

# A Computer Vision and Vibrohaptic Glove-Based Piano Learning System for the Visually Impaired

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**Abstract**—The visually impaired are unable to enjoy leisure activities as much as ordinary people due to various limitations. To expand the scope of leisure activities for the visually impaired, we have developed a vibration glove-based system that helps with piano learning. Previous research used 88 infrared light-emitting diodes and gloves with infrared receivers to provide feedback to the user, but this method had many limitations. In particular, the inconvenient user experience and low accuracy were the biggest problems. Our method solves both problems using a camera and an image processing algorithm. As a result of testing the model on 20 piano images, it was shown that all keys were perfectly recognized in 75% of cases, and the gloves could be comfortably used in practice without any difficulty. Thus, our method presents a simpler user experience for the visually impaired, without requiring any special modifications to the piano.

**Keywords**—Image Processing, Computer Vision, Piano Pedagogy, Visual Impairment, Assistive Technology

## I. INTRODUCTION

The visually impaired face many obstacles in life, one of which include the enjoyment of leisure activities. Since the visually impaired cannot read text with their eyes, they must use braille. However, according to the 2020 Disability Survey conducted by the Ministry of Health and Welfare of South Korea, only 9.4% of all visually impaired people responded that they could decipher braille or were learning it, and 90.6% could not decipher it. [1] In addition, according to the 2023 Braille Usage Ability Survey conducted by the National Institute of the Korean Language on 301 visually impaired people aged 20 to 69 nationwide, approximately 4 out of 10 visually impaired adults had braille usage skills below basic. [2]

Due to these and other limitations, it is extremely difficult for the visually impaired to enjoy normal leisure activities. This difficulty can have a negative impact on the satisfaction and quality of life of the visually impaired. [3] Kim et al. found that among the weekly leisure activities of the visually impaired, watching TV or videos accounted for an overwhelmingly high proportion of 85 to 95%, but the proportion of watching culture and arts, or participating in hobbies and self-development activities was significantly low at about 5% each. [4] In addition, the proportion of the visually impaired who are satisfied with their leisure activities had greatly improved to 50.5% by 2020, but about half of the visually impaired were still dissatisfied with their leisure activities. Therefore, devising a method to improve access to a more diverse set of activities could be an effective way to improve their quality of life.

Playing a musical instrument is one example of a leisure activity that is not easy for the visually impaired to access and

learn. In particular, the biggest problem with the piano is that it is difficult to read the sheet music directly and find the location of the keys to play. Although there is a braille music notation system that was developed to allow the visually impaired to read sheet music, it would be infeasible for most of the population to learn the new braille notation system and become familiar with it quickly, given the significantly low braille literacy rate. Even if they become familiar with the notation, it can be difficult for beginners to locate the piano keys corresponding to specific notes written on the sheet music and play them. As such, it is not easy for the visually impaired beginner to learn and become familiar with the piano.

Therefore, this study aims to develop technology that allows visually impaired people who are not skilled in playing the piano to practice on their own. We developed a pair of smart gloves that uses vibration feedback to effectively convey detailed elements such as the location of the keys and the length of a single note, as well as the overall flow of a piece to the visually impaired without sheet music.

## II. RELATED WORKS

The work of Uchiyama et al. validated the use of vibration feedback in the guidance of the visually impaired. [5] The researchers created gloves that aid in the navigation of visually impaired wheelchair users. Using 9 motors in the form of a 3-by-3 grid, the gloves were able to provide information on obstacles, space, and directions. Through this, the researchers were able to confirm the effectiveness of vibration feedback.

Previous research by Kalra et al. investigated an infrared-based piano training system for the visually impaired. [6] The researchers created vibro-haptic feedback gloves for the purposes of informing the user of the next note to play on the piano. The system operates as follows: Using a MIDI library, it plays introductory notes from a music piece. Then, light emitting diodes (LEDs) corresponding to the notes are turned on by a microcontroller. The gloves that the user is wearing features infrared receivers sense the finger that is receiving the signal and subsequently activates the vibration motor on that finger. To decide whether to move to the next note, flex sensors on the back of each finger detect whether the user has already played the current note.

