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Performing Music in Virtual/Augmented Space

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Abstract

With the evolving technologies in virtual and augmented reality, new applications are emerging in the field of music production. In this paper, we will introduce three virtual and three augmented reality instruments and evaluate them in terms of efficiency, learning curve and usability and point out future perspectives and possible improvements concerning this new way of musical expression.

Keywords: Music, mixed reality, virtual reality, augmented reality, musical instruments

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1 Introduction

Music is considered a universal language that all humans share. It can be regarded as a historical document of every human culture and human history itself. During the medieval times, music mainly consisted of vocals and very simplistic instruments. With the rise of the renaissance, new instruments were invented and the baroque era gave birth to opera and the orchestra. The classical age was the time of famous composers such as Mozart, Beethoven and Haydn who developed new forms of musical composition like homophonic playing styles that consisted of a single melodic line supported by chords. When the romantic era began, the musical restrictions of the past eras were broken and experimentations and thus artictic creativity became dominant. Finally, since the beginning of the 20th century, music has achieved a broad spectrum of styles which do not fit into the old categories and laws anymore. Experimentation is what defines music nowadays and with the technologies that evolve from day to day, there are endless possibilities yet to discover. Electronically generated sounds are the most famous invention of this era and new electronic interfaces have been invented for music production. One of the first

Fig. 1.1: Léon Theremin

electronic instruments of the 20th century is the Theremin. It was invented in 1919 by the russian physicist Lev Sergeivitch Termen, also known as Léon Theremin. It consisted of a box with two radio antennae and was controlled by moving the hands within the proximity of these two antennae. The right hand was the controlling instance of the pitch which was increased when moving the hand closer and decreased when moving the hand away from the antenna. The left hand controlled the amplitude by moving it close to the loop-shaped antenna at the left side of the box. When moving the hands, the instrument caused a sine wave sound. Besides being one of the first electronical instruments, the Theremin also represents the first gesture controlled instrument whose modern offsprings will be introduced later in this paper.

2 Virtual and Augmented Reality

Virtual reality or VR is the interaction paradigm which involves a user interacting with a synthetic or virtual 3D environment. Special devices would have to be used in order to achieve this. One of the earliest virtual-reality devices was developed by Ivan Sutherland in 1966. He was able to build the predecessor of the head-mounted display which featured stereoscopic vision. Since then, more and more research has been put into the development of new devices and techniques. A VR system would consist of a visual display which normally allows stereoscopic viewing. Stereoscopic displays enable the viewer to see images in 3D like in the real world instead of simply perceiving flat objects. The user of the system only sees computer-generated images. Specialized display devices such as a head-mounted display (HMD) give the user the relative freedom to physically move his head and get the impression of being immersed in the virtual environment. Other systems implement displays which are back-projected and cover the walls and the ceiling in an enclosed room. These systems are generally called CAVEs and allow stereoscopic visualization only if the user wears shutter glasses. It is essential that the images on the display correspond to the head movements of the user to give the viewer an impression of being surrounded by and immersed in the virtual environment. For such a purpose, tracking devices would be necessary to monitor head movements, for example. Different tracking techniques exist and have been used in different systems. Some of these adopt different technologies such as electromagnetic, ultrasonic, inertial, or optical techniques. Camera or vision-based trackers trained on references or fiducials have also been widely used. Interacting in a virtual environment would require input devices which allow three dimensional control. An example of a specialized input controller in 3D space is the space mouse. Data gloves, which detect finger and wrist movement, are also commonly used. Augmented Reality (AR) is similar to VR except that a user sees the real, outside world and the computer-generated images at the same time. AR systems create an illusion of virtual objects coexisting with the real world. Compared to VR, AR technology has many practical applications [1]. AR systems also make use of display devices similar to VR but allow composite viewing of the outside world and the virtual entities. A typical display is an optical see-through HMD. This display enables the viewer to see through translucent glasses and view the augmentations as well. In the case of AR applications, tracking plays a more crucial role than in VR systems since the virtual overlay would have to match real objects. This is an important issue in AR and is also called registration. The term registration denotes the alignment of objects in real and virtual worlds.

