Creating a Virtual Piano with Leap Motion Technology

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***Abstract*—With advancements in technology in the recent decades, almost all aspects of life have obtained a virtual form, especially with the recent COVID-19 pandemic. As a society, we have found a way to do almost all of our activities online, including learning. Music technology and education has taken a new shape as virtual instruments can oftentimes be more convenient and cost effective. This paper discusses the creation of a virtual piano that can be played with the Leap Motion controller. It will discuss previous research in virtual instruments, the creation of the virtual piano, a research study of the project, and potential future work.**

***Index Terms*—Leap Motion, music technology, technological piano, Unity, virtual learning.**

1. Introduction

The rise of gestural recognition platforms have given way to new opportunities of musical instruments. Using newer technologies, we have begun to explore potential improvements to the existing virtual instrument field, where users can interact with realistic instruments without the need for one. Ultraleap's Leap Motion controller, an optical hand tracker, is one of these technologies that have allowed the creation of new interactive virtual instruments.

Our team has created a virtual piano that can be played using the Leap Motion device. Users hold their hands above the controller which sits flat on the table in front of the computer keyboard. The user's hand movements are reflected onto the computer screen where they can interact with the virtual piano. This project has the potential to create interactive tools with an abundance of uses including music education, medical rehabilitation, and the replacement of a real piano.

Since the start of the COVID-19 pandemic more than a year ago, virtual programs are now required more than ever. Schools continue to teach online which has greatly impacted the way music is taught. Many students no longer have access to real instruments which can greatly impact the effectiveness of their learning. Teachers have resorted to showing videos which are less effective than hands on learning. This project could allow students to continue learning about music while still remaining in a virtual environment.

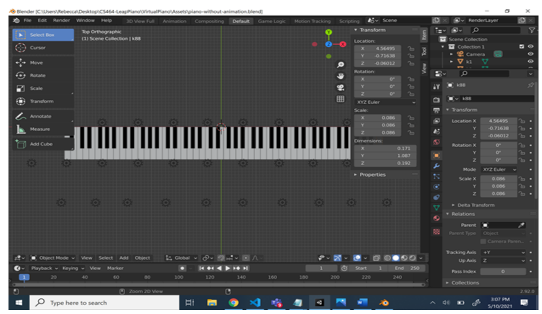

Figure 1. This is the model developed by a previous group in Blender. We have added additional components in Unity to create the virtual piano. Image taken by Kopacz and VandeRiet.

Interactive tools provide more opportunities for education, and virtual musical instruments can be the perfect tool for music education. The virtual piano is significantly cheaper than any other option currently on the market. They are also smaller, portable, and have the potential to include a multitude of instruments students might not usually have access to. These benefits could allow schools to stock their music rooms with many instruments at a fraction of the cost. Teachers and students would be able to have more resources readily available to use at their discretion.

Additionally, gestural based technology and Virtual Reality (VR) have become increasingly helpful tools within the medical industry. One of the uses of this technology, is within rehabilitation and physical therapy. Patients are able to incorporate their entire bodies which allows them to recuperate in a new and improved way. "Within Medicine, VR has been used in teaching anatomy, training in diagnostic procedures (such as virtual colonoscopy, or virtual bronchroscopy), teaching open and minimally-invasive surgery procedures, and in rehabilitation," [19]. While a virtual piano may not be a necessary tool for most medical needs, the base technology is a potential tool that could contribute to the development of medical related VR programs and rehabilitation.

2. Background

The introduction of gesture based interaction and new input technologies have given rise to many new forms of Human-Computer interaction, including the debut of digital based musical instruments. Electronic music has become an increasingly popular development in the last few decades, though it is not new technology. One early example of electronic music is the Theremin invented in 1919. This instrument was also gesture based as it was played by moving one's hands between two metal antennas to control frequency (pitch) and amplitude (volume). Recent developments in digital musical instruments enjoy increasingly more user interfaces. Touch screen and Virtual Reality (VR) devices are just some of the many interfaces that have allowed for advancements in the music industry.

