We Can Do More to Save Guqin: Design and Evaluate Interactive Systems to Make Guqin More Accessible to the General Public

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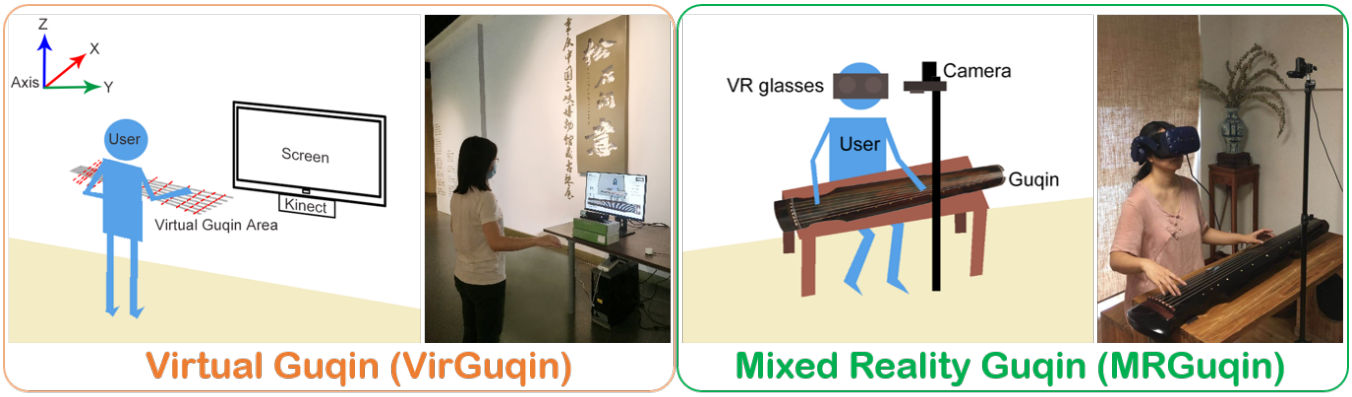

Figure 1: Illustration of our VirGuqin and MRGuqin systems.

ABSTRACT

Guqin is a plucked seven-string traditional Chinese musical instrument that exists for over 3,000 years. However, as an Intangible World Cultural Heritage, the inheritance of Guqin and its culture in modern society is in deep danger. According to our study with 1,006 Chinese worldwide, Guqin as an instrument is not well-known and barely accessible. To better promote Guqin, we developed two interactive systems: VirGuqin and MRGuqin. VirGuqin was developed using a low-cost motion tracking device and was tested in a museum. 89% of 308 participants expressed an increase in interest in learning Guqin after using our system. MRGuqin was developed as a mixed reality learning environment to reduce the entry barrier to Guqin, and was tested by 16 participants, allowing them to learn Guqin significantly faster and perform better than the current practice. Our study demonstrates how technology can be used to help the inheritance of this dying art.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; *Empirical studies in HCI*.

KEYWORDS

Guqin Art, Augmented Reality, Cultural Preservation, Interactive Design

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CHI '21, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05…$15.00
https://doi.org/10.1145/3411764.3445175

ACM Reference Format:
Minjing Yu, Meng Zhang, Chun Yu, Xiaoguang Ma, Xing-Dong Yang, and Jiawan Zhang. 2021. We Can Do More to Save Guqin: Design and Evaluate Interactive Systems to Make Guqin More Accessible to the General Public. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3411764.3445175

1 INTRODUCTION

Guqin, as a Chinese seven-string bridgeless zither, has existed for over 3,000 years. Because of its strong influence on Chinese and their culture, Guqin is considered the most important of the "four arts" (Guqin, chess, calligraphy and painting), which was the requirement for literati in ancient China. In 1977, a recording of the famous Guqin tune "Liu Shui"(Flowing Streams) was chosen to be included in the Voyager Golden Record sent to the space by NASA to represent the "Sound of Earth"[48]. In 2003, Guqin was included in the "Representative List of the Intangible Cultural Heritage of Humanity" by UNESCO (United Nations Educational, Scientific and Cultural Organization) as the most representative Chinese traditional instrument[45]. However, in the past ten decades, the inheritance of Guqin art has encountered greatest challenges. Studies show that Guqin was only played by no more than two hundred people in China in the 1930s. This number decreased to less than one hundred in the 1950s[26] . As of today, although there are more people playing Guqin, but in a country with a population of 1.3 billion people, less than a thousand are well-trained Guqin players and less than fifty are considered experts[45]. Therefore, it's urgent to protect Guqin and its culture from extinction.

The current practice of how Guqin art is promoted can be summarized into four main categories[38, 42]: (1) Literary works, such as movies, novels etc.; (2) Concerts or exhibitions; (3) Associations organized by Guqin players; (4) Course in school or oral mentoring by Guqin teachers. Among these methods, literary works are the most common way for people to begin to learn Guqin. In China, conferences and seminars are also held regularly by some associations related to Guqin. The Ministry of Culture and Tourism of the People's Republic of China has a program that recruits Guqin experts [37] to ensure their skills, documents, and Guqin instruments can be passed on to the younger generation. Despite all these efforts, Guqin art is primarily taught verbally[44]. However, finding a good teacher is hard, especially in remote regions. As such, opportunities are rare for people to learn to play Guqin.

