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KULLIYYAH OF INFORMATION AND COMMUNICATION TECHNOLOGY

Advancement in ICT: Exploring Innovative Solutions (AdICT)

Series 1/2024

KICT Publishing

ADVANCEMENT IN ICT: EXPLORING INNOVATIVE SOLUTIONS (AdICT) SERIES 1/2024

Editors
Noor Azura Zakaria
Dini Oktarina Dwi Handayani
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KICT Publishing

ADVANCEMENT IN ICT: EXPLORING INNOVATIVE SOLUTIONS (AdICT) SERIES 1/2024

First Publication 2024

Published by

KICT Publishing
International Islamic University Malaysia
53100 Kuala Lumpur, Selangor, Malaysia

e ISBN 978-629-99388-0-4

9 786299 938804

Cataloguing-in-Publication Data

Perpustakaan Negara Malaysia

A catalogue record for this book is available from the National Library of Malaysia

eISBN 978-629-99388-0-4

KICT Publishing

(Online)

Preface

Advancement in ICT: Exploring Innovative Solutions (AdICT) Series 1/2024 is an e-book showcases the collective achievements of Final Year Project (FYP) in Kulliyyah of Information and Communication Technology (KICT). This compilation represents evidence to the technical passion and academic skills of our students before they venture into the professional realm.

FYP is a journey that demands creativity, critical thinking, and perseverance. This book encapsulates the diverse range of projects undertaken by our students, each a unique exploration into the vast landscape of Information and Communication Technology (ICT). From cutting-edge software applications to groundbreaking research, these projects not only demonstrate technical proficiency but also the ability to address real-world challenges.

In this comprehensive collection, the topics covered span a spectrum from cutting-edge software development, cybersecurity, artificial intelligence and multimedia technologies reflecting the breadth and depth of our academic program. This offers a curated journey through the diverse landscape of final year ICT projects toS the readers while appreciating the impact these projects can have on the wider community.

This e-book carries significant benefits and impact whereby it serves as a valuable knowledge repository, offering a diverse audience—from students and educators to industry professionals—a comprehensive view of the latest innovations and technological solutions in ICT. Moreover, the book fosters a culture of knowledge sharing and collaboration, as each project represents a unique contribution to the broader technological landscape.

“When the human being dies, his deeds end except for three: ongoing charity, beneficial knowledge, or a righteous child who prays for him” *– Sahih Muslim*

Editors

Noor Azura Zakaria
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3D Natural Interface to Teach Piano for Beginners

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***Abstract*—In this project, we use the Leap Motion controller together with Unity engine to develop a virtual piano application to teach beginners how to play the piano. With Leap Motion, the users can interact with the application as if they are playing it in the real world. The proposed system and its implementation are described. A usability test is also conducted to identify the effectiveness of the application for learning purposes.**

Keywords—Leap Motion controller, virtual piano, Unity, 3D natural interface

I. INTRODUCTION

Many people are interested in learning to play piano. However, musical instruments like the piano is too expensive to purchase, and most families are unable to pay high lesson fees to learn playing their favourite musical instrument [1].

To give an equal opportunity to those who have the interest to learn playing piano but are limited to factors such as budget or time, this project aims to provide an alternative method to learning piano using a Leap Motion controller that allows the users to interact with a virtual piano, as if they are playing it in the real world.

This application provides several songbooks options for the users to learn, as well as tutorials where they can follow the songs step-by-step. Other than the gesture recognition method, the users will also be presented with a keyboard option. At the end of the learning session, the system will analyse the user's performance and display some comments.

II. RELATED WORK

There is a lot of work done on virtual piano. Since this project uses a Leap Motion controller, the main focus of the review is on the application implemented with the said device. Several other approaches are also reviewed to identify some common features.

A. Virtual Piano Applications Using Leap Motion Controller

Qiao et al. [2] implemented a virtual piano with a Unity engine which allows the users to play the piano by moving their hands above the controller, as shown in Figure 1. The interaction was made to work as if the real key is pressed through a hinge joint, a physical model built in Unity for two connected objects to move with the hinge as a movement constraint. A qualitative experiment was conducted to evaluate the accuracy of the finger movement.

Another similar work was conducted in [3]. The implementation utilizes the HandController's game object and script provided in the Leap Motion SDK to attain the location, orientation and speed of the hand models, followed by the collision detection between the fingers and the keys. A usability test was conducted on experienced pianists and amateurs, and the result reveals that the former has a more success in playing the virtual piano. There were also a few problems reported such as the users accidentally played the incorrect keys due to the actual movement required for the wrist and finger in order to play a key.

