Audio-Tactile Paintings for Visually Impaired Accessibility in Museums

Chidiel Opara
Kingston University London
United Kingdom
K2244656@kingston.ac.uk

Makayla Lewis
Kingston University London
United Kingdom
M.M.Lewis@kingston.ac.uk

Islam Choudhury
Kingston University London
United Kingdom
I.Choudhury@kingston.ac.uk

This paper presents a tactile sonified painting prototype for accessible human-computer interaction in museums. The design responds to a common problem: paintings often depend on sight, while visitors who are blind and visually impaired are mainly offered spoken description or guided support. The prototype turns a selected painting into a touchable and listenable interface. A tactile surface divides the artwork into raised tactile zones, while an ESP32 touch system detects contact and triggers mapped sounds. Spatial audio is used to place these sounds near, far, left, or right, so visitors can build a mental map of colour, shape, texture, mood, and layout. The paper argues that this method is original because it joins tactile modelling, sonification, and spatial listening within museum objects. It also shifts access from passive reception toward active exploration. The paper contributes a practical framework for inclusive museum interaction and future audio-tactile studies. It offers a clear path for museums seeking access tools that are practical and user-led.

Accessibility. Sonification. Spatial Audio. Tactile painting. Museum access. Blind and Visually Impaired.

1. INTRODUCTION

Many paintings rely on sight to provide their meaning, but the museum promises public learning. Visitors who are blind and visually impaired (BVI) are often provided with access through verbal description, guided tours, or fixed audio guides. These approaches might be helpful, but they may lead to a passive visitor. Tactile modelling and audio can yield better HCI results (Avni et al., 2025; Reinhardt et al., 2024). This paper introduces a novel prototype for an accessibility feature incorporating a tactile sonified painting with spatial audio. The design includes a tactile painting surface, the ESP32 microcontroller, touch sensors, and placed sounds. If a visitor touches an area, it plays a sound that is associated with the colour, texture, figure, mood or spatial position. The main argument is straightforward. A painting can be more than a spoken description of an object; it can also be a tactile, aural interface. This is significant because museum technology is sometimes seen as just a way to deliver content in museum experiences. The prototype embraces access as an encounter between body, artwork, sound, and place.

2. RELATED WORK

Access to museums has not only shifted from simple accommodation to richer, multisensory design, but also from a traditional to a progressive approach. Avni et al. (2025) demonstrate that visitors who are BVI appreciate control, short audio information, and physical user interfaces. In addition, Reinhardt et al. (2024) assert that 3D models can contribute to cultural access if touch is considered as knowledge. Dini et al. (2023) further this idea via colour sonification in museums. In their work, they have demonstrated that sound can carry the visual qualities without overwhelming the art. Spatial audio can enhance graph learning with touchscreens, and sonification grammars can make auditory mappings clearer (Kim et al., 2024; Robinson Moore et al., 2024). Guided practice is also found to assist users in developing spatial memory, as shown by the audio-tactile maps (Tran et al., 2024). These studies constitute a sufficient basis for a painting interface that combines touch, sound, and spatial layout. They also show a gap. A few systems allow a visitor to explore a painted surface as a tactile map and an audio scene.

© Opara et al. Published by BCS Learning and Development Ltd.

3. SONIFICATION AND SPATIAL AUDIO

Sonification is important because it can translate shape, movement, contrast, and intensity via sound. In this prototype, darker areas can be represented by the use of low tones. Lighter areas can be indicated by brighter timbres. Sharp boundaries can be indicated with short pulses, and blended areas can be indicated with smoother tones. Furthermore, spatial audio can also be utilised. A sound may be played to the left, right, near, or far, which will aid the visitor in creating a mental map. This method is inspired by recent research demonstrating spatial and non-verbal auditory feedback across various data, video, and scene access tasks for users who are BVI (Gupta et al., 2025; Liu et al., 2026; Ning et al., 2024). It also addresses a lack of regular description. Speech communicates to the visitor what has been chosen by another person. The visitors can select the path, the speed, and the level of detail in the presentation, using the sonified touch. The sounds should not emulate sight. They should provide reliable clues to make structure, relation, and feeling possible through listening.

4. PROTOTYPE DESCRIPTION

The prototype starts with a chosen painting. Important areas are divided into tactile areas: background, body figure, object, border and colour field. A raised texture and mapped sound are provided for each zone (see Figure 1). The ESP32 microcontroller touch system can detect touches and play audio using a speaker or headphones. Spatialised playback may be tested using stereo headphones. The prototype is designed to be functional and intuitive, with a series of touch-to-sound interactions. The tactile zone provides the viewer with a point of contact; the connected audio provides additional information. The raised surface helps to distinguish one part of the painting from another even before any sound is heard. An ESP32 system is used as a bridge between the tactile surface and the audio output when a zone is touched. The sound is then heard via a loudspeaker or headphones (in the appropriate setting). The primary interaction in this setup is straightforward: making contact with a precise surface, sensing its texture and hearing its mapped sound. Spatialised playback can be tested on stereo headphones, which can help to compare the experience of the audio position changes.