With more sophisticated gesture based technologies, the world of digital musical instruments is growing. Now, technologies can better emulate playing a real instrument without actually needing one. Devices like Microsoft's Kinect, Nintendo's Wii, and Virtual Reality headsets have opened doors for an even wider range of possibilities. The Nintendo Wii remote's debut in 2006 allowed for many cost effective experiments including, the "Wiiolin" [9], a virtual violin that could be played by moving the Wii's sensor bar over the Wii remote. Another example is the ChromaChord, which uses an Oculus Rift headset and Leap Motion controller. The leap motion controller, made by UltraLeap, is an optical hand tracking module which captures the movements of the user's hands. The device plugs into the computer's USB port and sits flat on the table in front of the keyboard. Users hover their hands about six inches over the device, and the leap motion will imitate the hand motions onto the screen. The device has little to no noticeable latency, allowing the user to comfortably play without frustration. This system allows a performer to play single notes and chords [15]. Developing virtual reality musical instruments such as the Wiiolin and the ChromaChord is a challenge, but they are extremely beneficial to the continuous growth of human computer interaction.

Others areas of technology in music have been studied including tempo, latency, and precision with instruments. In 2011, as multi-touch surfaces became increasingly popular, Montag, Sullivan, Dickey and Leider explored the effects of audio latency and how it provided a negative experience to any kind of musical technology using the interface. They then created a multi-touch table that uses a system output that simultaneously drives the audio display and the haptic display, resulting in no latency between audio and haptic feedback systems. Performance context and behavior were also studied in relation to the analysis of digital musical

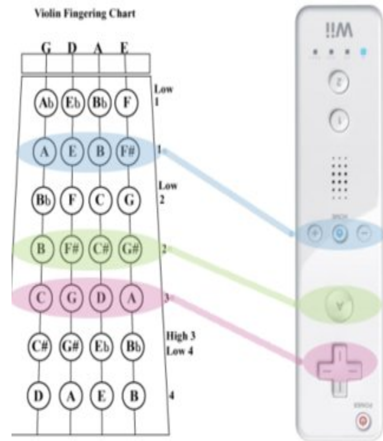

Figure 2. This is an image that describes how the "Wiiolin" works. This image is by Tracy Anne Hammond on reasearchgate.net. Found using a public domain.

instruments and new interfaces to do so [11].

While many musical technologies have emerged, virtual teaching devices for music are still in the early stages of development. "[M]ost instrument implementations in VR are simple string or tapping based instruments," [14]. The more complicated an instrument is, the harder it is to develop it as a virtual reality musical instrument. Camera-based motion tracking is a common technology used with musical interfaces and human computer interaction. It utilizes cameras and infrared sensors to "see" a person's motion [2]. The use of wearable technology, such as data gloves, is another popular way of determining the gestures of humans. It is effective with the detection of joint angles and other orientations of the body [2].

One combined approach, of camera-based motion and wearable technology, is the Leap Motion tool. The Leap Motion "is a USB peripheral designed to create an invisible air space surrounding a computer screen that can be interacted with," [13]. Since its development in 2013, the Leap Motion has contributed a lot to musical interfaces and human computer interaction. Unlike the Xbox Kinect and other similar systems, the Leap Motion is capable of tracking larger movements and more precise gestures. It is a groundbreaking device that is a widespread tool for any interface of musical expression.

The Leap Motion and other technological systems have contributed a lot to the development of virtual reality musical instruments, but they are also important to other human computer interaction activities. However, unlike other activities, "music seems to involve almost aloof the brain," [6]. It can involve the whole body, not just the mind, which is vital to those suffering from Alzheimer's and other diseases. Music helps people to engage their bodies and minds. The combination of both music and body movement can really help with rehabilitation for many patients.

The piano is one musical instrument that has been created into a virtual reality musical instrument many times. Augmented reality (AR) has played an important part in the development of piano teaching techniques. “The application of augmented reality technology in teaching has great potential, which can optimize the presentation effect of teaching materials and promote the interaction between teachers and students in class,” [7]. Although the piano has been recreated virtually several times, there is always a need for more improvement.