3 Music in Virtual and Augmented Space

As technologies evolve, new possibilities have opened up new ways in the field of musical expression. The first electronic instruments were created in the beginning of the 20th century, the Theremin being one of a few examples. The rise of electronic musical sound synthesizers in the 50's and 60's gave birth to novel musical forms and will continue to trigger further experiments concerning new ways of composing music and creating new performance instruments. With the birth of virtual and augmented reality, entirely new perspectives have risen. One of the most notable aspects of music creation in VR and AR surely is learnability. When learning a classical instrument, musicians must require skills to control and manipulate their instrument physically. This is acquired by auditive and haptic response of the instrument. No visual feedback is given. One of the main aspects of VR and AR instruments is the aspect of visualization. Most of these interfaces come along with visual feedback which is supposed to faciliate users to understand large quantities of information [8]. New instrument interfaces can be seen as a playful approach to creating music for novices and an additional aiding tool for music professionals in improving nuances in their playing style.

3.1 Instruments in Virtual Space

In the following section, we will present three virtual reality instruments created and used in a virtual room called EVE. EVE is a cave-like room in the laboratory of the Helsinki University of Technology's ALMA project whose aim is the construction of physical models for sound synthesis in HCI. The virtual room is 3x3 meters large with three walls and a floor onto which the visualizations are back-projected. The perception of the 3D virtual environment is provided through active shutter glasses worn by the user. Audio perception is given by 15 loudspeakers positioned behind the walls all around the room which allow sounds to emanate from any direction through Vector Based Amplitude Panning [1].

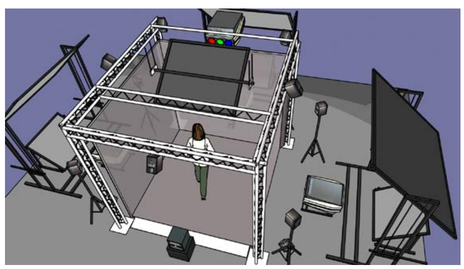

Fig. 3.1: Virtual room EVE

The interaction between the users and the system is carried out through data gloves having magnetic sensors attached to them which are detected by a six sensor magnetic motion tracker. The motion tracker calculates the position of the gloves via three-dimensional sensor location at a 100 Hz rate. The data gloves are able to measure the finger flexure due to optical fibers and return one integer value for each finger. The information received from the gloves and the magnetic tracker is then sent to the main frame running the virtual room which produces the graphics.

3.1.1 Virtual Xylophone

The Virtual Xylophone is an interface whose main components are a virtual mallet and an arbitrary number of virtual xylophone plates. In his left hand, the user wears a data glove that he uses for selecting the xylophone plates and place them wherever he wishes to within the virtual environment. The plates are created through grabbing the keys of

[1] method for positioning virtual sources to multiple loudspeakers [22]

a virtual keyboard that is placed on the left side of the user. The right hand holds a magnetic sensor which visualizes the virtual mallet. After creating a new plate with the left data glove, the new plate is attached to the user's hand ready to be placed wherever desired in the 3D world. Note names are always displayed above the respective plates and plates can be stacked on top of each other to play chords. Thus, the user can arrange the virtual plates in the manner he wishes to play on them and create the layout best suiting his/her playing style and piece. When playing a plate with the mallet, the collision is detected by a simple detection library. The hitting velocity is mapped to an impulse amplitude and sent to the sound model which interprets the signal and realizes the note that is being played. A piece can be saved, loaded and modified at will, making individual customization of the interface possible.

3.1.2 FM Gestural Synthesizer

The FM Gestural Synthesizer is yet another instrument created by the ALMA project. It is to say the virtual version of the Theremin introduced above, only with the sound of a predetermined FM synthesizer instead of a sine wave sound. The interface consists of a virtual piano keyboard which is displayed vertically serving as additional help. When selecting a pitch, the interface visualizes a thin line originating from the users hand onto the respective pitch (which is infinite) on the virtual keyboard. The sounds are produced by moving the hands wearing data gloves. The right hand controls pitch by moving up and down whereas the amplitude is controlled by opening and closing the right hand's fingers. The left hand is responsible for changing the timbre. Depending on the hand's relative position the timbre is calculated resulting in slight changes in the modulation indexes [2]. However, the modulation indexes are constant when the left hand is open.

3.1.3 Virtual Air Guitar

The last virtual music device created by the ALMA project that we will present in the following, is the Virtual Air Guitar. As the name already implies, it is not meant to simulate a classical instrument as the two latter ones do. It merely is ought to serve as an entertainment device. Thus it does not require any musical abilities. One of the main intentions that motivated the creation of the virtual air guitar was its use during a science center exhibition for offering an eye-catching attraction for visitors. Two versions of this device have been created: one is used in the virtual room EVE, the other on a Linux PC with a web-interface. It features a distorted guitar sound and is played by making guitar playing gestures. The main control variables consist of the distance between the hands for detecting pitch and the right hand's movements for plucking of strings. The interface provides a number of guitar playing styles such as sliding or vibrato which are produced by a sliding movement of the left hand along the non-existent guitar neck and shaking the left hand.