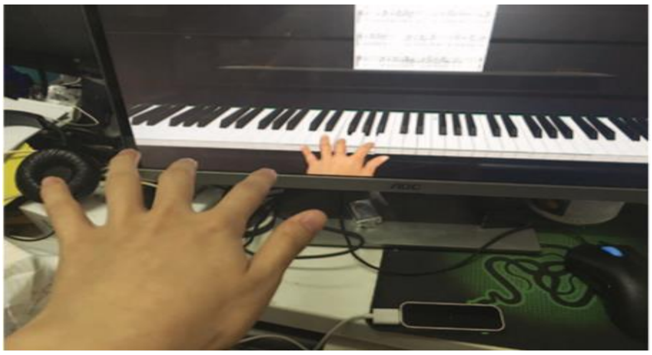
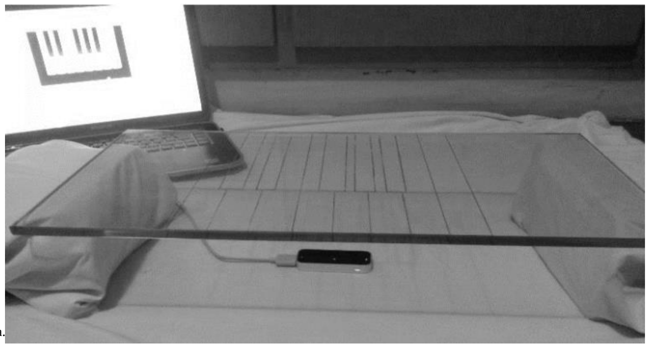


Fig. 1. Playing the virtual piano.

Source: Adapted from [2]

In [4], the application was developed when Leap Motion was in its early release. Thus, the focus of the project was more on the effectiveness of the controller as a gesture interface. A simple piano interface with one octave was implemented on a glass "table" that was setup above the device, as can be seen in Figure 2. The evaluation was done on a series of hand manipulations, articulations movements, and gestures. It was found that the simulation was great when played in slow rhythm, but an unacceptable latency occurred when playing normal-fast paced songs.



a.

Fig. 2. The setup with Leap Motion controller underneath the glass.
Source: Adapted from [4]

A slightly different approach is taken by [5] where the Myaree muscle sensors are used to detect the electromyography readings of the virtual piano, thus enabling the dynamic variation while playing, as shown in Figure 3, and is enhanced with tactile sensation using a transparent acrylic board, similar to the implementation in [4]. An experiment was conducted on experienced and novice players. Based on the results, it appears that the application generally showed high accuracy in discrete notes playing, as well as receiving a positive rating in usability and realism. It was also reported that the overall user experience when using the system is influenced by the usability, workload, and realism of the application.

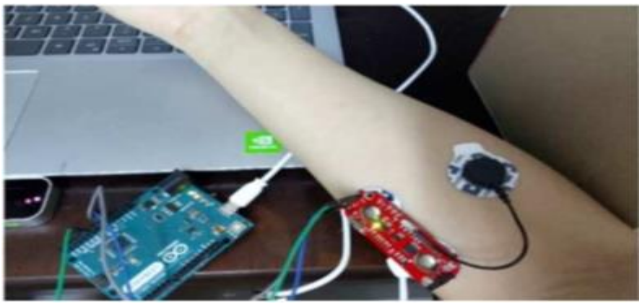


Fig. 3. The MyoWare muscle sensors on the arm.
Source: Adapted from [5]

The final application reviewed under this category is the work of Wijaya et al. [6]. They used two Leap Motion sensors to create a wider hand tracking area, and multiple pressure sensors attached on the user's fingertips for a better accuracy in checking the piano key press. As with [4]-[5], they also used a transparent acrylic board on top of the sensors for finger pressing. To further increase the piano-playing experience and piano learning, the application is equipped with an HTC Vive headset for an immersive VR environment during the learning session. Figure 4 shows the hardware setup of this project.

Fig. 4. VR piano learning platform.
Source: Adapted from [6]

B. *Other Virtual Piano Applications*

Virtual reality (VR) and augmented reality (AR) are other popular options for the virtual piano application. Guo et al. combined the use of machine learning (ML) and AR to develop a piano tutoring system [7]. The ML algorithm generates the hand motion animation automatically and the animation is displayed with a real piano using a head-mounted display.