## III. METHODS

### A. Overview

We propose a solution that enables more efficient practice for the visually impaired in several ways compared to [6]. The infrared method requires attaching a band with 88 LEDs to the piano so that each LED corresponds to its key position.

However, the size of the band and the difficulty aligning each LED to its correct position makes it impractical. Our invention eliminates bulkiness by recognizing the position of the fingers from a single overhead webcam.

The method in this paper can also provide more accurate information. The gloves in [6] recognize infrared light when the finger is close to the correct key and provides information to the user through vibration. Since infrared light spreads out over an angle, the glove is likely to vibrate even when the finger is not on the key. In addition, since only a single infrared receiver is located on the back of the hand, it cannot transmit vibration to a specific finger. This study proposes a method that matches the coordinates of the fingers and keys to be played, so the possibility of providing vibration feedback at the wrong location is significantly reduced.

### B. System Design

The entire system consists of two gloves that can transmit vibrations to all ten fingers and a central computer that communicates wirelessly with the gloves. The central computer has a camera that monitors the piano and motion of the hands. The computer has information about the user's hand position and gestures and is responsible for the music playback using MIDI and communication with the gloves. The gloves, which use an Arduino Nano as a microcontroller, operate the motors based on the data from the computer, controlling which fingers to vibrate to, the length of vibration, and more. They also monitor which finger the user uses and provides that information to the computer. The following section will provide detailed information on the various functions of the central computer.

### C. Central Computer

The central computer detects the user's hand movements using a camera and detect which keys were pressed. It also detects the keys of the piano from the camera using OpenCV library. Since we need to find out the exact location of the user's fingers, we use the Mediapipe's hand detection AI model and find the coordinates of the landmarks of the hand, such as the joints of the fingers and the wrist. The location of the keyboard is found using a set of filtering techniques discussed in the next section. We can find out which key each finger is on by comparing the coordinates of each finger with the coordinates of the piano keys.

The user's hand gestures are detected in real time to perform various functions like restarting or ending the practice session. To detect the gestures in real time, the computer uses an individual thread that continuously monitors the user's hand gestures. Since the main process that manages the overall flow of the program must obtain the user's hand motion information from the other thread, an IPC (Interprocessor Communication) system is used to allow the main process and the monitoring thread to communicate. For The monitoring system unidirectionally dispensing the data to the rest of the process, we used shared memory method for the IPC for its capability to allow multiple processes to easily and efficiently access a single resource.

The flow of the practice is also controlled by the central computer. After reading the music sheet data from the file, the last practice location is loaded. Since it is very inefficient to analyze standard sheet music that not been processed in real time, a file format that binarizes the information contained in music sheets was developed separately. The start position of the practice can be adjusted by reading the user's hand gesture.

After the initialization of system and starting position, the central computer checks if the user has pressed all the keys and moves on to the next part of the piece to practice. The computer reads the position of the active finger immediately after receiving the finger number from the glove. It compares the key data received by the user and the sheet music data, and if the user has pressed all the keys, it moves on to the next part to practice.

### D. Key Detection

We used OpenCV library to process the image of the piano and detect all the keys of the piano. Prior to the key detection, the area of the piano needs to be detected and extracted from the image. First, the image undergoes the thresholding process using Otsu's method, which automatically determines the threshold value for binarization from the image's intensity histogram. Second, the contours of the images are detected from the binarized image, using the findContours() function provided in OpenCV library. Third, using the Oriented FAST and Rotated BRIEF (ORB) feature detection algorithm, coordinates of the points from the image that matches the template image of the piano are calculated. ORB algorithm computes the features of an image and compares the quantized feature values to an image to detect commonalities between the two images. It was chosen for its speed and ability to recognize rotated objects. Finally, the contour that contains the points that matches the template the most is the contour that encompasses the piano.