In recently years, the development of interactive technology, such as somatosensory sensors and touch screens, makes it possible for people to perform music without the need of a physical instrument[49]. Studies have been largely focused on using technologies to teach or learn piano[33, 41, 50], drums[21], guitar[11, 30] and beyond[9, 24], but little work has been focused on Guqin. The goal of this work was to make Guqin more accessible to the general public and to ease the learning process of Guqin for beginners using interactive technologies that are easily accessible to the general public. As an attempt to understand the inheritance of Guqin in today's modern society and identify the challenges in promoting Guqin at scale, we conducted a survey with 1,006 participants and found that for people who have never learned to play Guqin, the main challenge is related to the lack of access to Guqin instrument. In contrast, for beginners, the bar of entry to learning Guqin is very high because it is hard to (1) learn and understand Guqin notation, (2) find the right place to pluck or press, and (3) find the right phoneme. To overcome these challenges, we developed two systems with the goal of making Guqin more accessible to the general public and making learning Guqin easier, respectively. We demonstrate the effectiveness of our approaches through user studies in a museum and in a Guqin school (see Fig.1).

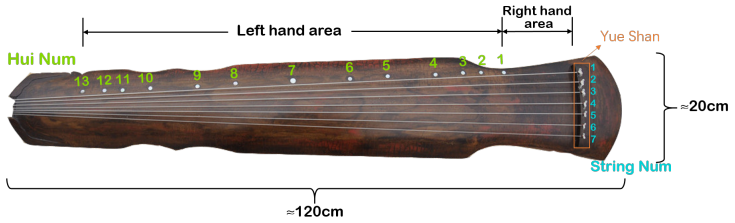


Figure 2: The structure of Guqin.

This paper makes the following contributions:

(1) We conducted a survey involving 1,006 participants to understand the challenges in promoting Guqin and its culture.

(2) For people who have no knowledge or access to Guqin, we developed Virtual Guqin system (called VirGuqin) to make it possible for them to play the music without a physical Guqin instrument. The system was deployed in a local museum and was used by over three hundred people within a week. We found that our system could largely improve people's interest in learning Guqin;

(3) For Guqin beginners, we developed a learning tool (Mixed Reality Guqin, called MRGuqin) to ease the learning process and enhance user confidence. We studied the effectiveness of our system with sixteen Guqin school students and found that with MRGuqin students learned faster and better than than using the current learning method. Students also showed more confidence and persistent enthusiasm for learning Guqin.

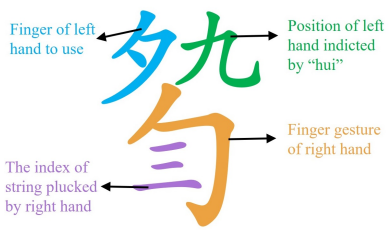
2 BACKGROUND AND RELATED WORK

The main body of Guqin is made of wood, it is about 120 *cm* in length, 20 *cm* in width and 2 *cm* in thickness. The bottom plate is flat and the panel is curved. There are seven strings made of either silk or steel-nylon with thirteen small marks-called "**Hui**" on the panel. Hui is used as the reference on pitch. On the right part of the instrument, a piece of hardwood embedded horizontally is called "**Yue Shan**". When playing, the right hand moves between first Hui and Yue Shan, and the left hand moves between 1st Hui and 13th Hui.

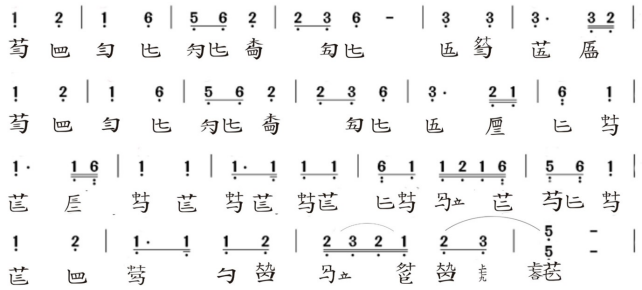
The timbre of Guqin can be categorized into following types:

- **San Yin**: Produced by directly plucking the string with fingers of right hand.
- **Fan Yin**: Produced by touching the strings (not pressed down to the panel) with fingers on the left hand, and plucking the string by fingers of the right hand.
- **An Yin**: Produced by pressing the string on the panel of the Guqin with the fingers of left hand, and then plucking the string by fingers of right hand.
- **Hua Yin**: A kind of An Yin, produced by sliding finger along the string while pressing the string to panel.

Unlike other musical instruments using staff or numbered musical notation, Guqin has its own notation, which is called "**Jianzi Pu**" or "**Reduced Notation**". It indicates how to perform by illustrating which finger should be used and which string should be plucked. However, the reduced notation does not indicate the rhythm of the music, so Guqin players need to decide the rhythm by themselves, or imitate the performance of their teachers. Fortunately,



(a) A character of reduced notation.



(b) Reduced notation and corresponding numbered musical notation.

Figure 3: Reduced notation. (a) An character of reduced notation. It includes the information player need when perform: the index of string and Hui, as well as fingering. (b) Reduced notation and corresponding numbered musical notation. Since the reduced notation have no rhythm identification, nowadays it always be equipped with the corresponding numbered musical notation or staff.

well-trained Guqin players have determined rhythms of some classic music pieces, and equipped it with staff or numbered musical notation (called "**Da Pu**"), allowing us to play ancient Guqin masterpieces. At present, there are more than three thousand pieces of Guqin music, but only less than 10% of them are equipped with modern notation[15].

Most of Guqin music is closely related to Chinese traditional culture. It is well known that the Chinese philosophy is dominated by Confucianism and Taoism. Their different philosophical thoughts can be reflected in Guqin music. For example, Taoism advocates nature, emphasizing inaction and carefree. The representative Guqin music includes "Zhuangzhou Meng die" (Zhuang Chou Dreams A Butterfly), "Ou Lu Wang Ji" (Forgetting Vulgar's Ideas) and "Yuan He Shuang Qing"(Apes and Cranes are Both Pure)[4]. Confucianism emphasizes justice and peace, believing in that art can enlighten human beings. The representative Guqin music includes "Wen Wang Cao" (Chant of Emperor Wen) and "Kong Zi Du Yi" (Confucius Reads the Book of Changes)[4].

