Music Everywhere – Augmented Reality Piano Improvisation Learning System

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ABSTRACT
This paper describes the design and implementation of an augmented reality (AR) piano learning tool that uses a Microsoft HoloLens and a MIDI-over-Bluetooth-enabled electric piano. The tool presents a unique visual interface—a "mirror key overlay" approach—fitted for the AR environment, and opens up the possibility of on-instrument learning experiences. The curriculum focuses on teaching improvisation in blues, rock, jazz and classical genres. Users at the piano engage with interactive lessons, watch virtual hand demonstrations, see and hear example improvisations, and play their own solos and accompaniment along with AR-projected virtual musicians. The tool aims to be entertaining yet also effective in teaching core musical concepts.

Author Keywords
Augmented reality, Microsoft HoloLens, transformational games, music learning, improvisation

ACM Classification
Human-centered computing~Mixed / augmented reality,
Applied computing~Sound and music computing,
Applied computing~Interactive learning environments

1. INTRODUCTION
The majority of computer-aided piano education tools use a screen-based display to convey information to the user [1, 2]. Other systems use hardware-based indicators—such as embedded LED key lights [3]—to guide users to the intended keys to play. There are problems with both of these approaches.

Traditional screen-based learning tools require users to visually transfer information from the device or screen to apply on the actual instrument. Hardware-based learning tools provide more direct guidance, but user engagement is diminished due to its limited display capabilities.

As a solution, augmented reality (AR) technology provides an ideal piano-learning environment. By projecting information onto the instrument, an AR system can create more direct interactions for the user [4], removing the need to transfer information from a separate screen. With its ability to project virtual objects into the user's visual perspective [5], it creates a new space to explore additional user-engagement activities and learning possibilities, beyond what existing screen-based or hardware tools can achieve.

2. RELATED WORK
A number of piano-learning applications already exist in the field. The *Piano Tutor*, developed by Dannenberg et al. (1990) [6], was one of the early implementations. Among its features is a grading mechanism that evaluates aspects of a user's performance and identifies mistakes such as accuracy of pitch, timing and dynamics. As an intelligent system, it reports these errors and provides user guidance to correct mistakes. A MIDI interface is used for such detection. The project established the foundation for other commercial music education systems that followed, such as *Yousician* [1] and others, which use screen-based displays. There are even other systems, like *The ONE Smart Piano* [3], that share similar lesson methodologies, but use hardware in place of the screen-based displays.

A recent system implemented by Chow et al. (2013) [4] goes further by utilizing AR as their display technology. It follows previous AR piano learning initiatives such as *AR Piano Tutor* (Barakonyi 2005) [7] and *Piano AR* (Huang 2011) [8] and uses a MIDI interface and an optical marker for tracking the position of the real piano.

Rocksmith [9] by Ubisoft, emerged from a family of products that combine game mechanics with music learning. Its system uses a MIDI-enabled guitar to communicate the notes and chords the user should play.

Figure 1: The rock showcase demonstration (Mixed reality capture shot)

3. DESIGN
The core of the Music Everywhere experience is a scaffolded curriculum, designed primarily to develop instrument familiarity, train pianistic skills, and provide immersion and engagement.

Lessons direct users to work with their hands apart at first, isolating for right hand improvisation and left hand accompaniment. Further, the user's focus is limited to only a few notes, gradually adding new ones as the lessons progress.

Throughout each step of the curriculum, users are guided through improvisation examples, demonstrated both aurally and visually. Focus is placed on encouraging correct play rather than highlighting mistakes made, and reinforcing aspects of melodic development, variation, rhythmic phrasing and other musical strategies. Users learn concepts and techniques via interactive lessons and rehearse their skills in practice sessions with the virtual musicians.

To accomplish these learning objectives, the following features were designed and applied.

3.1 Bluetooth-over-MIDI Connection

To facilitate communication between the HoloLens and the electric piano, a MIDI-over-Bluetooth protocol is employed. Music Everywhere's I/O module uses the Universal Windows Platform (UWP) MIDI support API, through which bidirectional key events can be detected, sent and received, allowing the HoloLens to know when a piano key is pressed—along with the associated velocities and durations—and/or the electric piano to know when a piano key should be triggered automatically.

3.2 Visual User Interface (UI) Design: Mirror Key Overlays

Figure 2: Different type of overlays – Precision overlay indicators (left), Improvisation overlay indicators (right)

Augmented reality "mirror key" overlays are positioned perpendicularly to the physical keys, providing unobstructed visual instruction, while connecting directly to the indicated keys. Additionally, their location encourages proper eye-positioning, directing the user's focus above the keys during play. This counteracts the tendency to drift one's gaze downward. In the mirror key system, there are two distinct types of UI overlays:

- **Precision overlay indicators** guide users to play individual notes, at specific timings and durations, all with the proper fingerings. This is useful and effective when the objective is to teach the user a particular melodic line.

- **Improvisation overlay indicators** highlight a range of notes that will sound harmonious when played along with chords in a given progression. As the background chords change, the note ranges shift to match.

3.3 Virtual Musicians

During the Music Everywhere lessons, guests play alongside animated, virtual musicians in blues, jazz, rock and classical ensembles. In addition to providing enhanced visual engagement, their inclusion in the AR space offers several important experiential benefits.

- Genre theming informs users about the style of music they will play without the need for lengthy instructional exposition.

- Synchronization between the music and visually-represented musicians simulates the real experience of playing with others.

- Users learn the correct context in which to use improvisation and, alternatively, accompaniment skills.

3.4 Additional Features

- Animated Hand: In order to demonstrate correct hand positioning and more advanced playing techniques, a 3D virtual hand is introduced into the AR space. Users can observe the demonstrations or place their hands directly within the projection during play to follow along. A hand recording pipeline was implemented to capture the performance of a real pianist. A Leap Motion hand tracking device was used, in conjunction with a custom-built glass casing to overcome Leap Motion's capture errors. Further, we developed a key frame animation system to edit and improve loss and inaccuracies commonly obtained during the hand data capture process.

- Lesson Builder: A development framework was deployed to ensure the creation of engaging lesson content. The lesson builder includes multiple component nodes (e.g. key highlighting, virtual musician spawning, audio clip playback, etc.) and provides a graphical user interface (GUI) editor for non-technical designers to build and iterate lesson sequences.

- Score Reader: The system can import and parse any musical score from the notation software, Sibelius, via the MusicXML format. Once score data is loaded, all lesson components can access the imported music. For example, an animation node can sync a virtual musician's movements to the notes contained in the player's musical score, coordinating with the particular sound files for their parts. As well, the piano "mirror key" overlays are driven by data from an imported Sibelius score.

4. ACKNOWLEDGEMENTS

We are grateful to the faculty and administration of Carnegie Mellon University's Entertainment Technology Center for approving and supporting this graduate student pitch project. Special thanks to Roger Dannenberg, Anthony Daniels, Tina Blaine, Ralph Vituccio, Dave Culyba, Brenda Harger and Jesse Schell for their valued insight and assistance.

5. REFERENCES

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6. VIDEO APPENDIX

Product video: https://goo.gl/D33VQt
Demonstration video: https://goo.gl/FL3ptp