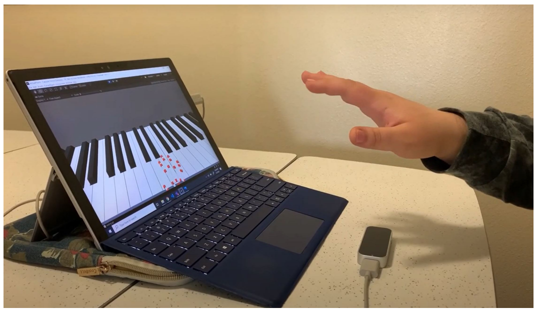

Figure 3. Kopacz demonstrates the virtual piano on Unity using the Leap Motion device.

3. Methods

To create the virtual piano, our team adapted a piano model in Unity to virtually play the instrument using a Leap Motion device. We added the existing model, created by another team in Blender, to Unity and added additional components like the Leap Motion, lighting, and adjusted the camera to view the notes around middle C. From there, we added colliders to every key as well as capsule colliders to bone three of each finger (the tip). When a finger and key collide, a script which is attached to each key is called. We developed the script using Visual Studio Code. In the script, the audio clip for that note is played and the key is depressed. When the two are no longer colliding, the key raises back up. This allows the user to press and hold notes.

After we created the script, we attached an audio clip to each key. We were unable to find a full range of notes that were of good quality and cost effective. The piano currently has the notes from C4 to B4, chromatically. This means it has a total of 12 notes.Users of the virtual piano are able to use one or both hands, as shown in Figure 3.

Our repeated-measures experiment for this project allowed us to get feedback from a group of volunteers and get their opinions on the features and format. We created a survey using Google Forms to allow participants to complete the experiment while working remotely. The participants were first asked a few questions to get a feel for the demographic. Some of the questions included gender, age, career background, etc.. We also asked a few questions regarding their musical background to see how familiar the participants were with musical instruments. The participants were then asked to watch a short video we created as an overview of the project. It included an explanation to how the piano was developed and how it is played. It also featured several angles to allow the volunteers to understand as much of the project as possible. In the future, we hope to allow people to test the virtual piano in person. Next, we asked some followup questions: rate, on a scale of one to five, how close the virtual piano is to a real piano, what features is the piano missing, and what should be taken out or changed in order to improve the functionality.

Figure 4. Virtual piano model in Unity. Image taken by Kopacz and VandeRiet.

4. Results

The results of the survey gave us some valuable insight to improve the first prototype of the virtual piano. We found that of the 22 participants, 13 play an instrument, eight of which are the piano. This was important because it allowed us to see how the virtual piano compares to a real piano. These eight participants have extensive knowledge on the look and feel of a piano, though most people have at least touched a piano before. Close to 80% of all of the participants believed that the virtual piano could be closer to a real piano after improvements.

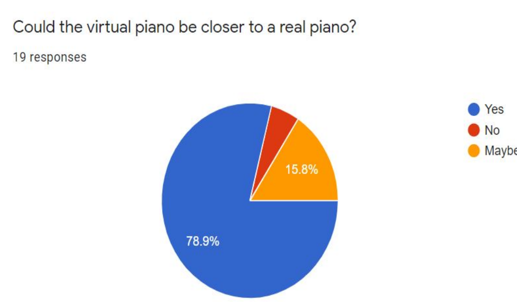

Figure 5. This graph was taken from survey feedback from participants. It shows how most participants believed that after some improvements, this virtual piano could function closer to a real piano.

The main criticisms included that the virtual piano was too sensitive, and that the accuracy needed to be improved.

Due to the high sensitivity, it is not uncommon for multiple keys to be pressed at the same time. The Leap Motion sensor is not as accurate as this virtual instrument requires, and that could be a feature that is improved in the future.

Additionally, adding a sustain pedal was suggested by multiple participants, which could allow for longer notes, although more sensors or hardware would be necessary. Several people also stated that to play a piano well, it requires haptic feedback to allow them to play the correct notes without looking. While the Leap Motion Sensor does not have this capability, it is possible that another technology could allow this feature.