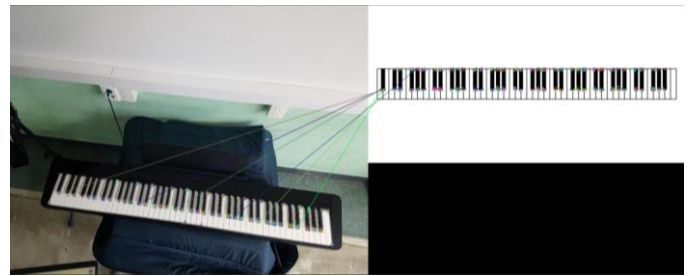


Figure 1. Feature detection using ORB algorithm



Figure 2. Piano area cropped from the original image

With filtering, the contours of the piano keys are detected from the piano image. The first step of detecting the contours is to detect the black keys of the piano. This is because the black

keys have highly distinct colors from white keys and are easy to detect, as they are farther away from each other than white keys. Detecting the black keys' area and truncating the black keys from the white keys reduces the disturbance in detecting the white keys.

When the piano is separated from the image, getting the outline of the black keys is disturbed by the black background, as there exists no boundary between black keys and black background. To create the outline between black background and black keys, the contours of the white keys are created, and using the Convex Hull Algorithm, the outline of the piano is created.



Figure 3. Contour algorithm

Once the piano's outline is created, the distinct black rectangles are detected using contour algorithms again, and the rectangles of the black keys are finally generated.

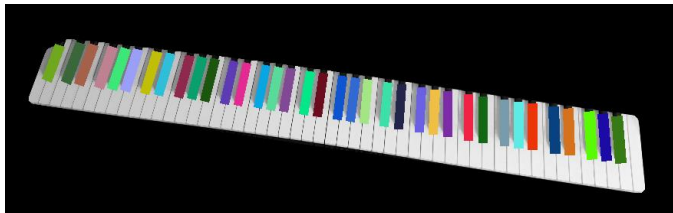


Figure 4. Contours of the black keys (approximated with rotated rectangle)

Now that the black keys are detected, the white keys are detected from the black key's data. To minimize the disturbance of black keys, the region that contains black keys is removed from the image. After the removal, the contours between the white keys are magnified using the adaptive thresholding algorithm.

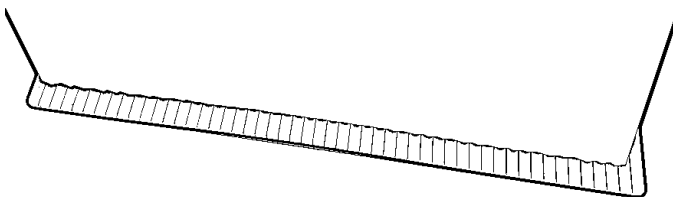


Figure 5. Removal of black keys and adaptive thresholding

These white keys have much lesser height than the originals, the heights of these white keys are adjusted by referencing the nearby black keys. The location and area of all keys are saved in a RotatedRect structure in OpenCV, which contains the rectangle's center of mass and its rotated angle. Later, when the coordinates of each finger are given, we can circulate the list that contains all the RotatedRect structures of the keys and compare the finger's coordinate to detect what key the user's finger is on.

## E. Hand Detection

The detection of hand location from the image is done after the main program detects all the locations of the keys. We used Mediapipe for the detection of hand's landmarks. As Mediapipe only supports the python library, we used threading and IPC (specifically, Shared Memory) to communicate between the hand detection agent (written in Python) and the main program (written in C++.) The main program creates a new process of the python-build hand detection agent and using the shared memory pool receives the coordinates of landmarks of hands. This execution of an AI agent occurs whenever the main program requires hand-detection AI to analyze the frame. The main program compares the data given from the python agent and obtains what keys the fingers are on.