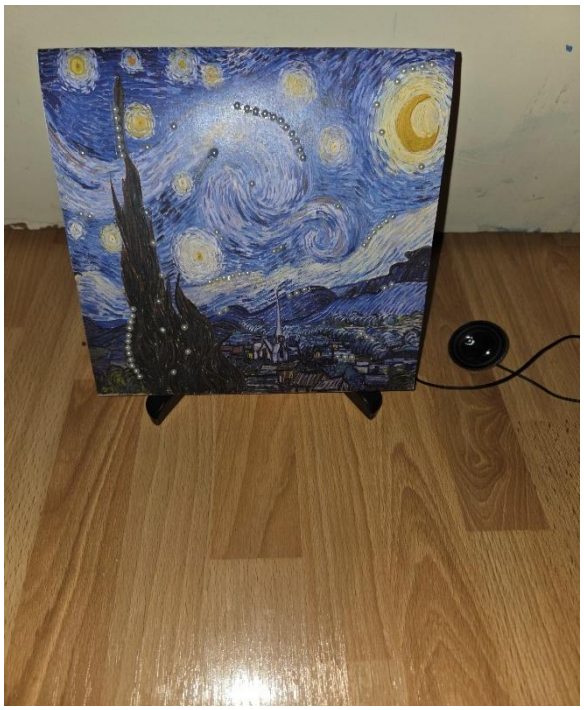

Figure 1 *– Microcontroller Tactile Image*

The system is built around an ESP32-C3 Mini microcontroller, which serves as the central controller for the prototype. It is connected to an MPR121 capacitive touch sensor to detect inputs from copper-foil touch pads; this is what provides the responsive interaction (see Figure 2). These inputs are translated into serial commands sent to a DFPlayer Mini V3.0 module, which manages audio playback by decoding MP3 and WAV files stored on a microSD card. Audio output is provided either through a 4 Ω 3 W speaker or a 3.5 mm stereo jack for headphones, with the selected pathway controlled via an SPDT switch. A 10 kΩ potentiometer regulates the output volume, while power is supplied through a USB-C port to ensure stable operation during extended use. Circuit integrity is supported by several passive components, including 1 kΩ resistors for signal conditioning, a 1000 µF electrolytic capacitor to prevent voltage drops during high-volume peaks, and a 100 nF ceramic capacitor for high-frequency noise filtration. All components are mounted on a printed circuit board using male and female headers to create a durable, maintainable assembly suitable for repeated handling in a museum environment.

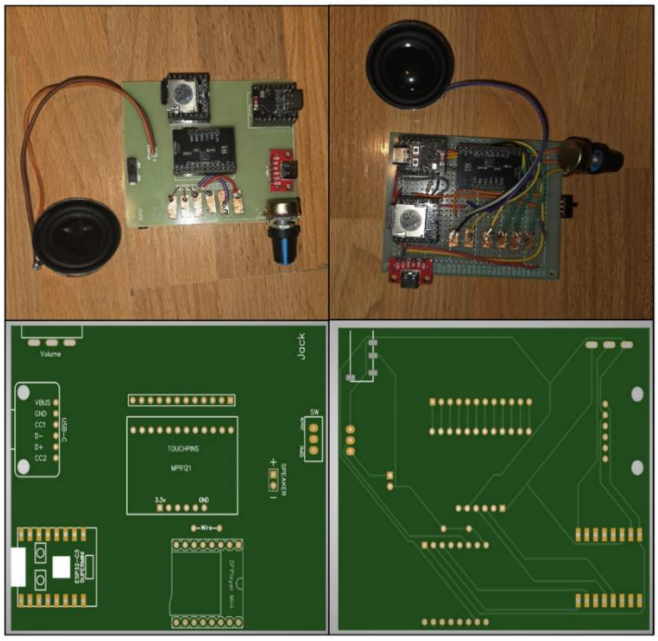

Figure 2 *- Printed Circuit Board (PCB) of the touch system: Components attached to the PCB board (Top Left), Components attached to a prototyping perfboard (Top Right), Digital Image of front PCB created in EasyEDA (Bottom Left) and Digital image of back PCB created in EasyEDA (Bottom Right).*

5. CONTRIBUTION

The first contribution is a minor but important design change. The prototype doesn't add sound next to the painting. It makes the painting itself an interactive auditory-tactile surface. This change reframes the sound not as a supplementary feature, but as something embedded directly into the museum piece. The second contribution is an interaction model that can be used in painting interactions. It outlines a set of hand-based actions that visitors perform when exploring an artwork. They can scan, pause, compare, return, and build meaning using hand movements. Through this model, visitors can engage more meaningfully with the museum artwork. A third contribution is in the form of a practical mapping scheme. All the visuals turn tactile, all the sounds turn sonic, and the spatial audio remains aural and place-specific. Unlike several other AI description tools that may have some level of trust and quality issues (Gonzalez et al., 2024; Li et al., 2026), this is not the case. It's also unlike the tactile-only copies since sound can convey colour, rhythm, depth, and atmosphere. The prototype is original because it is the first object in a museum environment to integrate a microcontroller, zones of tactile paint, and spatial sonification without any expense. It also provides curators with a clear visual language to determine which visual elements should be heard.