The ancient Chinese believed Guqin music can be used to influence people's thinking and affect people's behavior. A famous Chinese legend states that the Emperor Shun used his creation of a song, called "Nan Feng" (South Wind), to rule the country. In addition, Guqin music also reveal the idea of its player. Such as "Mei Hua San Nong"(Three Stanzas of Plum-blossoms), it admires people with noble moral character by the praise of plum blossom's white color (representing its pure spirit) and cold resistance (representing its strong character).

2.1 Reduced notation understanding and generation

In the 1980s, Chen developed a digital coding system to input, display and storage the handwritten reduced characters[6]. Zhou proposed a reduced characters paratactic coding scheme and a graphical subtractive processing method based on enhanced metafiles[36]. On this basis, they provided a Guqin notation input and editing software system, which solved the problem of reduced characters input, editing and sorting[34]. In order to read notation in batches, they proposed an extraction algorithm and segmentation method of reduced character components, and constructed a complete reduced notation reading system, which provided important technical support for the digital processing of handwritten reduced characters[35].

2.2 Guqin music analysis and composition

Digital technology has been widely applied to the research of Guqin music. In 2002, Chen developed the first MIDI Guqin with analog performance function, which can play the pre-collected Guqin sound through the interface control system. Penttinen proposed a sound synthesis model for Guqin based on the digital waveguide technique[18]. Zhou analyzed and collected the timbre of the Guqin and developed a simulation reconstruction[52]. Then they used a cluster analysis for the emotions of Guqin music[29], and selectively established a library of melodies with emotional representations. The rhythm of the synthesized music has a certain ups and downs, which assembles music performed by human. In order to speed up the time-consuming and laborious process of "Da Pu", Zhou analyzed and interpreted the timbre, fingering, string sequence and other information of the reduced characters to perform the auxiliary notation work of the score[16]. The translation ultimately forms a modern music score with clear rhythmic annotations. Sun used a machine learning method to study the Guqin music recovery problem which tries to use the Guqin music notation to recover the duration of each music note[43].

2.3 Interactive applications of Guqin

In recent years, there has been increasing numbers of researches and explorations on the combination of Guqin and human-computer interaction. He studied a physical method for acquiring Guqin fingering, and developed a Guqin fingering recognition system in which the user can output the Guqin fingering by wearing sensor gloves when playing[17]. Art is always interlinked, and many studies have begun to focus on the integration of Guqin art with other fields of art. The "MelodicBrush" developed by the Hong Kong Polytechnic University is a cross-modal system that combines brush calligraphy and Guqin music. Writing brush characters can generate Guqin music, which can greatly exercise the creativity of users[20]. The "3D Guqin" developed by the National University of Singapore combined dancing with Guqin music[23]. The dancer generates Guqin music by touching the laser strings in space. Chen combined ink painting with Guqin music, which converted the gestures captured by Leap Motion[31] into Chinese paintings

that change with the sound of the Guqin[7]. In terms of teaching, Zhang of Tsinghua University has introduced Augmented Reality (AR) into the Guqin teaching, and proposed the interactive Guqin learning aid system named "ChinAR", which provides a systematic auxiliary program for the overall coordination of vision, hearing and movement in the process of performance learning[51].

2.4 Musical instruments and HCI

There are many research efforts in combining musical instruments with human-computer interaction (HCI) technology, and develop new interfaces for musical expression [22].

Novel virtual instruments without the real physical instrument have been widely studied. Ren designed a virtual musical instrument that users can operate collaboratively[40]. Since camera-based motion tracking has become a popular support technology for gesture-based human-computer interaction[53], Nicholas proposed a gesture-controlled virtual instrument "Digito" whose internal sound engine can be discretely and continuously controlled by a variety of complex gestures[13]. Similarly, the virtual instrument system developed by Matthew used the real-time posture detected by the Kinect device[32] to interact with the instrument[10]. Hsu uses the Kinect device to implement three virtual instruments, including drums and guitar[19]. Volioti combined the Kinect device with the Leap Motion device and introduced an "invisible musical instrument" using publicly available off-the-shelf motion capturing [46]. Liang realized a virtual piano system by estimating the position of each joint and predicted the tapping of the fingertips [27]. There also exist many music games on the market with a wide variety and popularity, such as Guitar Hero[1], Magic Tiles[2], AudioSurf[5], Piano Magic[14] and Dream Piano[25].

Because of its ability to integrate virtual content into the real world, augmented reality (AR) has been applied to the field of interactive musical instruments and education [12]. iDVT[28] is an interactive violin learning system that provides users with guidance through image recognition and voice recognition, aiming for an effective learning experience. Chow explored the use of AR technology in creating an immersive learning experience with the screen prompts in the head mounted display (HMD) [8]. The tool can improve the efficiency of piano learning for beginners. P.I.A.N.O. [41] is a piano learning system with interactive projection, which accelerates the learning process. The direct projection of monophonic symbols onto the instrument allows users to map the notes on the score to the piano keys without prior knowledge.

Many traditional musical instruments, which are not known by the general public for various reasons, are particularly well suited to the new HCI technology. Leng presents Virtual Kompang[21] as a novel digital musical interface for the traditional Malay percussion instrument Kompang. Wikarsa developed a Kolintang application that allows cross-platform multi-player online collaboration for music playing. The application supports various input devices such as a webcam, keyboard, mouse and touch screen [47]. Bryan-Kinns presented a cross-cultural co-creation design of a Digital Musical Instrument inspired by Duxianqin[3], aiming for preserving and promoting Duxianqin, a traditional Chinese instrument, through interactive technology.