When playing the air guitar, the interface must map gestures to sound parameters which

[2] describes by how much the modulated variable of the carrier signal varies around its unmodulated level [23]

Fig. 3.2: The Virtual Xylophone, the Virtual FM Synthesizer and the Virtual Air Guitar

happens on three levels. Gestures are detected by an input module which sends out the data further on to a gesture recognition module for the identification of guitar playing gestures. These gestures can either effect the sound model directly or be sent to a phrase database first to produce musical phrases. The phrase database saves data on the gestures being made and the order and the time for sending them on to the sound model controller. The sound model controller then converts the data that the sound model can interpret. It is able to identify basic guitar playing techniques such as hammer-ons, pull-offs, sliding, vibrato and mute. The interface provides play modes such as free play or rock solos with built-in scale quantization which makes sure that only harmonious chords are produced and thus uses predetermined sound scales.

3.2 Augmented Reality Music Applications

Three systems which make use of augmented reality techniques will be discussed. Although AR technology has found its way into many different applications, not so many AR-based musical interface systems exist.

3.2.1 Augmented Groove

The Augmented Groove is a musical interface jointly developed by the ATR Media Integration & Communications Research Laboratories in Japan and the HIT Lab in the University of Washington. It makes use of augmented reality techniques which help the user produce and visualize musical patterns with the use of marked vinyl phonograph or long-play (LP) records. The setup of the system consists of a round table with the LP records placed in a rack. The user wears an optical see-through, head-mounted display (HMD) which allows her or him to see the outside world and the corresponding virtual augmentations. A user interacts with the system by physically manipulating the marked LP records. Unique visual patterns are pasted on the LPs. A ceiling-mounted camera coupled with a computer vision tracking software identifies and senses the marked objects and their movements. Every time an LP record is pulled out of the rack and moved, a corresponding dance music track is played. The music's pitch, distortion, and resonance can be altered by changing the position and orientation of the marked LP record relative to the overhead camera. Animated virtual 3D characters composited onto the LP records can be seen by the user through the HMD. The appearance and animated movements of the virtual characters correspond to the resulting variations in the musical output, thus enhancing the user's musical experience. The Augmented Groove features the capability for collaborative musical performance. Two users wearing HMDs could hold a jam session by playing together an improvised, unrehearsed musical piece – each one taking each other's cues or complementing the harmony produced by the other.

3.2.2 The Music Table

The Music Table is a further development of the Augmented Groove project. A table and overhead camera makes up the basic system setup. Instead of using vinyl records, cards with fiducial markers are employed. A large screen display is also used instead of HMDs. The interface mimics that of the Augmented Groove system. The Music Table however goes further than its predecessor by extending its control and visualization features. The physical cards are classified into note cards, copy cards, phrase cards, phrase-edit cards, and instrument cards. A note card comprises the basic element in the composition of a musical pattern. A note-sequence is played every time a note card is placed on the table. The card's relative position to the user determines the pitch and loop-timing of the note being played. Rotating the cards controls the volume and tilting them alters the length of the note. Arranging more note cards on the table would produce a musical pattern. A pattern or musical phrase could be captured using a copy card and saved onto a phrase card. Another special card called the phrase-edit card can be employed to make changes onto a captured musical pattern. Specifying a particular type of instrument to play a particular note or phrase is also possible with the help of an instrument card. Applying the different functionalities of the special cards is as simple as manipulating them or putting them in close proximity to the other objects. Just like the Augmented Groove, the Music Table makes use of augmented visual representations. Animated characters can be seen in the large display as overlaid onto the cards. The 3D characters in a note card appear as small legged-creatures which change their appearance, visually representing changes on the note's musical parameters. Increasing a note's volume, for example, shows the virtual creature on the note card mutating with spikes. Increasing the note's length by tilting the card results in an elongation of the virtual creature's body.

