Radarmin: A Radar-Based Mixed Reality Theremin Setup

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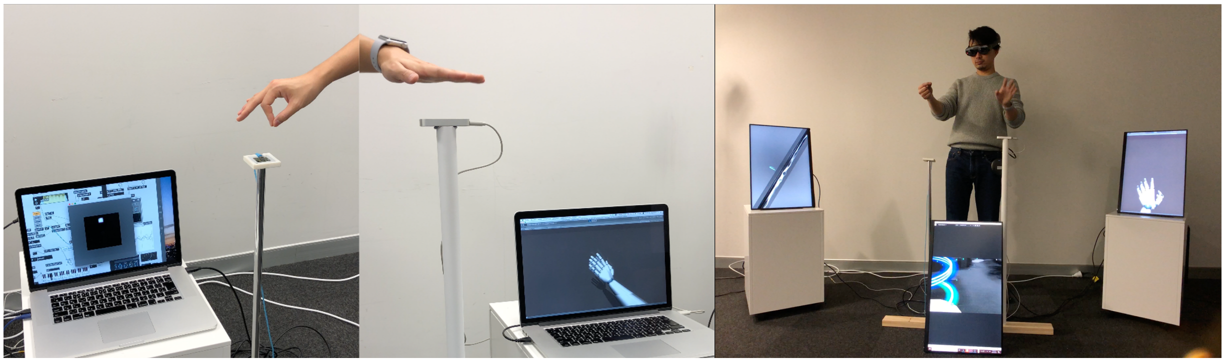

Figure 1: The Radarmin setup (right). A radar for theremin pitch control (left) and a Leap Motion for drum input (middle). The inputs are visualized on the left and right screens, with the middle one showing the MR view

Abstract

The theremin can be a difficult musical instrument to master because the slightest of motion across the whole body, or even nearby people can impact the sound. To create an intuitive theremin-like experience, we present Radarmin, a simple setup consisting of a Leap Motion sensor[1], the Magic Leap[2] Mixed Reality (MR) headset, and a miniaturized Range-Doppler-based radar for detecting fine grain finger motion. The precise position of the fingers on the right hand is mapped to pitch control, while the left hand's larger movements uses the Leap Motion for complementary instrumental input. To make playing easier we provide MR guidance cues of virtual images for hand placement and spatially mapped sound visualization. Participants experience Radarmin in a rhythm game, where they can learn how to play the musical instrument with the appropriate visual and audio feedback in MR. Radarmin's main goal is twofold; to use a miniaturised radar as an interactive input device in XR, and to develop a MR tool to teach how to play the theremin.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

The theremin is difficult to master for two key reasons: 1) the pitch characteristics are non-linear and 2) it quickly varies according to the environment [7]. This means that people with little to no experience in playing an instrument cannot even play a required pitch correctly [1]. Any form of exaggerated movement, or even that of a bystander passing by, can affect the music output. Even though other musical instruments also require fine-grained finger movements such as the guitar, the theremin lacks any form of tangible feedback, leading to its overall arguably higher difficulty to master.

In this work, we present Radarmin, which uses a miniaturized radar, the Google Soli [6], as input for a virtual theremin. Unlike conventional hand tracking solutions, the Soli sensor is able to detect fine grain movement of the fingers and is not affected by occlusion [8]. We couple this with a Leap Motion sensor for complementary drum input, and the use of the Magic Leap headset for experiential and training visualization. In our system spatial audio and visual MR cues are used to show participants where to correctly place their hands to play the instrument in a rhythm game.

2 Related Works

The use of virtual musical instruments as a form of rhythmic gaming is a popular choice for both training and entertainment. For example, the HyperDrum [3] was a set of virtual drums that is played between two individuals in VR, which could be used to teach drumming. VRmin previously explored the possibility of using MR for theremin tutoring [5], and it was proven that the performance error was significantly smaller with the aid of MR [4]. However, these studies rely on VR hand tracking, which is not as accurate.

The use of a radar to aid in musical instrument use has been explored [9]. However, the radar used was custom-made and large in scale, making the act of playing it feel unnatural when compared to the physical instrument. The Soli sensor [6] was first introduced in 2015 as a miniaturized radar sensor operating at 60Ghz that is able to detect micro finger motions through material and with very little power consumption [8]. It is used in the Google Pixel 4 smartphone[3] for contactless gesture sensing. The sensor has also previously been used in a musical interaction tool, O Soli Mio [2],

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[1] https://www.ultraleap.com
[2] https://www.magicleap.com/en-us/magic-leap-1
[3] https://store.google.com/us/product/pixel_4

as an audio synthesizer. From these related work, the key novelty of Radarmin is that it uses a commercialized radar sensor that is compact, robust (no moving parts and able to penetrate material), and accurate that, when coupled with our MR implementation for hand guidance placement, creates an experience that is both educational and accessible for many.