Table 1: The reasons caused people losing interests in Guqin.

Reason	Ratio
No access to Guqin instrument	36.3%
No interest in the existing ways of how Giqin is promoted	33.3%
The price of a Guqin instrument is too high	20.0%
Others	10.4%

The creative combination between HCI and musical instruments brings fantastic results.

3 SURVEY

3.1 Participants

We recruited 1,006 Chinese (479 males and 527 females) worldwide to participate in this study. For the participants recruited in China (95.8%), we ensured that we covered all the provinces of the country. We also recruited overseas Chinese from Japan, Tajikistan, United States, Canada, United Kingdom, Germany, Australia and Ecuador. The age of our participants ranges from 8 to 72, with an average age of 29.32.

3.2 Questionnaire design

According to their knowledge in Guqin, participants can be divided into three groups:

(A) Never heard of Guqin;

(B) Heard of Guqin but don't know what it looks like;

(C) Heard of Guqin and know what it looks like.

For group A and B, we inquired which factors limited their interests in Guqin. For group C, we further ask whether they have learned to play Guqin and if so, what difficulties they encounter in the beginning; if not, they will be asked the question for group A and B, i.e. asking what factors limited their understanding or learning in Guqin (see Fig.4).

3.3 Questionnaire Result

Among all the participants, 348 people said they had heard of Guqin, which means that more than 65% of participants have no knowledge of Guqin at all. However, almost all participants said they have heard of piano or guitar. This data shows that the popularity of Guqin is far less than that of piano, guitar and other mainstream instruments. 13 people said they have learned Guqin systematically, accounting for 1.3% of the participants. 72 people indicated that they have tried to learn Guqin but eventually gave up, accounting for 7.2% of the participants.

For those who have never learned to play Guqin (921 people), we further inquired the main reason for their lacking of interests in Guqin. 335 people chose "No access to Guqin instrument". 307 people chose "No interest in the existing ways of how Giqin is promoted" (details in the Introduction). Further, 184 people chose "The price of a Guqin instrument is too high". The results can be referred in Table 1.

Learning Guqin is, in general, considered difficult, hence lacking in the sense of achievement is the main reason for novices to give up in the early stage. For those who have learned Guqin (79 people),

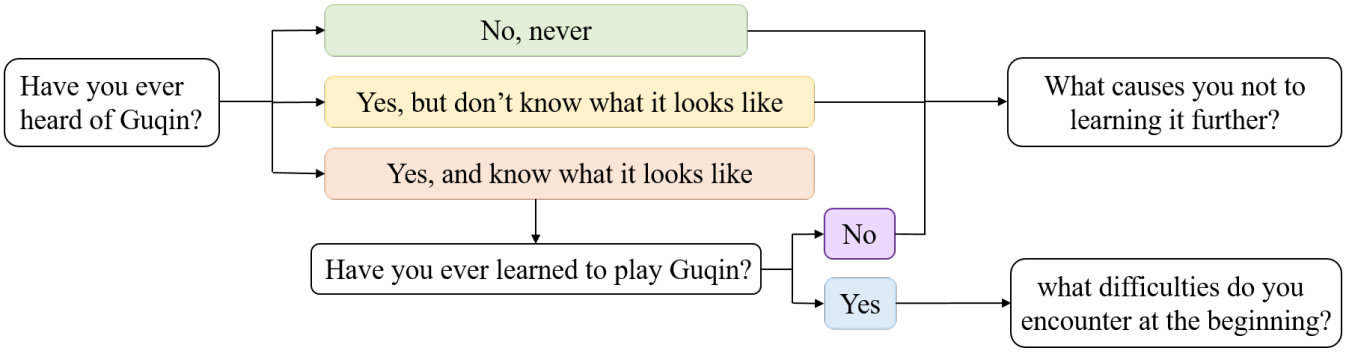


Figure 4: The design of the questionnaire.

Table 2: The difficulties caused novices giving up learning Guqin

Difficulty	Ratio
Find the exact location they should place fingers quickly	39.2%
Grasp the rhythm very well	35.4%
Understand reduced notation	17.7%
Others	7.7%

we inquired the biggest challenge they meet in the early stage. Thirty one of them told us that they could not easily find the exact location where they should place their fingers. The reason is that the combination of Hui and string is complicated, the finger location on the Hui can be in 1/10 incremental between any two Huis. For example, in some cases, the performer needs to press the 7.7 Hui (located at 7/10 between the 7th and the 8th Hui). It is difficult for new learners to quickly locate the exact spot. Twenty eight participants said they could not quickly grasp the rhythm very well. Because the traditional Guqin notation does not indicate rhythm, which is fundamentally different from that of most modern music. The number of beats in each bar may vary within a single piece of Guqin music (see Fig.3(b)), which may largely confuses beginners. Fourteen participants chose the learning and understanding of the reduced notation as their main challenge. And the difficulties can be referred in Table 2.

3.4 Interviews

Our goal is making Guqin more accessible to the general public, two interview cases are presented: Study case 1 (S1) is a 20-year-old man with little knowledge of Guqin and Study case 2 (S2) is a 32-year-old women who have learned Guqin for half a year. The interviews were conducted to find the reason that hindered their perception and understanding of Guqin.

