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# Image and Object Recognition using HaptX DK2 Tactile Smart Gloves for the Visually Impaired*

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## I. Introduction

The World Health Organization estimates that 2.2 billion people are visually impaired. Despite recent progress in assistive technologies for blind and low vision people (BLVP), traditional braille interfaces and text-to-speech systems face usability and scalability limitations with regard to interpreting images and complex visual information. Full comprehension of visual content remains a significant challenge for BLVP. When accessing visual information, BLVP often rely on computers, tablets, or smartphones to convey image descriptions through alternative text or use touchscreen-based accessibility features to explore content, but these mediums often lack spatial nuance and engagement.

Our work builds upon these approaches by proposing a novel integration of computer vision and tactile rendering using the HaptX DK2 smart glove system to enhance image accessibility. While prior solutions focused on static image overlays or limited vibration feedback, our system enables real-time, spatial exploration of segmented digital imagery to foster a stronger sense of understanding. While most haptic feedback solutions incorporate vibration feedback for events such as collisions with objects, these typically require users to hold controllers, limiting the ability to grasp and manipulate virtual objects naturally; however, smart gloves provide a more intuitive and immersive experience by aligning haptic feedback with the biomechanics of the human hand.

We developed an image-to-haptics pipeline using DK2 tactile smart gloves in collaboration with HaptX, a leader in wearable haptic technology. Our system integrates computer vision with active tactile actuator rendering, allowing BLVP to perceive and interact with digital environments in novel ways. Specifically, we leverage a super boundary-to-pixel direction (Super-BPD) segmentation technique to efficiently transform input data into structured segmentations. Our approach addresses existing limitations in tactile resolution and sensor placement, enabling dynamic rendering of braille text, graphics, and interactive diagrams. By integrating deep learning-based segmentation with haptic feedback, we aim to establish a new standard in assistive technology.

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## II. Methods

### A. Overview

HaptX DK2 tactile smart gloves [1], seen in Fig. 1, function as a dynamic refreshable display, and support the conversion of digital images into tactile feedback via a segmentation-based rendering pipeline, in conjunction with the HaptX Software Development Kit (SDK) [2]. Using super boundary-to-pixel direction (Super-BPD) segmentation [3], the system extracts key objects from visual scenes and transforms them into interactive, tactile representations. Integrated within the Unity framework, the system translates virtual objects into haptic responses, which are dynamically projected onto the glove's tactile actuators. The system's real-time software continuously adjusts the tactile actuator activations based on user hand movements, ensuring seamless and intuitive haptics.

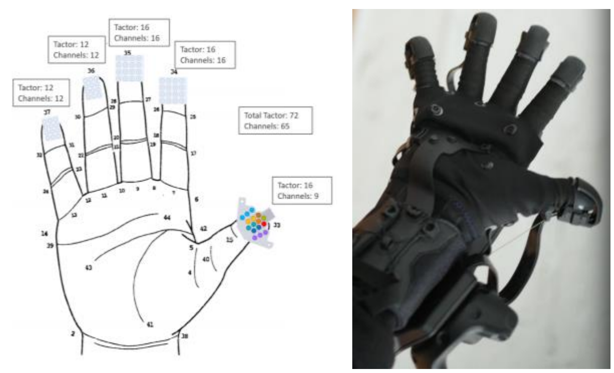


Fig. 1. Left: The distribution of the tactile actuator grids for each fingertip in the HaptX DK2 smart glove. Right: The right hand of the DK2 smart glove. Tactile actuators are beneath the black thimble-like structures on the fingertips.

### B. Image and Object Segmentation with Super-BPD

In a typical visual scene, sighted individuals rely on color, shading, and contextual cues to identify object boundaries, even when edges are indistinct. However, BLVP require clearly defined, unambiguous tactile representations to effectively explore an image. Standard image segmentation methods fail to produce precise contours necessary for tactile rendering, particularly when object edges are gradual, occluded, or embedded in cluttered backgrounds. Traditional methods also struggle with small, intricate features, which are critical for distinguishing textures, symbols, and fine details within an image. Incomplete or ambiguous segmentation can lead to confusion for BLVP users when interpreting tactile graphics, particularly if spatial relationships between components are poorly delineated.

To address these challenges, we use Super-BPD segmentation, a fast and powerful method that enhances object delineation by encoding directional information at each pixel. Super-BPD ensures that spatial structures remain intact and accessible through haptic feedback. This refinement ensures that a segmentation maintains both boundary precision and object coherence, preventing fragmentation that might result in disjointed tactile feedback. The emphasis on precise boundary preservation, robust edge detection, and hierarchical segmentation can be seen in Fig. 2.