3.2.3 The AR Disc Jockey

The AR-DJ is a 3D device for making collaborative music in clubs. The system's sound engine includes various sound samples which can be loaded and mixed with regular sound features. The interface enables the DJ to drag and drop specific sound sources in a virtual 3D model of the dance floor using a pen tracker and a keyboard for switching and accessing the sound sources. The model provides visualization of the sounds related to their positions within the actual dance floor and rearrangements of sound sources via small hand movements. The number of sound engines applied can be altered as desired in order to produce several output channels which are compatible to existing club sound systems. This possibility can be used for two different interface versions. One being a 1:1 model of the real environment where any changes can be made in real-time, the other being an exact simulation of the real world but with a different sound set for prelistening and mixing. This feature is useful for collaborative sound production with one user arranging sound sources on the dance floor in real-time and the other premixing sounds at the same time.

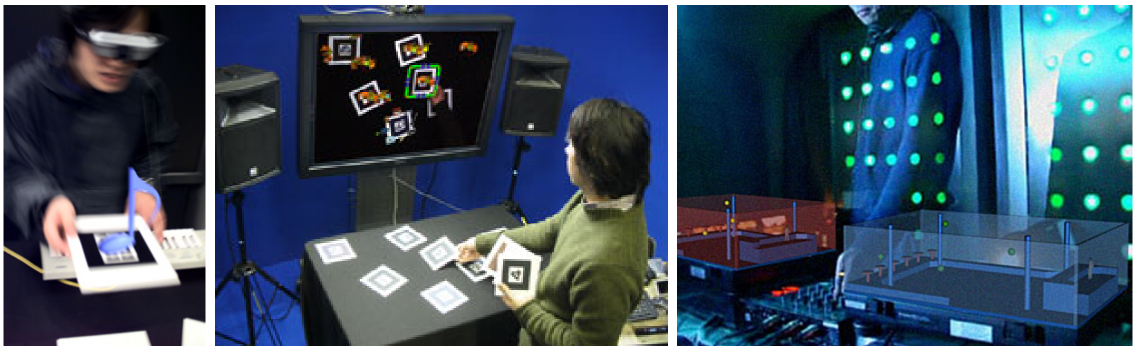

Fig. 3.3: The Augmented Groove, AR Music Table and AR-DJ

4 Discussion

4.1 Working in an Augmented/Virtual Environment

Human-computer interaction in augmented/virtual space or VR/AR environments opens up a wide range of possibilities. It paves the way for enhancing musical experience and extend its function and control. The techniques involved with VR/AR environments afford interface schemes which could not be done in normal situations. There are certain issues however that are peculiar to the technology and which still need to be addressed. We will now discuss some of the factors involved which makes working in an augmented or virtual environment unique and discuss the issues that arise with regard to its application to music-generation systems.

4.1.1 Natural Mappings in 3D Space

Compared to a typical PC desktop environment where mouse and keyboard control is confined to a mere two-dimensional space, the world of virtual and augmented reality is considered in three dimensional terms. This puts musical interface systems based on augmented/virtual techniques at an advantage over conventional desktop approaches. A consequence of this is the ability for a human to interact with the system with a greater degree of freedom in terms of movements and gestures. The different musical instruments presented in the previous section made thorough use of natural mapping, that is, as Donald Norman defines it, ”taking advantage of physical analogies and cultural standards” to establish a relation ”between the controls and their movements and the results in the world” [14]. In the FM Synthesizer application, moving the right hand upward increases the pitch of a note. This is an example of mapping height relations with quantitative properties. Opening one’s hand results in an increase in volume - establishing an effect compared to 'releasing' sound from the hand. The Augmented Groove and Music Table also map relative height movements of the marked objects to pitch control. With the Music Table, moving a card close to another establishes a relationship between both objects like copying or pasting phrases with a copy card. Card manipulations include tilting and rotation. These movements characterize the six degrees of freedom (6-DOF) as an inherent property of three-dimensional space. The 6-DOF include identifying locations in 3D-coordinates and the orientation properties of yaw, pitch, and roll [7].

4.1.2 Spatial Resolution

Spatial resolution is a constant issue among the different musical applications that have been reviewed. In VR/AR environments, movements or changes in position or orientation of objects would have to be sensed or tracked. Due to inherent inaccuracies of tracking systems, the VR/AR instruments encounter problems achieving the same spatial precision as that of a traditional instrument. As a case in point, the developers of the Virtual Xylophone designed the virtual plates to be larger than its physical counterpart to facilitate tracking. In effect, a different degree of playing style would be necessary to play the instrument as compared to a real xylophone. Likewise, the Air Guitar could not be played with plucking maneuvers. The tracker could only sense coarse hand movements like strumming and not the finger placements on the virtual fretboard.