S1 is a college student who likes reading Kung-fu fictions. He heard about Guqin from novels. He told us he only knew Guqin by its name with no further knowledge. Actually, he could not describe how Guqin looks like and could not distinguish between Guqin and Guzheng, which is also a traditional Chinese instrument. "I have played piano for many years, and piano works and shops are very popular. However, there are few Guqin instrument in general musical instrument shops. I don't know where I can get access to Guqin." When offered a Guqin instrument, he said "I don't know how to play it, but if you can teach me, maybe I can have a try." For S1, the biggest barrier is that he has no access to Guqin and no one can teach him.

S2 is an office lady who is interested in traditional Chinese culture. She once went to a teahouse and someone was playing Guqin there. "I think Guqin music is quite beautiful and decided to learn it immediately." Then she started learning to play Guqin with a teacher. "But half a year later, I found it really difficult to play Guqin. I've never seen reduced notation before. Understanding it in a short time is a problem for me." Most of Guqin songs are ancient music, which modern people are not familiar with. So grasping the rhythm is also a challenge. "Finding the right location to put my finger fast is also difficult. It takes time and effort to map from reduced notation to the right place. Wrong rhythm during playing is inevitable" When asked what kind of help she needs, "It will be good if there is a system that could instruct me how to play, for example, where to put my finger or how long the note lasts."

3.5 Result Analysis

According to the results of questionnaire and interviews, the restrictive factors that hinder the promotion of Guqin art can be divided into two categories:

(1) For people who know little about Guqin, the biggest problem is that they have no access to Guqin.

Due to the complicated manufacturing technique and high requirements for raw material, Guqin is too expensive to afford. The wooden part of Guqin needs special treatment according to traditional craftsmanship, leading to longer production process and higher price - usually more than 3000 US dollars. Even a factory-made entry-level Guqin costs more than 500 US dollars. Moreover, the popularity of Guqin remains at a low level, people seldom have access to it besides some traditional promotion method, like concerts or literary works. But through these ways, the general public cannot interactive with Guqin, thus unable to experience the fun of playing it, resulting in the lack of interest.

(2) For Guqin novices, the challenges includes finding the right place to pluck or press, grasping the rhythm and understanding the reduced notation.

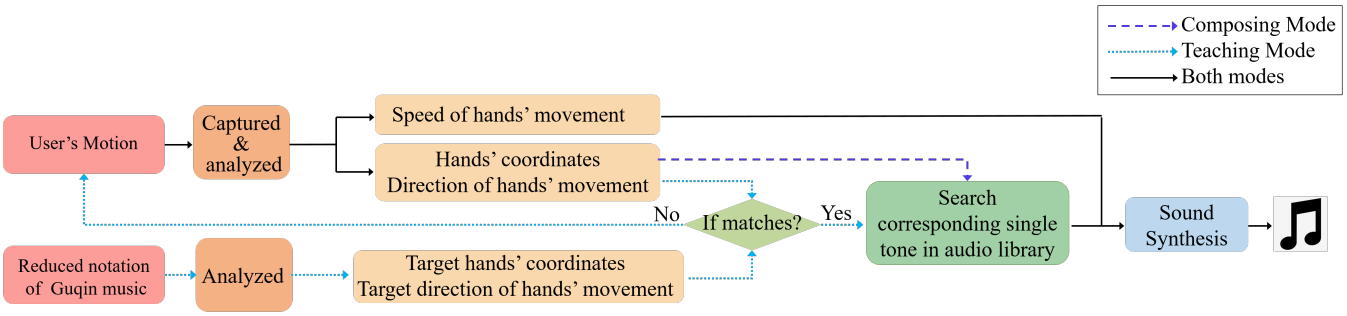


Figure 5: The design concept of VirGuqin.

There are seven strings and thirteen Hui on the Guqin. The high number of different combinations makes it hard for novices to quickly find the right place corresponding to the reduced notation characters. Rhythm is another barrier for novices. Since the reduced notation have no rhythm identification, players must read the equipped numbered musical notation or staff at the same time (see Fig.3(b)). Moreover, the beginners may be unfamiliar with the melody due to the fact that the Guqin music is not popular. Especially when they are trying to play a piece of music for the first time. This makes it hard for them to master the rhythm. Furthermore, 225 types of finger gesture and 107 types of combination methods lead to massive notation characters, and more than 6000 characters among them are commonly used. There is no doubt that reading reduction notation is a great challenge for beginners. All of these reasons may cause the decrease in confidence and the lost of interests.

4 SOLUTION

In order to overcome the challenges in promoting Guqin, we proposed two solutions:

- **Virtual Guqin (VirGuqin)**. Designed for people (who may have little knowledge in Guqin). Users can interact with Guqin without physical object. The goal is to attract people's interest.
- **Mixed Reality Guqin (MRGuqin)**: Designed for novice learners. Users can quickly find the right place to pluck or press and have a good grasp of the rhythm using a head mounted display (HMD). In addition, understanding the reduced notation will no longer be a problem with the help of the HMD, since the reduced notation are all translated into simplified symbols shown at the location, where the fingers need to be placed.

4.1 VirGuqin

As the name suggests, we replaced physical Guqin by a low-cost motion tracking device (e.g., Kinect). VirGuqin overcomes the difficulties for people who has no access to physical Guqin and brings a new way of interacting with Guqin in a more affordable way. While an alternative approach was to develop our system as a mobile app, we see that using Kinect allows the user to play in the actual size of a Guqin, which can be more natural and engaging.

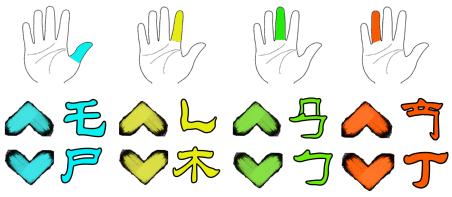
There are two modes in our VirGuqin system, teaching mode and composing mode.

