1) to test the feasibility of integrating SIM and CamIO in a form that is usable to BLV individuals. In this study, two floor plans were created with SIM and rendered as TMs on swell paper using a ZyFuse machine. Corridors and other walkable areas were marked with a distinctive tactile dot pattern, and each door was indicated by a tactile circle whose diameter matched the door's width. Floor plans were also automatically converted to CamIO format, but with manual hotspot annotations to specify unique names for each room. The experimenter ran CamIO on a Windows laptop with an external document webcam positioned to capture a clear view of each tactile graphic, which was secured to a table using tape. Participants were first instructed how to activate hotspots by making a pointing gesture, with the index finger pointing straight and the other fingers curled into a fist (see setup and pointing gesture in Figure 3.) The study was organized into three tasks. First, participants were given the names of 3 rooms on the map and were asked to locate them. Then, given the names of two distinct rooms on the map, they were asked to trace a walking path from the first room to the second. During this task, participants were instructed to enter and exit each room through its designated entrance or exit door. Finally, participants had to trace the border of a specific room.

Next, a follow-up study was carried out with five participants (**P3-P7**, Table 1). Compared to the preliminary study, the main differences included the addition of a short training session with one TM, testing on three additional TMs, and the inclusion of SUS [3] and NASA-TLX [7] questionnaires, as well as a semi-structured interview. The testing on each TM was the same as in the pilot study, except with an additional task in which the participant was asked to find the room number corresponding to a specific name (the room number was the CamIO name of the room and the occupant name was its CamIO description).

Table 1: Participants' demographic data.

ID	**Age**	**Gender**	**Disability**			**Expertise**	
			Type	**Onset**	**Forms/Light**	**Braille**	**Tactile Graphics**
P1	53	M	Cortical impairment	Birth	Both	None	Low
P2	47	F	Optic atrophy	Birth	Both	High	Medium
P3	40	F	ROP	Birth	No	High	High
P4	39	M	Congenital Lieber's	Birth	Light	High	Mid
P5	78	F	ROP	Birth	Forms	High	Low
P6	36	M	LHON (Leber)	14 y	Both	High	Mid
P7	24	F	Scelero cornea	Birth	Light	Mid	Mid



(a) Setup showing webcam, TM and laptop (b) Participant making a pointing gesture on the TM

Fig. 3: Experimental setting and interaction.

4.2 Study results

In the pilot study, both participants **P1** and **P2** successfully completed the first and third tasks. For the second task, participants succeeded when using the TM with larger door symbols (due to the map's larger spatial scale), but experienced difficulties locating the door symbols in the other TM.

In response to this issue, a uniform sized door symbol was used in all the maps in the follow-up study, which also included an additional map used solely for a brief training period at the beginning of the experiment. All five participants completed the tasks successfully, with one exception: **P3** was unable to find the room occupied by a specified person for one map, likely because this room was significantly smaller than the others on the map, preventing the participant from triggering its hotspot.

Many positive aspects of the system were noted, including the opportunity to understand the rooms' spatial layout, the information contained in the tactile features and the usefulness of the audio feedback for interpreting the TMs without the need to read braille. Participants also highlighted several areas for improvement: (a) the need for lower latency in hotspot announcements; (b) confusion about audio feedback when the finger points directly on a wall, which can unpredictably trigger the hotspot on either side of the wall; (c) the desire to elicit feedback with a special gesture such as a double tap, to enable silent exploration with one pointing finger (since some participants primarily use their index finger to explore a tactile map); (d) the system should indicate when their fingertip was pointing outside the map; and (e) sometimes the hand tracking algorithm was confused by the presence of two hands simultaneously visible to the camera. When asked how they might use the system in real life, participants expressed interest in using it to preview grocery stores and other shopping areas, medical office buildings, sports arenas, airports and other unfamiliar areas; **P5** suggested using it to find a walking route to a desired destination in a building with many offices.

System usability was overall positive, with a mean SUS score of 77.0 ± 14.83, corresponding to a B grade (70–79th percentile) according to established benchmarks. Item-level results show generally high usability, with the highest-rated questions being **Q1** (4.0 ± 1.22), **Q4** (1.4 ± 0.89), **Q5** (4.4 ± 0.89), and **Q9** (4.8 ± 0.45), suggesting strong willingness to use the system, low need for support, good integration of functionalities, and high user confidence. Lower scores were reported for **Q6** (2.4 ± 1.34) and **Q7** (3.6 ± 1.14), suggesting and a step learning curve to use the system. Overall, results are above the average SUS benchmark and fall within the "good" usability range.