4.1.3 Dynamic Visualization

Dynamic and even stereoscopic visualization are the common techniques used in VR/AR environments. This signifies an important feedback mechanism which strongly enhances a system's functionality. Traditional musical instruments generally provide audio and tactile feedback, but not much of visual output for indicating vibrating strings or pressed keys. VR/AR visual enhancements could offer visual cues to facilitate music playing. The FM Synthesizer, with its visual display of notes, turned out to be an easier instrument to play compared with the Theremin, from which it was originally modeled. In the case of the Virtual Xylophone, the user can visualize certain playing styles such as chords with stacking them on top of each other. The Augmented Groove and, more specifically, the Music Table implement visual characterizations of musical abstracts such as notes and phrases. Adjusting musical parameters such as pitch and volume does not only produce the corresponding aural alteration but visual feedback as well. The AR/DJ displays a scaled-down virtual 3D model of the dance floor which helps the disc jockey to clearly visualize positions in 3D space.

4.1.4 The Issue of Registration Error and Latency

Rapid movements generally cause dynamic registration errors. This effect is normally due to end-to-end system delays wherein the different subcomponents of tracking, communication, and scene generation take up considerable amount of time [1]. Registration errors are more prominent in AR-based systems such as the Augmented Groove or the Music Table applications. As can be noticed on videos, the virtual characters superimposed on the marked objects sometimes tend to drift or lag. However, the minute inconsistencies of the virtual augmentations do not play a critical role in the overall interface. The instruments themselves do not call for visual precision as compared with applications in other fields such as medicine.

With regard to audio output, a considerable amount of delay results due to performance limitations of tracking devices. Hitting a plate of the Virtual Xylophone produces the corresponding sound only after a delay of 60 ms. The same holds for the FM Synthesizer which also suffers from latency effect. Statistical findings however point out that latency ceases to be an issue for as long as it does not reach a length of over 60 ms. Latency problems with the FM Synthesizer and the Virtual Xylophone were not noticeable due to the fact that the delayed visualization compensated for the audio delay.

4.2 Taxonomy of Existing Systems

The six different musical instruments presented in the previous section can be categorized according to three different classification schemes. One classification is based on the input and control method used by the system; another deals with the modalities for feedback; a third classification considers performance capabilities.

4.2.1 Gestural vs. Tangible Input

We categorize the instruments based on the methods used for input and control. Of the six instruments discussed, the VR-based instruments, namely, the Virtual Xylophone, the FM Synthesizer, and the Air Guitar, solely rely on gestures to interact with music and therefore fall under the first category. The FM Synthesizer is controlled just by waving and moving the hands. The Virtual Xylophone also relies on hand gestures and arm movements to play the instrument. While wearing data gloves, the player makes a pounding gesture with his right hand using a virtual mallet to hit the virtual plates. The virtual objects can only be perceived with the shutter glasses worn by the user. The player of the Air Guitar mimics the playing of a real guitar without holding anything in his hands. The AR-based instruments on the other hand, make use of tangible objects to interact with the system. As such they fall under the second category. The Augmented Groove, the Music Table, and the AR/DJ require the manipulation of marked or tracked physical objects such as an LP record, a card, or a pen, as input mechanisms.

4.2.2 Plain-Aural vs. Visual-Aural Feedback

All the instruments discussed make use of both aural and visual modalities to provide feedback. The Air Guitar is the only system reviewed which does not employ visualization. The designers of the Air Guitar consider their creation as a pure entertainment device rather than a professional instrument. The system does not attempt to teach the basics of guitar playing and neither is the device difficult to play. As such, visual augmentations were not deemed necessary.

4.2.3 Solo Performance vs. Collaborative Capabilities

The VR-based instruments were thought of as solo instruments whereas the AR-based systems were designed with the collaborative features in mind. The designers of the Augmented Groove envisioned collaborative jamming as a manner of musical expression within a community of performers. The Music Table boasts of the ability to compose and capture complex musical structures and to allow remote collaboration via networks. The AR/DJ was designed for a pair of disc jockeys who would assist each other in manipulating the system's control features.

4.3 UI Metaphors

The degree of flexibility which a VR/AR environment offers, opens up countless ways of implementing user interface design. We will now look at the particular UI metaphors used by the VR/AR instruments.