- **Teaching mode**: Users are guided to learning a processed track of Guqin music. To relieve their cognitive burden, the complex reduced notation characters are translated into symbols that can be easily understood. Users can follow the symbols step by step to play the Guqin music.
- **Composing mode**: Users are given the freedom to play their own rhythm.

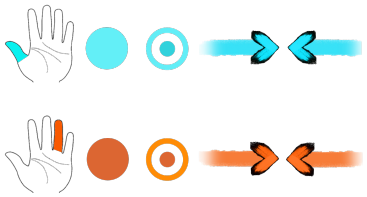
4.1.1 Design Concept. The design concept of VirGuqin is showed in Fig.5. The system has both audio and visual feedback. The visual feedback displays the user's hand position and the audio feedback plays the sound of the note that the user is playing. The input of the device is the user's hand motion, which is captured by Kinect to obtain the location of the hand, the direction of its movement, and the speed of its movement. In the composing mode, the hands' coordinates and the movement direction is used to search the corresponding tones in the audio library. The retrieved tones are then combined with the movement speed of hands to create the corresponding music. In the teaching mode, an extra step is added for comparing the location of the user's hands with the target location inferred from the reduced notation. Our system only proceeds to find the corresponding tone and generates the music if user input matches the desired target locations.

4.1.2 Prototype. For the convenience of users, Kinect, which is a peripheral device that has no physical intervention on the users, was chosen to track the motion rather than other wearable devices. The prototype of VirGuqin is shown in Fig.1 (left) , which consist of a Kinect and a screen. As soon as the user stands in front of the Kinect about 100 *cm* and raised their hands above their torso center, our system begins to capture their gesture. The area in front of the user is identified as the "virtual Guqin" area, which is the same size as the physical Guqin. The area is divided into several parts according to the Guqin's structure.

A coordinate system is constructed as shown in Fig.1 (left). The origin o is set to be the center of users' body. The $+x$, $+y$ and $+z$ direction corresponds to the front, left and upward of the user body, respectively. The X-axis coordinate of the right hand determines which strings is being plucked and the Y-axis coordinate of the left hand determines which Hui is being pressed or touched.



(a) Right hand's symbols



(b) Left hand's symbols

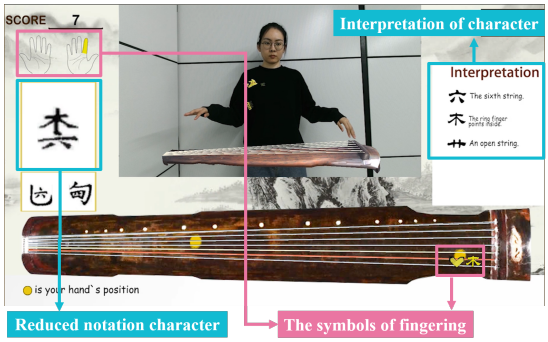
Figure 6: The visualization of Notation in VirGuqin. (a) The symbols used to represent fingering of right hand. Different colors were used to represent different fingers. Upward arrow means moving away from body and downward arrow means moving closer to body. Corresponding reduced notation character is next to the arrow. (b) The symbols used to represent fingering of left hand. Dot represents An Yin. Dot in a cycle represents Fan Yin. Arrows represents Hua Yin.

4.1.3 Notation Visualization. In order to eliminate the difficulties in reading the reduced notation, the characters are translated into symbols that can be easily understood.

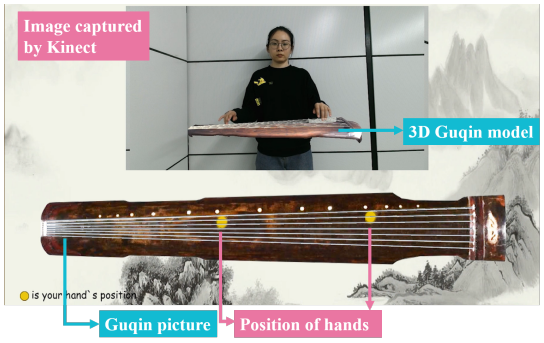
The fingering of the right hand mainly includes the movement direction and the finger that needs to be used. These can be represented by using arrows with different colors (see Fig.6(a)). Different colors were used to represent different fingers, and the arrow indicates the movement direction of the finger. Upward arrow means moving away from the body and downward arrow means moving towards the body. The corresponding reduced notation character is illustrated next to the arrow in Fig.6 (a).

The fingering of left hand is more complex(see Fig.6(b)). An Yin, where the string should be pressed down to the panel when played, is represented by a dot (refer to the second column in Fig.6(b)). Fan Yin, where the string should be touched but not pressed, is represent by the symbol with a dot in a cycle (refer to the third column in Fig.6(b)). Hua Yin is a kind of An Yin where the finger should press the string and slide along the string in a certain direction (refer to the last two column in Fig.6(b)).

4.1.4 User Interface. The user interface of VirGuqin is shown in Fig.7. The interface of composing mode is concise. The image captured by Kinect is displayed on screen. When a user was recognized in the camera, the system generates and displays a high precision Guqin model right in front of the user. The 3D coordinates of the user's hands was projected on the panel of a 2D top-view picture of Guqin with the Hand Coordinates indicated using yellow dots as shown in Fig.7(a). Based on the composing mode, more elements are added on the interface of teaching mode: the reduced notation



(a) Teaching Mode



(b) Composing Mode

Figure 7: The interface of teaching and composing mode respectively.

character and its interpretation, the symbols translated from character showing the fingering and target location, and the score the user played.