## F. Vibrotactile Feedback Gloves

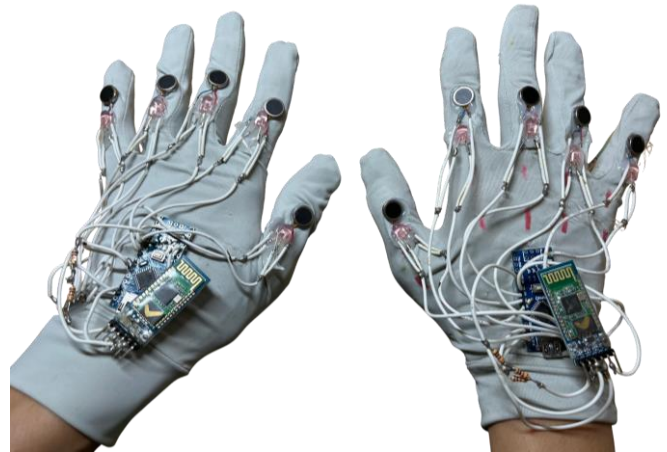


Figure 6. A picture of the feedback gloves being worn

The hardware was created according to the designed circuit, and light-emitting diodes were added for easy confirmation of motor operation. The gloves allowed flexible finger movements suitable for playing the piano, and the motors allowed precise feedback for each finger. The weight did not feel heavy at all, and all vibration motors worked properly. Additionally, the authors were able to practice as usual on the piano without any difficulty.

## G. Environmental Variables Application

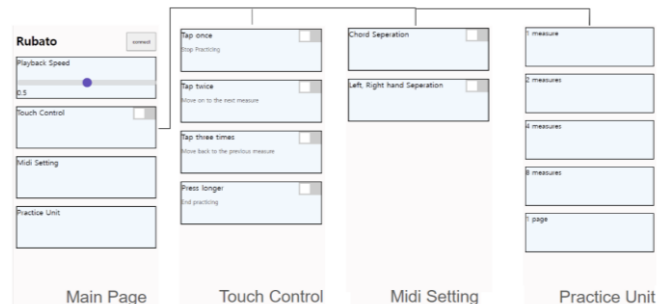


Figure 7. Environmental variables application flowchart

A mobile app for customizing environmental variables like the unit of practice (measures or lines) has also been developed. In addition, Bluetooth was adopted as the communication

protocol between the mobile phone and central computer since it allows easy communication. The environment variable modification function was implemented by building a program that handles Bluetooth communication inside the central computer and updates the environment variables based on data received from the app.

#### IV. RESULT

##### A. Procedure

We tested the accuracy of the main program with photos of the piano taken from various angles and brightnesses and checked whether the overall piano area is accurately detected and whether the piano keys are properly detected. 20 test images were prepared, and the piano area was well detected in each image and the degree to which the keys are detected is recorded.

##### B. Result

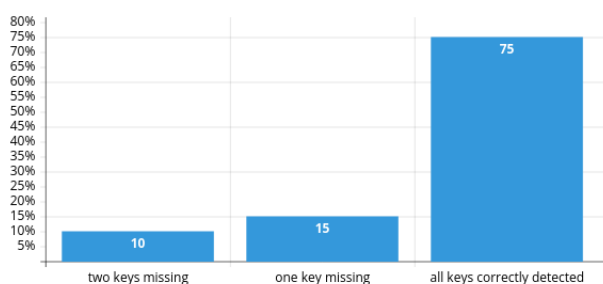


Figure 8. Test result

From the 20 test cases, the program all correctly detected the keys from 15 cases, however from three test cases the program missed one key, and from two test cases the program missed more than two keys. This is due to the contours of the white keys being not visible because of the low resolution of the camera or ambient illuminations. Furthermore, in the removal of black keys, the height of the edge keys become anomalous and result in a skewed bounding box, which is another reason for failing to detect the key correctly.

##### C. Analysis

Test cases that exceed more than two misses are the result of the failure to detect the black keys. The reason for this failure is because of the main program mistakenly detecting the shadows as black keys. This can be remedied by changing the threshold value in binarizing the image of piano in the detection of black keys or detecting the excessively large bounding box that was merged with the shadows and separating the bounding box into proper bounding boxes.