Fig. 4.1: Creatures evolving from Music Table cards

4.3.1 Traditional Musical Instruments

Musical instruments, which have existed and evolved through the centuries, would obviously be considered as models for designing musical interfaces. In the same way that the desktop metaphor is considered as an ideal representation of one's digital workspace, and a CD-player metaphor is deemed appropriate for a computer-based media player interface, it would also be logical to consider using known and existing devices or environments such as traditional musical instruments for a musical user interface. Among other things, this would facilitate natural, cultural mappings. The Virtual Xylophone, FM Synthesizer and the Air Guitar replicate the interfaces of their physical counterparts in terms of control and certian visual elements.

4.3.2 Live Creatures and Objects

The Augmented Groove and Music Table make use of virtual creatures that move, react and mutate (Fig. 4.1). The UI depicts animated characters that attract the curiosity of a small child. Their size and puny appearance offers an affordance of being manipulated or carried around. They visually express musical abstracts which entertain both the eyes and ears and help establish a relation between what is seen and heard.

4.3.3 Scaled Model of Physical Environment

The AR-Disc Jockey shows two virtual models of the dance floor. The model depicts the exact scaled-down replica of the floor area where the DJ works. The correspondence between the replica and the real environment is a perfect mapping of the input controls and the output. The disc jockey gets the impression of having the capability to control his environment according to the degree he/she is able to control its virtual replica.

4.4 Criteria for Evaluating Musical Instruments

In the analysis of musical instruments, we wish to make use of the criteria proposed by Jordà in his analysis framework [9]. Nielsen also cited these two criteria as quality components for usability [13]. Poupyrev et al. also identified other criteria in a workshop paper on new interfaces for musical expression such as expressiveness, sophistication and aesthetics [18]. Although we consider them to be as important, we decided however not to include them in our discussion due to the fact that the concepts have yet to be clearly defined and a valid and subjective evaluation scheme would need to be established.

4.4.1 Efficiency

Sergi Jordà describes the efficiency of a musical instrument as the relation between the musical output complexity and the input complexity on the part of the performer. This is further scaled by the freedom with which the performer has in terms of movement and choice. This definition underlines the fact that although a CD player could produce a complex musical output just with a simple control input (i.e. through pressing a button), it is not considered as an efficient instrument for the simple reason that the user does not have as much freedom to influence the music being played. With this definition in mind, we could evaluate the different VR/AR instruments with regard to their efficiency as interfaces for musical expression. The Virtual Xylophone introduces more real-time control and is therefore considered more efficient than a real xylophone since the position and spacial orientation of the plates can be configured according to the user's preference. The FM Synthesizer allows more musical parameters to be controlled as compared to the original Theremin and therefore warrants greater efficiency over the latter. Users of the Air Guitar do not exercise greater freedom of expression in comparison to an actual stringed instrument. The Air Guitar is therefore not as efficient in terms of instrument comparison although it is sufficiently designed for its purpose. The Augmented Groove is only able to play predefined disco tracks whereas the Music Table allows note-level composition. The greater degree of freedom and control makes the Music Table more efficient than its predecessor. The user of the AR/DJ is able to produce a great degree of control over the mixing of sound samples and positioning of sound sources which would otherwise be more difficult using traditional interfaces. Special audio effects like compression and reverb can also be achieved easily. Comparing it with conventional DJ control devices, the AR/DJ has greater efficiency.

4.4.2 Learning Curve

The learning curve of a musical instrument is a function of the acquisition of a musical skill level in relation to the number of times it has been used. Some authors define it as the period to achieve the rewarding point or the mastery point [9]. The VR/AR instruments that have been presented in this paper all have a steep learning curve, considering the visual enhancements and intuitive interface which they feature.

5 Conclusions

Virtual and Augmented Reality have lately stirred a lot of interest especially with the recent, major developments that have been brought about in the field of imaging technology. This field of computer research has found many practical applications in different domains. One of these is in the field of music which promises novel interface schemes. We have looked at six different systems which have been developed. Three have been classified as VR-based and the other three as AR applications. The results of the designs show that such systems in VR/AR space have the potency for greater efficiency than conventional instruments. They could also facilitate learning and appreciating musical abstracts and bring music-making to the masses. A good number of disadvantages have also come to fore. The technology itself such as tracking and visualization still has a lot of room for improvement and several technical issues would need to be addressed. Besides, the designers of musical interfaces in VR/AR space would also need to consider other criteria related to human, emotional, social and psychological factors to capture and enhance the level of expression which conventional musical instruments have achieved through the centuries. More than just a musical tool, there exists a relation between the performer and the instrument which is interactive and intimate. The current systems and the technology itself still have a long way to go and a lot to achieve.

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[24] Music Table Creatures