4.2 MRGuqin

MRGuqin system is designed to lower the bar of entry to learning Guqin. According to the survey result, these challenges includes quickly finding the right place to pluck or press, grasping the rhythm and understanding the reduced notation. We used AR to overcome the challenges by showing additional information augmented on a real Guqin. The artistic concept of music reflects the scene or the story that the music depicted, which is important for the understanding of the music. This is the reason we chose Virtual Reality (VR) devices, which makes it possible for users to experience the scene described by the Guqin music. Combining of above considerations, we proposed Mixed Reality Guqin (MRGuqin).

4.2.1 Design Concept. This system takes the real-time picture captured by camera facing a real Guqin. Several candidate pieces of Guqin music are stored in MRGuqin system. We analyzed the music manually to obtain the information about fingering and artistic concept. Fingering information learned from the reduced notation characters was translated to symbols that can be easily understood. While we expect that our system will largely benefit from an automatic approach, we decided to leave it for future research. Different

(a) Right hand's symbols

(b) Left hand's symbols

Figure 8: The visualization of Notation in MRGuqin.(a) The symbols used to represent fingering of right hand. The finger to be used is green. Upward triangle means moving away from body and downward triangle means moving closer to body. (b) The symbols used to represent fingering of left hand. Dot represents An Yin. Cycle represents Fan Yin. Arrows represents Hua Yin.

from VirGuqin where the translated symbols are displayed on a screen with a still image, the MRGuqin projects these symbols to the real-time image of a physical Guqin captured by a camera. The user can play Guqin by following the step-by-step guidance shown on the HMD. Further, we consulted Guqin teachers to understand the artistic concept that is expressed by a particular piece of Guqin music, based on which, we created the virtual scene using the pictures and videos that depict the Guqin music. Combining the symbols, real-time Guqin photo and related background pictures and videos, the interface of the MRGuqin is formed and displayed in VR.

4.2.2 Prototype. A VR helmet and a camera are needed for MRGuqin. HTC Vive and Logitech C930e were chosen in our implementation. The camera was mounted about 50 *cm* above the physical Guqin to ensure full coverage of the Guqin. When user chooses a piece of Guqin music from our MRGuqin system, the corresponding virtual scene is then shown to the user with a virtual desk in the middle of the scene. And the real-time pictures taken by the camera will be mapped onto the surface of the desktop. Similar to teaching mode in VRGuqin, the symbols translated from the reduced notation will be augmented on the Guqin in the picture, and users can follow the on screen directions to play.

4.2.3 Notation Visualization. In MRGuqin, the symbols of the current note and the next note are displayed simultaneously, with slight differences in transparency and size. This way the user can prepare for the following note when playing the current note.

The symbols for the right hand are simple (see Fig.8). The finger to be used is shown in green. There are green triangle displayed on strings, the upward triangle means the finger should move away from the body while the downward triangle means the finger should move towards the body.

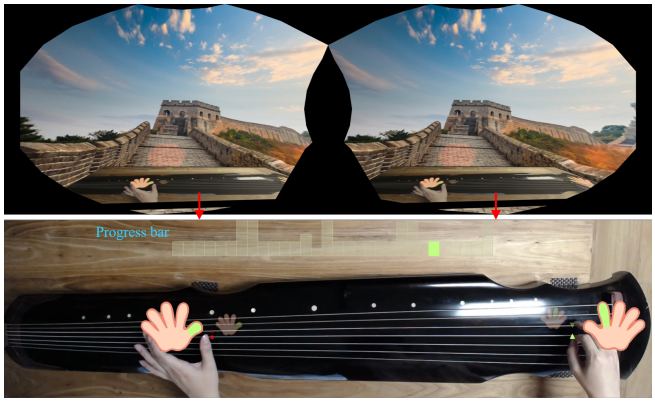


Figure 9: The scene users can see in MRGuqin. There is a virtual scene shown to the user with a virtual desk in the middle of it. And the real-time pictures taken by the camera will be mapped onto the surface of the desktop.

The symbols for the left hand are slightly complex. In the display, the finger to be used is colored in green. An Yin, Fan Yin and Hua Yin was represented by red dots, red circles and arrows, respectively. Two colors are used for the Hua Yin symbol of the current and the next note, namely the green and red arrow. This setup can enhance the readability and distinct the current and the next note for Hua Yin.

4.2.4 Interface. When wearing the VR helmet, users will see a virtual scene related to the Guqin music with a virtual desk in the center. The Guqin image captured by the still camera will be projected onto the desktop and the direction symbols showing which finger should be used and which string to be plucked or pressed is augmented on the real-time image of the Guqin (see the Fig.9). A process bar in the middle of upper area is used to show the process of the music, with a green bar indicates the current note. The height of a bar denoted the length of current note. The green finger shown in the display illustrate the which finger should be used when playing. The symbols for current note are bigger and brighter whereas the symbols for the next note are translucent.

5 USER STUDY

Two user studies were conducted to measure the effectiveness of VirGuqin and MRGuqin.

5.1 VirGuqin

In order to verify whether VirGuqin can effectively engage people's interest in Guqin, we deployed our system in a local Museum in China and invited visitors to participate in the study. We chose to conduct our study in a museum because:

1. There was a Guqin exhibition in the museum, displaying several famous Guqins and Guqin-related paintings, sculptures etc. The exhibition is considered as one of the common practice in promoting Guqin. We could thus use it as a baseline to compare it with our system.