Huang et al. also developed a markerless AR-based application for beginners to practice playing the piano [8]. In this application, the real piano is tracked trough image processing, contour extraction and analysis, keyboard recognition, and finally pose estimation.

Still within the VR/AR field, Li et al. developed a VR Piano Beginner application that focuses on the finger training system with auditory and visual feedback using data gloves, for children's intellectual development [9].

Another work conducted within the context of training uses a gamification technique for piano tutoring and integrates AR as a mean to reduce congnitive load with a continuous feedback system [10]. In this way, learning is made intuitive, interesting and more importantly, motivating.

The last AR application reviewed within this subsection is a mobile application for learning keyboard instruments [11]. The proposed application utilizes the Google Cardboard for visualizing a virtual character and instructions, where the character is programmed to give users real-time visual feedback based on the evaluation of their music playing performance by the system.

There are also other technologies used to develop a virtual piano. For example, a combination of computer vision and motion tracking can help to capture the information during the users interaction with the device, where the use of an acoustic piano can be simulated [12]. Similarly, Qiu et al. also used computer vision in images and videos for human posture recognition, followed by detecting and locating the virtual key position to implement the piano playing system [13]. VR and computer vision can also be combined to create a virtual piano appliation where the users can play the actual piano by just touching its image or projection, as demonstrated in [14].

III. PROPOSED SYSTEM

The main goal of the project is to implement an application that focuses on providing a fun learning environment to a beginner piano player, rather than just as an entertainment. This virtual piano uses the Leap Motion controller as its interaction method, which can improve the user experience by providing a more accurate finger tracking and natural interaction.

A customized MIDI converter algorithm is implemented in every songbook practice to convert the MIDI format file into piano notes and display them to the users at a slower speed. A tutorial practice is also included as one of the features. At the end of the practice, the whole learning process will be analyzed and displayed to the users.

The following subsections present the detailed requirements relevant to this project.

A. *Motion Detection Tool*

The Leap Motion controller is a small device that is connected to a computer that enables the manipulation of digital objects via hand motions. Its performance monitoring movement is at a speed of 200 frames per second rendering, and has a precision of one-hundredth of a millimeter.

The detection area of the controller is two feet above the controller by two feet wide and two feet deep on each side as shown in Figure 5. Furthermore, Leap Motion also provides sufficient number of libraries to simplify the implementation of hand detection.

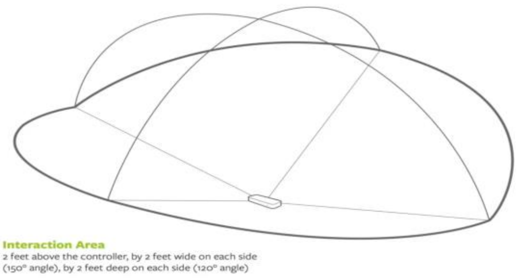


Fig. 5. Leap Motion controller detection area.
Source: Adapted from [15]

B. *Improvement of Accuracy*

Leap Motion provides basic libraries to detect and capture hand motion. However, it is difficult to produce a high accuracy finger tracking results using the Leap Motion library without implementing a more accurate algorithm. Using the Leap Motion libraries as its base, the new implemented algorithm must be written so that the application can differentiate each finger when the users play with several fingers instead of one. Apart from implementing the finger tracking algorithm, another concern would be in terms of the angle and position of the 3D model. The 3D model must be located at the most suitable angle to maximize the accuracy of the finger tracking. Moreover, the size of the hand model should be similar to the real world. The size of the hand should not be too big to avoid intentional collision with other notes.

C. *Leap Motion Stand*

When playing the piano, it is important for the users to be able to feel the keys they are pressing, and maintain the same level of their hand position. As demonstrated by [4]-[6], it is necessary to use a transparent acrylic board on top of the sensors for finger pressing, and to prevent muscle ache from occurring if they spend a long time practicing with the virtual piano. Based on the detection area of the Leap Motion controller, we designed the board stand accordingly as can be seen in Figure 6.