#### V. CONCLUSION & FUTURE WORK

In this paper, we proposed an assistive smart glove based on vibration motors to improve the efficiency of piano learning for visually impaired people. The test results confirmed that in most cases, the matching of specific fingers and keys was accurately determined. In addition, when the vibration motor of each finger was tested, it was confirmed that all motors attached to the glove worked properly. This shows that the assistive

glove in this study can help users conveniently find the location of the keys by providing vibration feedback to the appropriate fingers. Unlike previous studies, this device is more practical and accurate because it only attaches a wide-angle camera to the piano to check the matching of the keys and fingers using coordinates. These test results suggest that the assistive glove in this study is an effective practice aid for beginner learners of the piano with visual impairments.

In future studies, we plan to improve the following points. Since the pressure sensor in the glove can cause inconvenience, the pressure sensors will be replaced with additional software, or with flex sensors that detect the bending of fingers. When the user is supposed to play a chord, the vibration on the fingers holding the keys will continue until the last note is played. The hand detection model also will be improved to detect hands with higher accuracy using image correction.

The primary effect expected from the spread of the smart vibration glove proposed in this study is that more visually impaired people will become familiar with the piano. If visually impaired people use this device to practice the piano, the need to look at the Braille music sheet will disappear. Moreover, vibration feedback will allow them to easily identify the structure of the song and the location of the keys. In this way, this study has devised the most intuitive way for the visually impaired to practice the piano, and it is expected that it will contribute to improving the accessibility of the piano for the visually impaired.

The secondary effect will be the improvement of the quality of life of the visually impaired people due to the improvement of their leisure life. Leisure life is a very important element in the lives of the visually impaired people. Therefore, this study can be used as a process to further expand the scope of the leisure life of the visually impaired, and ultimately to increase their life satisfaction of them. From a broad perspective, it will be a useful device that can help more people access a part of art.

#### REFERENCES

- [1] S. Kim et al., "2020 Disability Survey," Ministry of Health and Welfare of South Korea, Dec. 2020. [Online]. Available: [https://www.mohw.go.kr/board.es?mid=a10411010100&bid=0019&tag=&act=view&list\\_no=369030](https://www.mohw.go.kr/board.es?mid=a10411010100&bid=0019&tag=&act=view&list_no=369030)
- [2] J. Park et al., "2023 Braille Usage Ability Survey," National Institute of Korean Language, Dec. 2023. [Online]. Available: [https://korean.go.kr/front/reportData/reportDataView.do?mn\\_id=207&report\\_seq=1149](https://korean.go.kr/front/reportData/reportDataView.do?mn_id=207&report_seq=1149)
- [3] D. Kim, C. Jang, and C. Cho, "Social, Cultural and Leisure Activities of People with Visual Impairment: Current Situation and Further Tasks," *The Korean Journal of Visual Impairment*, vol. 38, no. 2, pp. 45–65, doi: 10.35154/kjvi.2022.38.2.45.
- [4] S. Kim, M. Eom, S. Ahn, Y. Lee, and J. Cho, "Structural Relationships Among Stress, Leisure Activities, and Life Satisfaction for Persons with Visual Impairment," *The Korean Journal of Visual Impairment*, vol. 34, no. 1, pp. 25–39, doi: 10.35154/kjvi.2018.34.1.25.
- [5] H. Uchiyama, M. A. Covington, and W. D. Potter, "Vibrotactile Glove Guidance for Semi-Autonomous Wheelchair Operations," *Proceedings of the 46th Annual ACM Southeast Conference*, pp. 336–339, Mar. 2008, doi: 10.1145/1593105.1593195.
- [6] S. Kalra, S. Jain, and A. Agarwal, "Infrared Powered Vibro-Haptic Piano Training System for the Visually Impaired," *International Journal of Advances in Soft Computing and Its Applications*, vol. 9, no. 3, pp. 49–68, Jan. 2017.



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