Perceived workload was overall moderate, with a mean NASA-TLX score of 25 ± 14.62. Considering benchmark values for special-needs user studies, this corresponds to a relatively low workload compared to typical accessibility-related tasks reported in the literature [8]. Among subscales, mental demand (46 ± 25.35) and effort (44 ± 34.17) were the highest contributors, followed by physical demand (21 ± 30.29). Temporal demand (13 ± 13.04), perceived performance (13 ± 5.70), and frustration (13 ± 9.08) remained low, indicating limited negative affect and a generally manageable task experience.

5 Conclusions and Future Work

This work introduced an end-to-end pipeline for generating tactile maps from indoor floor plans, enriched with audio annotations through the integration of SIM and CamIO. The proposed approach reduces the effort required to create accessible maps while enabling richer, multimodal exploration for blind and low vision users. User studies demonstrated that participants could effectively perform spatial tasks and reported good usability and low workload, highlighting the potential of the system to support spatial understanding without relying on braille. At the same time, the findings revealed areas for improvement, including reducing audio feedback latency, refining interaction near walls and doors, and improving hotspot accessibility at small scales.

Future work will focus on addressing the issues identified in this evaluation, as well as exploring the integration of a large language model to complement tactile exploration and audio feedback with natural voice interaction.

Acknowledgments. We thank Dr. Nasif Zaman for valuable suggestions about the experimental protocol and help preparing the experimental materials.

Research reported in this article was supported by the National Eye Institute of the National Institutes of Health (NIH) under awards 2R01EY025332 and R01EY035433, by the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) under Grant 90REGE0018, and by The Smith-Kettlewell Eye Research Institute. The content is solely the responsibility of the authors and does not necessarily represent the official views of NIH or NIDILRR.

Bibliography

[1] D. Ahmetovic, J. Coughlan, G. Dal Santo, K. Ezrouri, M. Manzoni, and S. Mascetti. Camio in the browser: A cross-platform audio label tool for tactile graphics. In *Int. C. on Mobile Human-Computer Interaction*, 2025.

[2] B. L. Bentzen. Orientation maps for visually impaired persons. *J. of visual impairment & Blindness*, 1977.

[3] J. Brooke et al. Sus-a quick and dirty usability scale. *Usability evaluation in industry*, 1996.

[4] J. M. Coughlan, H. Shen, and B. Biggs. Towards accessible audio labeling of 3D objects. In *J. on technology and persons with disabilities*. CSUN, 2020.

[5] P. Edman. *Tactile graphics*. AFB, 1992.

[6] T. Götzelmann. Visually augmented audio-tactile graphics for visually impaired people. *ACM T. on Accessible Computing*, 2018.

[7] S. G. Hart. Nasa-task load index (nasa-tlx); 20 years later. *Proc. of the Human Factors and Ergonom. Society Annual Meeting*, 50(9):904–908, 2006.

[8] M. Hertzum. Reference values and subscale patterns for the task load index (TLX): a meta-analytic review. *Ergonomics*, 64(7):869–878, 2021.

[9] A. Madugalla, K. Marriott, S. Marinai, S. Capobianco, and C. Goncu. Creating accessible online floor plans for visually impaired readers. *ACM T. on Accessible Computing*, 2020.

[10] M. Manzoni, S. Mascetti, D. Ahmetovic, R. Crabb, and J. Coughlan. Mapio: A gestural and conversational interface for tactile maps. *IEEE Access*, 2025.

[11] J. A. Miele, S. Landau, and D. Gilden. Talking tmap: Automated generation of audio-tactile maps using smith-kettlewell's tmap software. *British J. of Visual Impairment*, 2006.

[12] L. Shi, Y. Zhao, and S. Azenkot. Markit and talkit: a low-barrier toolkit to augment 3d printed models with audio annotations. In *Annual ACM S. on User Interface Software and Technology*, 2017.

[13] V. Trinh, R. Manduchi, and N. A. Giudice. Experimental evaluation of multi-scale tactile maps created with sim, a web app for indoor map authoring. *ACM T. on Accessible Computing*, 2023.

[14] T. Watanabe, T. Yamaguchi, S. Koda, and K. Minatani. Tactile map automated creation system using openstreetmap. In *Int. C. on Computers Helping People with Special Needs*. Springer, 2014.

[15] J. Wiazowski. Can braille be revived? a possible impact of high-end braille and mainstream technology on the revival of tactile literacy medium. *Assistive Technology*, 2014.

[16] W. Yang, J. Huang, R. Wang, W. Zhang, H. Liu, and J. Xiao. A survey on tactile displays for visually impaired people. *T. on Haptics*, 2021.

[17] M. Zeinullin and M. Hersh. Tactile audio responsive intelligent system. *IEEE Access*, 2022.

[18] L. Zeng and G. Weber. The overview of haptic displays. In *Advancements in Pin-Array Tactile Displays: Designing Multimodal User Interfaces for Braille and Graphics*. Springer, 2025.