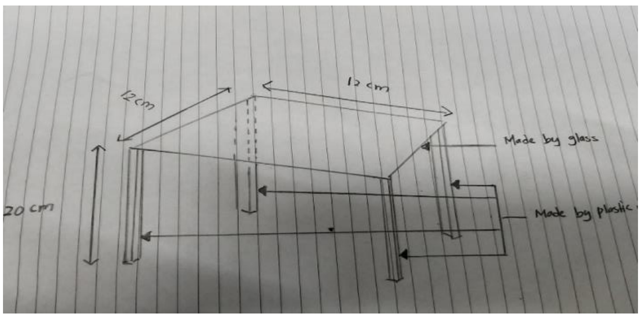


Fig. 6. Leap Motion stand draft.

D. *System Features*

Table 1 lists the important features implemented in this application, which considered a good learning experience for the piano players.

TABLE I. SYSTEM FEATURES

Features	**Description**
Songbook Practice	The application provides several songbooks for the users to play. On the songbook interface, it will display the difficulty, as well as a description of the song, as shown in Figure 7.
Tutorial Practice	The application provides a complete tutorial for the users to practice the fundamental of the piano. Users can select their desired tutorial. At the end of the tutorial, they are required to complete the test based on the learning outcome.
Free Practice	After the users have selected which song to play, the system will start the lecture lesson. The users are only required to follow the hints and instructions that are displayed on the piano keys, as shown in Figure 8.
Analysis Summary	At the end of each lesson, the system will display the user's final score and provide suggestion based on their previous performance, as demonstrated in Figure 9.
Demo Piano Play	The users can listen to the demo of the whole song being played. In this way, they can learn the songbook through visual and hearing.
Controller Guide	This feature displays the full instructions of the controller guide.

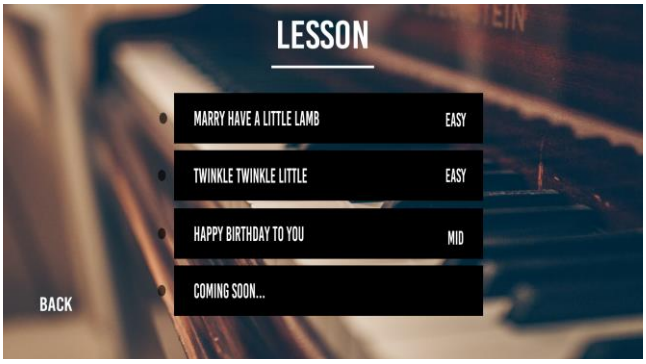


Fig. 7. The Songbook selection interface.

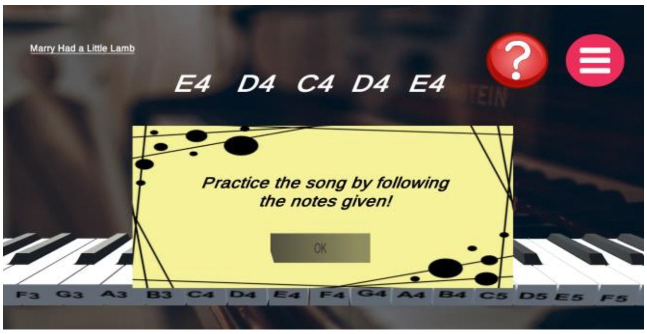


Fig. 8. Instruction is given for each practice.

Fig. 9. The Summary interface.

IV. System Design

A. MIDI Converter Algorithm

In order to fully control the display of the piano notes, a MIDI converter algorithm is implemented. The algorithm uses NAudio library to receive and read the MIDI file. Then, the Unity game engine is used to decode these binary files into MIDI events. Each MIDI event contains a MIDI message. There are three important elements in each message which are the command code, velocity and notes name. The command code represents the MIDI command name such as Note on, Note off, Timing Clock and Stop. The velocity represents the duration of the notes while the notes name represents the piano notes name of each MIDI events such as C4. Each MIDI events is queued accordingly in a queue called midiQueue. Only one MIDI event can be interpreted at a time. Hence, each MIDI event is removed from midiQueue after being played.

After obtaining these values, another algorithm is implemented to control the speed of the notes. With this algorithm, the tick per beat of the song can be manipulated manually. When the system receives a MIDI event, the algorithm will redefine the song's speed by multiplying the original time lapse with the tempo unit, which is then divided by the tick per beat.

Besides controlling the speed, the algorithm is also used to display the piano notes of each MIDI file by storing the MIDI files into the system, and generating the piano notes automatically. For the demo practice, the system converts the MIDI sequence into piano notes, and then plays accordingly as shown in Figure 10.