Overall, the participants thought that the current features of the virtual piano were necessary and should be kept, although the suggestions previously mentioned should be added eventually as improvements.

5. Limitations of Study

This virtual piano is rather simple to use, and easy to understand. However, there are plenty of limitations. The primary limitation is that users must know how to play the piano, or at least be familiar with one. It would be a challenge to play a more complicated piece of music on this virtual piano, due to its sensitivity, however upon improvements, it could certainly be possible.

Another limitation is that the program that was created cannot currently work with other virtual instruments. A virtual violin, guitar, or flute, for example, would all require completely different 3D models and programs started from scratch.

It would be possible to use a different sensor, rather than the Leap Motion, in order to attempt to decrease sensitivity, but it is likely that parts of the program would have to be rewritten. However, a sensor with less sensitivity and a more precise range would help improve the functionality of the virtual piano greatly.

6. Design Implications

With the current design and program, the development of the virtual piano is far from over. Currently, the best way to "play" the program is to use one's pointer finger to virtually touch the keys. Users simply hover their hands over the device and use their fingers to press down keys. When the user's finger moves down, the leap motion tracks this movement and presses a key down on the screen. Due to the inaccuracy of the Leap Motion tool, the program can mistake additional fingers also pressing down keys. This means keys next to the desired key are often times also played. When using two hands, the program can also struggle to see both hands clearly. When the user is primarily focused on one hand, the other hand has the potential to glitch. While using one finger is an easy way to get around these issues, the program was designed for the user to use both hands and every finger, just like they would with a real piano.

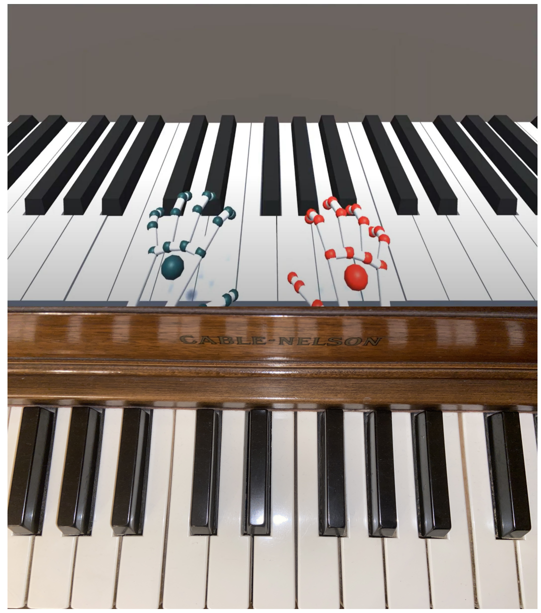

Figure 6. Figure 4 (top) is shown again with a comparison to the keys of a real piano (bottom). Both images taken by Kopacz and VandeRiet.

7. Conclusion and Future Work

Future research regarding virtual reality musical instruments could include the composition of music virtually. There are systems that are able to "compose music reflecting users' feeling of music," [17]. This could aim to produce music virtually through the use of systems such as the Leap Motion.

Additionally, adding more audio clips to correspond with more octaves would be another improvement for the virtual piano. Even further, changing the volume based on how fast the key is played could be incorporated. Currently, when a user virtually holds a key down or just lightly taps it, the sound is the same. Upon this improvement, the collision function would be able to track the magnitude of collision and play the corresponding audio clip at a certain volume for each magnitude type.

Also, virtual reality musical instruments are the future of adaptive music technology. "Adaptive music technology refers to digital technologies allowing people who cannot play traditional musical instruments to engage in musical activities, without external sources assisting in the music making," [4]. Virtual reality musical instruments have played an important part in the development of human computer interaction and have the potential to contribute to adaptive music technology and other developments in the future.

Overall, the project was a success. We started with just the 3D model of the piano, and were able to add all of the components to create a working prototype of a virtual piano that can be played using a Leap Motion. As this is a prototype, there are a multitude of potential improvements that could make this piano even better. Although many features could be added to this project, the foundations we have created are a good base for us and others to build upon in the future. The virtual piano itself needs plenty of improvements, but it is functional and exceeded our team's expectations.

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