6. DISCUSSION

The design asks questions that are relevant to HCI. First of all, it challenges the notion that accessibility is equated solely with translation into another format. It shows that access can also come from interpretation, playful exploration, and giving visitors different choices in how they interact. Secondly, it recognises that visitors who are BVI are active art readers and interpreters. This is in line with research that users are interested in being in control of timing, detail, and modality (Cheema et al., 2025; Natalie et al., 2024). Thirdly, it generates design tensions. Overloading with too many sounds. Not enough sounds can dull or even make the painting look flat. The solution is not greater audio; it is better layering. The visitor should hear a brief cue and ask for a little more detail. The studies in the haptic and audio domain also indicate that body position, workload and training influence success (Jiang et al., 2024; Ramôa et al., 2024). Museum use adds further limits. The device must be durable, quiet enough for shared rooms, and simple for staff to reset. These limits strengthen the research problem because they test whether inclusive HCI can work in public culture. Ethical design is also central. Participants should shape sound choices, not only approve them after building. Artists should help decide which interpretations of their work are suitable. The best result is not perfect translation. It is a shared method for making visual art open to more senses. The design is significant in HCI because it sees access not as a format issue, but as a real interaction issue

as well. The work relates touch, sound, choice, timing and control in museum use. It also illustrates the importance of considering the use of inclusive systems, rather than simply whether information is available in technical terms. The project is relevant to museums and public cultural areas beyond HCI. It implies that access to art is not limited to visual perception and can facilitate alternative readings of art.

7. FUTURE WORK

Future work should test several paintings, compare sound mappings, and study long-term use in museum settings. Visitors who are BVI, museum staff, and artists should be tested. Sessions would include free exploration followed by activities regarding layout, mood, and meaning. Data would include observations, think-aloud comments, task success, time, and short interviews. This approach is suitable for HCI work where access is understood as a situated, personal, and context-dependent process (Cheema et al., 2025; Jiang et al., 2024; Natalie et al., 2024). Three modes (spoken description only, tactile surface only, and tactile sonification) would be compared in terms of evaluation. The primary measures would be control, recall, comfort, and confidence. The prototype can also support comparison across visitors. Different paths through the same artwork can be logged without naming participants. Those paths can show which zones invite attention, confusion, or repeated listening. Such data can guide better sound design while keeping the museum focused on interpretation rather than surveillance. This evidence would make later field studies clearer, smaller, and easier for museums to approve and at lower risk.

8. CONCLUSION

Tactile sonified painting with spatial audio offers a focused contribution to accessibility HCI. It joins touch, sonification, and spatial listening to make visual art explorable by touch and sound. Its value is not only technical. It changes the visitor role from receiver to investigator. Studies on theatre haptics and tactile graphics suggest that cultural access improves when prototypes respect both artistic form and user agency (Benhamida et al., 2024; Ramôa et al., 2024). For that reason, the prototype can stimulate useful HCI debate about authorship, sensory translation, and inclusive museum practice. It also offers a realistic path for museums with limited budgets. Low-cost sensors, careful mapping, and co-designed audio can turn one painting into a repeatable model for wider access.

9. REFERENCES

Avni, Y., Danial-Saad, A., Sheidin, J. and Kuflik, T. (2025) Enhancing museum accessibility for blind and low vision visitors through interactive multimodal tangible interfaces. International Journal of Human-Computer Studies, 198, 103469. https://doi.org/10.1016/j.ijhcs.2025.103469

Benhamida, L., Larabi, S. and Metatla, O. (2024) Hapstick-Figure: Investigating the design of a haptic representation of human gestures from theater performances for blind and visually-impaired people. Proceedings of the ACM on Human-Computer Interaction, 8, pp. 649–673. https://doi.org/10.1145/3698152

Cheema, M., Seifi, H. and Fazli, P. (2025) Describe Now: User-driven audio description for blind and low vision individuals. Proceedings of the 2025 ACM Designing Interactive Systems Conference, Funchal, Portugal, 5–9 July 2025, pp. 458–474. ACM, New York. https://doi.org/10.1145/3715336.3735685