Fig. 10. The key played by the system based on the MIDI list.

B. Interaction Method

Two interaction methods are implemented for this application, using the keyboard, and the Leap Motion controller.

1) Finger Tracking Implementation

The leap motion library makes the development of the finger tracking simpler. It synthesizes the 3D position data by comparing the 2D frames generated by two cameras. It also provides a function to calculate the coordination of the user's finger movement in a millimetre unit.

To use the information provided by the controller, we must map the coordinate values from the controller to the appropriate application-defined coordinate system. The logic of mapping coordinates is applied to increase the accuracy of the finger tracking, using the formula shown in Figure 11. By applying the formula, the map of coordination can be changed to control the range of the detection area. If the detection area is increased, the interaction area will become wider.

$$x_{app} = (x_{leap} - Leap_{start})\frac{App_{range}}{Leap_{range}} + App_{start}$$

$$Leap_{range} = Leap_{end} - Leap_{start}$$

$$App_{range} = App_{end} - App_{start}$$

Fig. 11. The formula for mapping the coordinates.
Source: Adapted from [15]

After receiving the user's hand movement coordination, the origin of each hand is offset differently. Each hand's natural resting point is set as the center of the interaction area. The scale of the normalized coordinates is increased by a factor of 1.5 to increase the sensitivity of the finger tracking. Figure 12 and Figure 13 show the results of finger tracking.

Fig. 12. The UI for finger tracking.

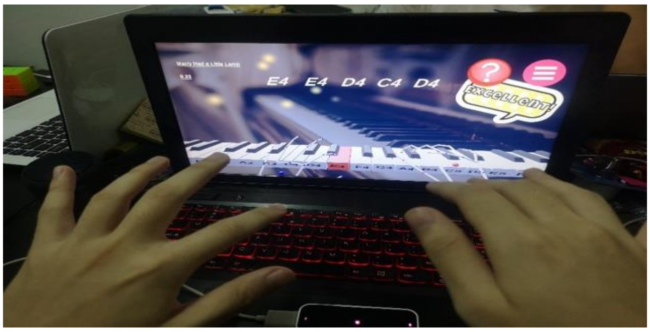


Fig. 13. The demonstration of finger tracking.

2) Keyboard Implementation

The arrangement of keys is important to provide a better user experience. Because of the limitation of the keyboard key, it is hard to imitate the position of the actual piano perfectly. The concept of the key arrangement is to group each octave into one region. The arrangement of keys is in a regular pattern so the users can easily get used to it. Figure 14 shows that each octave of the piano notes is well arranged in one region, based on the position of the octaves arranged according to the arrangement of an actual piano. For example, the 4th octave is arranged at the centre of the keyboard while the 3rd octave is arranged on the left side and the 5th octave is on the right side.

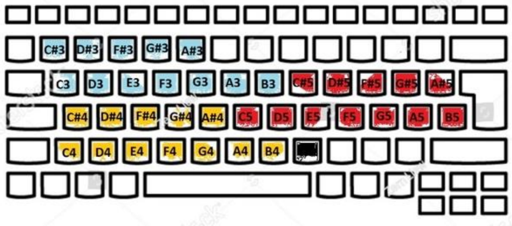


Fig. 14. Keyboard Arrangement Based on the Position of Octaves.

C. Sound Development

It is important to optimize the pitch and amplitude of each piano key to ensure that the users can enjoy the application without getting disturbed by the inaccurate frequency produced from the sound. After testing with different pitches and amplitudes, the frequency of the sound is set to 1000Hz, whilst the amplitude of the sound is set to 1db.

D. Development Tools

a) Programming Language: The programming language used in the project is C# since it is used in Unity scripting.

b) NAudio: NAudio is an open source audio toolkit. In this project, this library is used to receive and record the input of MIDI files.

c) Unity: The engine provides a wide range of tools and features that are easy to access. It supports cross-platform integration, allowing developers to switch to any suppoprted game platforms.

V. Discussion

A. Usability Test

The usability test was conducted on a total of 10 participants of different age groups and backgrounds. There are two age groups: i) between 18 and 25 years old; and ii) between 50 and 80 years old. The testing conducted for the second age group is an additional test to prove that the system can be used by senior citizens who are not proficient in using computer.

