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Review and Research Perspectives on the Development of Tactile Maps for the Visually Blind Community

Huitao Ma [a,b], Xi Tang [a,b,c]*

[a] *School of Geographic Science, East China Normal University, Shanghai, China. 51263901092@stu.ecnu.edu.cn, xtang@geo.ecnu.edu.cn*
[b] *Institute of Cartography, East China Normal University, Shanghai, China. 51263901092@stu.ecnu.edu.cn, xtang@geo.ecnu.edu.cn*
[c] *Key Laboratory of Geographical Information Science, Ministry of Education, Shanghai, China. xtang@geo.ecnu.edu.cn*

* Corresponding author

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Abstract:

People's cognition of the world mostly relies on vision. In contrast, blind people cannot use adequate visual perception to comprehensively understand the world, which makes them face great challenges in wayfinding, spatial orientation, and building mental maps. With the rapid development of communication and geographic information technologies, digital navigation maps have become indispensable tools in daily life. However, these products usually rely on visual interfaces for information interaction, making them unsuitable for the specific needs of blind users. Even with voice-assisted guidance, the spatial impressions created are often fleeting. For a long time, tactile maps have served as an alternative, enabling visually impaired individuals to achieve limited spatial cognition by turning information into tactile signals. However, the inherent analog medium of tactile maps prevents them from providing real-time and portable services, and their integration with digital maps remains challenging. In recent years, barrier-free cartography has become a focal point, emphasizing the need for mapping tools to minimize usage barriers for disadvantaged groups, which is also in line with the United Nations Sustainable Development Goal of "Leaving No One Behind". As a typical example of barrier-free cartographic products, tactile maps require a systematic revaluation of their development trajectory and potential.

Tactile maps communicate spatial information through tactile symbols, such as raised textures and Braille labels. The primary characteristics of tactile maps can be summarized in four points (Woolmington, 1976): (1) **Fragmented**: reducing cognitive load through dividing spatial information into smaller parts (e.g., local area segmentation); (2) **Augmented**: improving perception efficiency by integrating multimodal interactions (e.g., touch–sound interaction), such as using vibrations to indicate dangerous areas (Griffin et al., 2020); (3) **Schematized**: simplifying complex features with standardized symbols, for example, setting up a system of symbols with raised lines to represent roads (Lobben, 2015); (4) **Distorted representations**: adapting to tactile resolution restrictions by exaggerating essential feature proportions and simplifying geometry, as proposed by Yayla (2009) for scaled maps. Previous studies have focused on the technical implementation and cognitive adaptation of tactile maps: Traditional tactile maps often rely on manual carving or thermoforming techniques (e.g., microcapsule paper embossing), which involve long production cycles and difficulties in updating, while the introduction of 3D printing and automation technologies has significantly improved map accuracy and customization potential (Taylor et al., 2016); multi-sensory design has been shown to effective in reducing users' cognitive load (Griffin et al., 2020), and dynamic haptic interaction systems (e.g., Touch Explorer, Darvishy et al., 2020) have attempted to overcome the limitations of static maps by providing real-time speech feedback. However, current research on tactile mapping still faces three key bottlenecks: (1) **Insufficient involvement of blind users:** most studies have not systematically integrated their cognitive strategies and real needs; (2) **Lack of standardized symbols**: variations in symbol design across studies require users to repeat the learning process for each system; (3) **Inadequate integration of dynamic information**: current technologies struggle to synchronize real-time data updates and tactile rendering.

To this end, we reviewed and summarized the research progress of tactile maps for blind individuals, focusing on six key aspects: tactile cartographic technology evolution, information representation and perception, education and social applications, navigation and positioning support, automated and intelligent generation, and personalized customization. We proposed some ideas as follows: (1) The production techniques for tactile maps have evolved from traditional methods to modern 3D printing technology. The precision, durability, and customizability of 3D printing make it the most promising tool for real-time map generation. (2) Effective information representation and user perception in tactile maps remain key issues in this field. Users' particularity requires the cartographer to fully understand its spatial information processing strategy and, based on this, to clarify the principles for generalizing and transforming map elements to reduce

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cognitive load effectively. (3) Regarding education and social application, the accessibility and inclusiveness of tactile maps require further promotion. Awareness and coordinated efforts by governments, institutions, and other stakeholders in policies, technologies, and resources are essential to overcoming these barriers. (4) Integration with navigation systems is a cutting-edge direction, requiring breakthroughs in the conversion and coordination of digital and analog signals. (5) Advances in automation technology and artificial intelligence are promising to significantly improve tactile map generation efficiency and accuracy. (6) As the real users of tactile maps, the visually blind group should be more involved in the production process. Meanwhile, personalized design should be put on the research agenda so that tactile maps could offer diverse services to a broader audience.

Based on the above overview of research progress, we also explored the current technical bottlenecks and application challenges faced by this field and proposed future research directions. This paper suggests that the development of tactile maps should establish a set of unified symbol conversion rules, which should fully meet the cognitive needs of the blind while minimizing their cognitive burden. Moreover, future production should leverage new materials, techniques, and process to explore map customization and even real-time generation, with active participation from blind users. In this regard, new conceptual equipment for blind navigation is highly anticipated, whose core technology involves a multi-scale spatial generalization method based on key cognitive "anchors", a "data-to-shape" transformation mode of map graphic signals, voice command communication and interaction, as well as a prototype of rapid printing of tactile materials (Figure 1), with the aim of optimizing the navigation and spatial cognition reconstruction experience of blind people during real-time travel, providing a feasible technical route to promote barrier-free travel for the visually impaired.

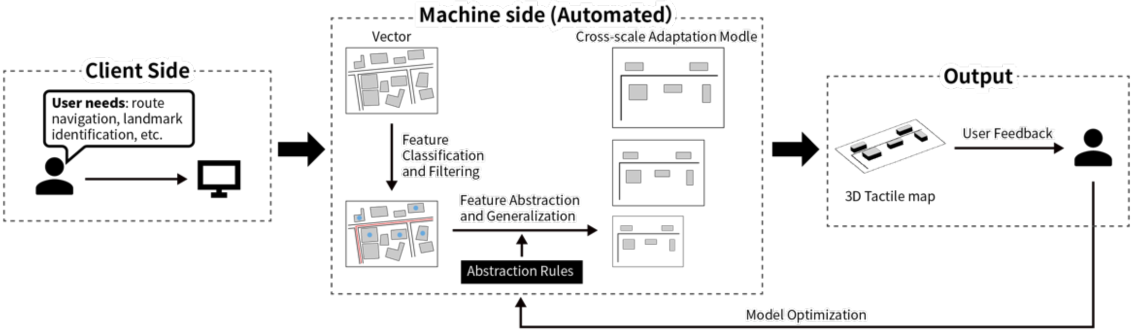

Figure 1. Technical Flowchart.

In conclusion, we hope to explore the direction of tactile map cartography, contributing to providing more reliable and convenient spatial cognition and service tools for the blind, helping them enjoy the benefits of technological progress in a more user-friendly, equitable, and barrier-free way, and better integrating into society.

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