Dini, S., Ludovico, L. A., Mascetti, S. and Valero Gisbert, M. J. (2023) Translating color: Sonification as a method of sensory substitution within the museum. 20th International Web for All Conference, Austin, United States, 30 April–1 May 2023, pp. 162–163. ACM, New York. https://doi.org/10.1145/3587281.3587706

Gonzalez Penuela, R. E., Collins, J., Bennett, C. L. and Azenkot, S. (2024) Investigating use cases of AI-powered scene description applications for blind and low vision people. CHI Conference on Human Factors in Computing Systems, Honolulu, United States, 11–16 May 2024, Article 901, pp. 1–21. ACM, New York. https://doi.org/10.1145/3613904.3642211

Gupta, C., Ram, A., Sridhar, S., Jouffrais, C. and Nanayakkara, S. (2025) Scene-to-Audio: Distant scene sonification for blind and low vision people. CHI Conference on Human Factors in Computing Systems Extended Abstracts, Yokohama, Japan, 26 April–1 May 2025, Article 471, pp. 1–9. ACM, New York. https://doi.org/10.1145/3706599.3719849

Jiang, L., Jung, C., Phutane, M., Stangl, A. and Azenkot, S. (2024) "It's kind of context dependent": Understanding blind and low vision people's video accessibility preferences across viewing scenarios. CHI Conference on Human Factors in Computing Systems, Honolulu, United States, 11–16 May 2024, Article 897, pp. 1–20. ACM, New York. https://doi.org/10.1145/3613904.3642238

Kim, H., Kim, Y.-S. and Hullman, J. (2024) Erie: A declarative grammar for data sonification. CHI

Conference on Human Factors in Computing Systems, Honolulu, United States, 11–16 May 2024, Article 986, pp. 1–19. ACM, New York. https://doi.org/10.1145/3613904.3642442

Li, F. M., Liu, M. X., Bennett, C. L. and Kane, S. K. (2026) ADCanvas: Accessible and conversational audio description authoring for blind and low vision creators. CHI Conference on Human Factors in Computing Systems, Barcelona, Spain, 13–17 April 2026, pp. 1–21. ACM, New York. https://doi.org/10.1145/3772318.3791158

Liu, C., Jiang, W., Ruan, S., Hara, K. and Wang, Y. (2026) Accessible fine-grained data representation via spatial audio. IEEE Computer Graphics and Applications, advance online publication. https://doi.org/10.48550/arXiv.2604.08979

Natalie, R., Chang, R.-C., Sheshadri, S., Guo, A. and Hara, K. (2024) Audio description customization. 26th International ACM SIGACCESS Conference on Computers and Accessibility, St. John's, Canada, 27–30 October 2024, Article 39, pp. 1–19. ACM, New York. https://doi.org/10.1145/3663548.3675617

Ning, Z., Wimer, B. L., Jiang, K., Chen, K., Ban, J., Tian, Y., Zhao, Y. and Li, T. J.-J. (2024) SPICA: Interactive video content exploration through augmented audio descriptions for blind or low-vision viewers. CHI Conference on Human Factors in Computing Systems, Honolulu, United States, 11–16 May 2024, Article 902, pp. 1–18. ACM, New York. https://doi.org/10.1145/3613904.3642632

Ramôa, G., Schmidt, V., Schwarz, T., Stiefelhagen, R. and König, P. (2024) SONOICE! a Sonar–Voice dynamic user interface for assisting individuals with blindness and visual impairment in pinpointing elements in 2D tactile readers. Frontiers in Rehabilitation Sciences, 5, 1368983. https://doi.org/10.3389/fresc.2024.1368983

Reinhardt, D., Holloway, L., Thogersen, J., Guerry, E., Diaz, C. A. C., Havellas, W. and Poronnik, P. (2024) The museum of touch: Tangible models for blind and low vision audiences in museums. In Lee, J. H., Ostwald, M. J. and Kim, M. J. (eds), Multimodality in Architecture: Collaboration, Technology and Education. Springer Nature Switzerland, Cham, pp. 135–155. https://doi.org/10.1007/978-3-031-49511-3_8

Robinson Moore, W. J., Kalal, M., Tennison, J. L., Giudice, N. A. and Gorlewicz, J. L. (2024) Spatial audio-enhanced multimodal graph rendering for efficient data trend learning on touchscreen devices. CHI Conference on Human Factors in Computing Systems, Honolulu, United States, 11–16 May 2024, Article 206, pp. 1–12. ACM, New York. https://doi.org/10.1145/3613904.3641959

Tran, C. M., Bach, N. G., Tan, P. X., Kamioka, E. and Kanamaru, M. (2024) Enabling self-practice of digital audio–tactile maps for visually impaired people by large language models. Electronics, 13, 2395. https://doi.org/10.3390/electronics13122395