For the first age group, the test was separated into two categories based on the participant's background, those who never play a piano, and the intermediate or advance piano players. The results of the first category were recorded and analyzed because they are the target users of this project, whilst the results of the second category were collected to ensure the learning materials used in the application were accurate.

At the beginning of the test, the participants were briefed on the objective and the procedures. All participants were required to read through the controller guide on different input devices before starting the test. Then, they were given a list of tasks to complete within a specific time frame, which are the completion of songbook practice, tutorial practice, review of demo practice, review of analysis summary and review of the overall interface.

For the songbook and tutorial practices, the players were required to complete using both input methods. They had to complete both of these tasks twice in order to obtain a more accurate average result. At the end of the test, the participants were asked to give feedback based on their experience. The duration for each participant to complete the tasks was also recorded.

B. Observation

For the songbook and tutorial practices, the result showed that the Leap Motion controller was not that easy to use on the first attempt. At the time this testing was conducted, the acrylic board for finger pressing was not implemented, which resulted in the difficulty to position their hands correctly when playing the virtual piano. After taking some time figuring out how to use the controller, most participants were finally able to complete the song practice, except for a couple of participants who needed step-by-step guidance throughout the first attempt.

For the second attempt, all participants were already familiar with the controller, and managed to complete the task in a shorter time. There was no obvious problem observed when the participants were using the keyboard.

The completion time using the Leap Motion controller of each participant on both attempts is recorded in Table II.

TABLE II. Completion Time On Both Attempts

Participants	**Attempts (in seconds)**	
	1	**2**
1	186	96
2	124	55
3	197	88
4	65	29
5	70	41
6	80	55
7	111	71
8	43	27
9	88	45
10	92	31

TABLE III. Average Score On Each Criteria

Criteria	**Average Score**
Interaction with the keyboard (accuracy, easy to use)	9.2
Interaction with leap motion (accuracy, easy to use)	8.0
Learning Material	8.8
Overall experience with tutorial practice/tutorial test	8.3
Overall experience with songbook practice	8.3
Review on the controller guide	8.1
Review on the summary analysis	7.1

All participants were also asked to rate the usability of the application. Several criteria were listed, with the maximum score of 10 for each item. The average score for each criteria was then calculated based on the rating given by the participants, as shown in Table III. As can be seen from the table, the criteria with the lowest average score is the review on the summary analysis, which is 7.1. From the feedback given, the summary information provided is insufficient. They recommended for extra information, such as the comparison with the previous performance to be displayed as well. They also suggested that the summary analysis to be archived into formats such as Word or Pdf form, which can be treated as their achievement.

Some other feedback received includes the time required to understand how to position the hands accurately so it can be detected by the controller.

For the songbook and tutorial practices, most of the users seemed satisfied with the step-by-step learning environment due to the clear instructions given in every tutorial.

To determine the ease of use of the UI, we observed the testing conducted on the second age group. In the beginning, most of them struggled to use the controller as they were not good at using computer. They needed step-by-step guidance throughout the test. After receiving a thorough guidance, every participant in this age group was finally able to complete the task even though they took a longer completion time compared to the first group.

VI. Conclusion

The aim of the project to teach users to play the virtual piano using a Leap Motion controller was achieved. The results show that the learning curve in using the controller is high, even for the older participants who are not familiar with computer and the current technology.

Having said that, some of the proposed features were not implemented due to the time constraint. To improve the application further, the following features are crucial to be added to the current application.

1) Leap Motion stand (acrylic board): As previously mentioned, it is important for the users to be able to feel the keys they are pressing when playing the virtual piano.

2) Improvement on the accuracy of finger tracking: Even though the virtual piano is playable, the accuracy of the current finger tracking is still imperfect.

3) Song import: With this feature, the users can import their chosen song into the application for a practice.

4) Ranking System: This is essential to motivate users to keep on improving. It can include rewards for the users when they level up. For example, they can unlock some special songbooks when they have successfully ranked up. A customized badge can be designed to represent each level.

Acknowledgment

I would like to express my deepest appreciation and sincere gratitude towards a few individuals who not only helped me in finishing the project but also gave me the motivation to accomplish this project.

First, a huge thank you to Dr Nurazlin Zainal Azmi for constantly checking the project's progress and for her guidance on how and what to do to complete this project. Second, I must express my very profound gratitude to Dr Christine Lee for keeping me updated with any information related to the final year project.

Lastly, a huge shout-out to all participants who are willing to participate in the usability test. Without them, the project will never be accomplished.

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