Fig. 2. Segmentation output (middle) from Super-BPD [3] for a natural image (left) compared to Meta's Segment Anything Model (SAM) [4] output of the same image (right); note SAM's incorrect segmentation of the hill, which improperly injects a rock-like structure into the scene of the two rhinoceroses.

### C. *HaptX Custom DK2 Tactile Smart Glove*

The HaptX DK2 tactile smart glove was designed to align with the natural biomechanics of the human hand, ensuring both comfort and precise tactile feedback delivery. The glove incorporates flexible knit fabric, minimizing interference with actuator inflation, while maintaining a secure fit that enables effective transmission of haptic stimuli. Design decisions for individual fingers prioritized larger tactile actuator grids on the index and middle fingers as these fingers serve the primary role in tactile perception. The smaller ring and pinky fingers' tactile actuator grids had less surface area and reduced tactile sensitivity. A modified DK2 thumb panel supported tactile actuators near the distal joint.

### D. *Software Integration for Interactive Haptic Scenes*

To convey visual information as haptic scenes, we propose a pipeline that (1) performs Super-BPD segmentations of natural images, (2) converts the segmentations into mesh objects, (3) imports mesh objects into a 3D Unity environment scene [5] and (4) uses HaptX-developed Unity engine haptic feedback to allow BLVP users to physically explore the objects of the original natural images. As seen in Fig. 2 and 3., the proposed system converts segmented visual data into palpably distinguishable virtual objects, which can be dynamically explored using the HaptX DK2 smart glove.

The first stage segments natural images with Super-BPD to divide them into distinct objects while preserving boundary integrity, resulting in a labeled image where each segmented region is assigned a unique identifier. The segmentation is the foundation for mesh conversion, accomplished by any type of surface reconstruction method. An example of the formation of simplified meshes is shown in Fig. 3. The resulting mesh structures are stored as OBJ files to retain texture mapping information essential for material assignment in Unity.

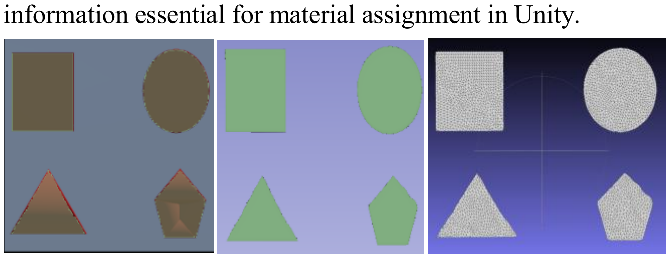

Fig. 3. A simple scene with shapes that were (from left to right) segmented as the foreground, then smoothed and isolated, and finally converted to simplified meshes for use as haptic feedback assets.

## III. Results

The DK2 gloves were successfully fitted with custom tactile actuators to form a refreshable tactile display device. All tactors were fabricated using a laser-cutting process, ensuring precise dimensions for tactile feedback. Examples of an inflated tactile actuator and the final tactile actuator grid are shown in Fig. 4.

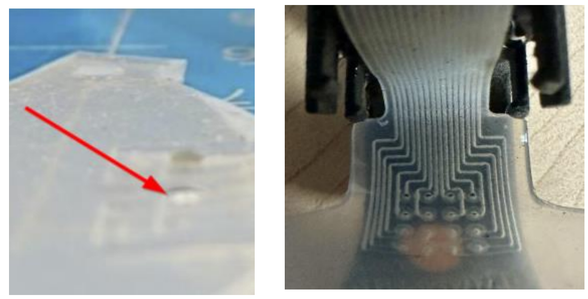

Fig. 4. Left, an inflated tactor. Right: the index fingertip of DK2 glove as a refreshable braille display using BANA standardized braille tactor layouts.

To validate the choice of Super-BPD, we perform an evaluation against Meta's Segment Anything Model (SAM) on a subset of low-contrast images, which often represent a significant challenge for segmentation methods. Super-BPD demonstrated superior performance in delineating object boundaries and preserving spatial relationships in these cases. In a low-contrast image subset, Super-BPD achieved an ODS F_b of 0.673, compared to SAM's 0.664, and an OIS F_op of 0.412, outperforming SAM's 0.378. Beyond accuracy, Super-BPD displays exceptional computational efficiency, achieving an average processing time of 36 ms per image.

## IV. Conclusion

This study introduces a method for transforming visual data into interactive haptic experiences using the HaptX DK2 smart gloves to enhance the accessibility of digital visual content for BLVP users. By combining advanced image segmentation and the Unity game engine with wearable tactile feedback systems, we create accessible digital environments that BLVP users can virtually explore. Currently, users may identify objects such as geometric shapes simply by touch. Future work will expand this approach to support complex scenes, investigate user performance in spatial navigation, and incorporate additional sensory cues for richer interaction. The proposed pipeline represents a step toward improving the accessibility of digital visual information for BLVP.

## References


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