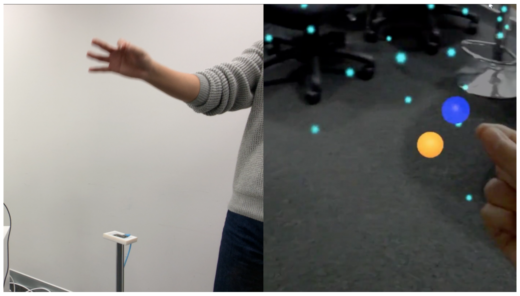

Figure 2: MR view of the virtual ball for hand guidance

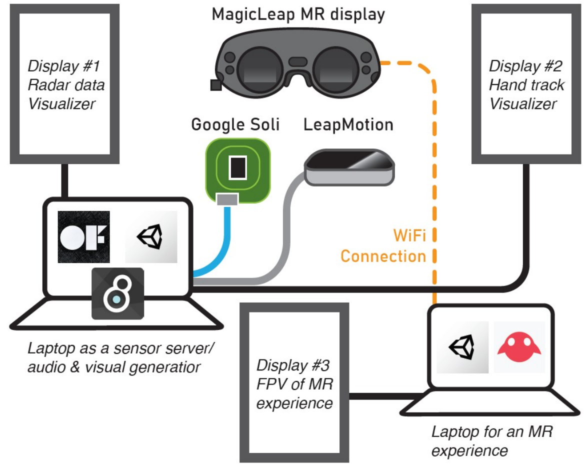

Figure 3: System diagram for Radarmin

3 Implementation

Radarmin uses a single Soli sensor paired with a Leap Motion and Magic Leap headset. We fabricated a setup out of a PVC pipe (length of $95cm$) that holds the Soli sensor, a hollow steel rod (length of $90cm$) that holds the Leap Motion, and a wooden block ($6.5cm \times 3.2cm \times 900cm$) that holds them together. A Macbook Pro laptop was setup to receive the raw signals from both of the sensors and to synthesize the audio. The audio is then broadcasted to a Windows desktop machine via Open Sound Control (OSC) for the MR visualization that is built with the Unity Engine[4].

From the collected Range Doppler signal of the Soli sensor, we compute the energy intensity and map it to the volume output. If no hand is present, no sound will be audible. We also compute the range signal, normalize it, and map it to a corresponding musical pitch (lower hand placement is equivalent to lower pitch, and vice versa). To aid with hand placement, we visualize a virtual ball in mid-air above the Soli sensor. The participant needs to place their pinched finger at the exact position of the ball for accurate pitch control, as shown in Figure 2. For the drum control, virtual rings will gradually fall on the drum as guidance for the right timing to hit the drum. The tracking solution for the left and right hand is separated because the drum input for the left hand does not require micro gestures and is merely dependent on the distance of the entire hand from the Leap Motion. Simultaneously, we also use the resulting synthesized audio to directly affect the virtual environment in the form of a reactive audio visualizer placed around the participant. The final setup is shown in Figure 1, with the system diagram shown in Figure 3

4 Experience

For our 5 minute long demo, participants would need to keep their right hand placement aligned with the virtual ball, while at the same time hit the drum with their left hand when a virtual ring hits the drum. They will be able to hear the resulting music that is produced from the Soli sensor detecting their finger movements in mid-air as the virtual environment reacts to it. With the Magic Leap on, they will see particle effects surrounding them that reacts to the audio generated from their performance. For the training side, a virtual blue ball is shown hovering above the Soli sensor and the participant is required to placed their fingers (a pinch-like gesture) over the blue ball and follow its movement for optimal performance. A virtual drum is placed above the Leap Motion with virtual rings falling on it to indicate the timing to hit it. At the end of the experience, participants will be shown a score of how well they performed, including a logged scoreboard to compare their performance with previous participants. The entire demonstration will take no longer than 5 minutes (about the length of one song), and we will improve the visualization and music quality to deliver a more immersive and educative experience.

5 Conclusion

We present Radarmin, a minimalistic setup for playing a theremin that consists of a Google Soli sensor for precise theremin pitch and volume control, a Leap Motion for complementary instrumental input, and the Magic Leap headset for MR guidance and visualization.

References

[1] A. Alford, S. Northrup, K. Kawamura, K. Chan, and J. Barile. A music playing robot. In *Proc. of the Conf. on Field and Service Robots*, pp. 29–31, 1999.

[2] F. Bernardo, N. Arner, and P. Batchelor. O soli mio: exploring millimeter wave radar for musical interaction. In *NIME*, vol. 17, pp. 283–286, 2017.

[3] R. Hajika, K. Gupta, P. Sasikumar, and Y. S. Pai. Hyperdrum: Interactive synchronous drumming in virtual reality using everyday objects. In *SIGGRAPH Asia 2019 XR*, pp. 15–16. 2019.

[4] D. Johnson, D. Damian, and G. Tzanetakis. Evaluating the effectiveness of mixed reality music instrument learning with the theremin. *Virtual Reality*, pp. 1–15, 2019.

[5] D. Johnson and G. Tzanetakis. Vrmin: using mixed reality to augment the theremin for musical tutoring. In *NIME*, pp. 151–156, 2017.

[6] J. Lien, N. Gillian, M. E. Karagozler, P. Amihood, C. Schwesig, E. Olson, H. Raja, and I. Poupyrev. Soli: Ubiquitous gesture sensing with millimeter wave radar. *ACM Transactions on Graphics (TOG)*, 35(4):1–19, 2016.

[7] T. Mizumoto, H. Tsujino, T. Takahashi, T. Ogata, and H. G. Okuno. Thereminist robot: Development of a robot theremin player with feedforward and feedback arm control based on a theremin's pitch model. In *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2297–2302. IEEE, 2009.

[8] S. Wang, J. Song, J. Lien, I. Poupyrev, and O. Hilliges. Interacting with soli: Exploring fine-grained dynamic gesture recognition in the radiofrequency spectrum. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, pp. 851–860, 2016.

[9] B. Wöldecke, D. Marinos, P. Pogscheba, C. Geiger, J. Herder, and T. Schwirten. Radartheremin-creating musical expressions in a virtual studio environment. In *2011 IEEE International Symposium on VR Innovation*, pp. 345–346. IEEE, 2011.

[4] `https://unity.com/`