2. In comparison to some of the alternative study venues, such as schools, museum visitors have a diverse range of age, occupation and educational background that is important to this research;

3. Museum visitors tends to have abundant time, so they can participate in our experiments with more patient.

5.1.1 Participants. 308 people were recruited to our experiment, including 125 males and 183 females. Their age ranges from 8 to 73. They were screened to ensure that they have never heard of Guqin, which indicates they had no interest in learning Guqin before participating our experiment.

5.1.2 Experiment. Prior to the experiment, each participant is briefed with the instruction of how to use the VirGuqin, that is to raise their hands above their waist and moved them back and forth. Participants experienced two modes successively. In composing mode, they moved their hands freely to make various melody. In teaching mode, we used the famous Guqin music "Yang Guan San die" for its simplicity as well as coverage of all the three timbres (Fan Yin, An Yin and San Yin). Reduction notation character and its corresponding symbols were displayed on screen. Participants followed the instruction symbols when playing. At the end of the experiment, all the participants completed a questionnaire asking about their thoughts about VirGuqin:

Q1: Compared with the traditional promotion methods, does VirGuqin effectively enhance your interest in Guqin learning?

Q2: Is VirGuqin easy to use? (The score ranges from 0 to 10, 0 means very hard to use and 10 means very easy to use)

Q3: Is VirGuqin enjoyable? (The score ranges from 0 to 10, 0 stands for very boring, 10 stands for very enjoyable)

Q4: Is the symbols easy to understand?

5.1.3 Result.

- **Effectiveness**: 274 people (88.96%) said that the VirGuqin enhanced their interests in Guqin learning than traditional promotions such as exhibitions and expressed their curiosity to learn more about Guqin art in the future.
- **Ease-of-use**: 91 people thought VirGuqin was very easy to use (score 10), accounting for 29.55% of all the participants. The average score is 7.48 ($SD = 2.26$). See Fig.10.
- **Joy**: 109 people thought VirGuqin was very enjoyable (score 10), which accounted for 35.39% of all the participants. The average score was 7.98 ($SD = 2.14$). See Fig.10.
- **Ease of understand**: 288 people thought that our symbols were easy to understand, accounting for about 92.44%.

According to the feedback from the questionnaires after the experiment, most participants expressed that the experience has increased their interest in Guqin. Some of our participants inquired us "Where can I find a good Guqin teacher?", "Is this system available for purchase?" or "How much is a physical Guqin?" and so on. As such, our result shows an evidence that VirGuqin could potentially increase people's interest in Guqin, which is in favor of promoting Guqin art.

5.2 MRGuqin

In order to verify whether MRGuqin can assist in teaching effectively and improve the learning confidence of beginners, we setup MRGuqin system in a Guqin school to conduct a user study.

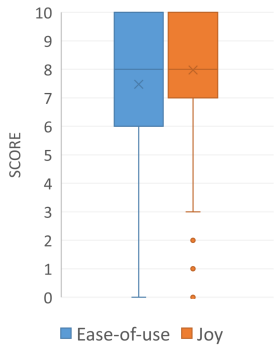


Figure 10: Box-and-Whisker graph of the result for ease-of-use and joy.

Table 3: Experiment design.

Group	Piece 1		Piece 2
A	Reduced notation	5-minute Break	MRGuqin
B	MRGuqin	5-minute Break	Reduced notation

5.2.1 Participants. 16 students (6 males and 10 females) were recruited to take part in this user study. Their ages ranged from 20 to 61 years old (average = 37.50, SD = 12.95). They were screened to ensure that: (1) They had normal or corrected-to-normal visual acuity and hearing; (2) They do not experience motion sickness in virtual environments; (3) They had learned to play Guqin less than 2 years.

5.2.2 Experiment. Two pieces (Piece 1 and Piece 2) from the music of "My Motherland and I" are selected as experimental materials, because its fingering covered San Yin, An Yin and Fan Yin but friendly for novices to learn. No obvious distinction in length or complexity is measured between the two pieces.The participants were divided into two groups with balanced age, gender and years of study distribution.

Prior to the experiment, each participant went through a training of MRGuqin with an example piece of music, ensuring that they understood the meaning of the symbols. 2×2 mixed design was used with group as the between-subject variable while learning method as the within-subject variable. Participants in Group A were asked to learn the Piece 1 with reduce notation character first and learn Piece 2 with the MRGuqin systems after a 5-minute break. Group B were asked to learn Piece 1 with MRGuqin system first and learn Piece 2 with the reduced notation after a 5-minute break (see Table 3).

Participants continued to practice each piece until they felt confident about playing it without the help of reduced notation or MRGuqin system (learning process). Two kinds of data were recorded: (1) Time of learning process; (2) Each piece of music played by participant without the help of reduced notation or MRGuqin.

After the experiment, participants were asked to complete a questionnaire focusing on their subjective assessment on MRGuqin.

Table 4: Average Time (in second). Standard deviation was in bracket.

Group	Reduced Notation	MRGuqin	Improvement
A	32.25 (13.53)	15.63 (6.02)	51.60%
B	26.38 (11.55)	13.13 (3.44)	50.23%

Table 5: Scoring by teacher. Standard deviation was in bracket. The result of both groups showed that the performance of the participants with MRGuqin got higher average score (91.00 of Group A and 91.13 of Group B) than that learned with traditional learning method (72.13 of Group A and 76.00 of Group B), and the improvements were 26.17% and19.90% respectively.

Group	Reduced Notation	MRGuqin	Improvement
A	72.13 (26.79)	91.00 (5.60)	26.17%
B	76.00 (24.92)	91.13 (3.83)	19.90%

5.2.3 Result. Learning time and the performance measured by the teacher and system were chosen to evaluate the effectiveness of our system.

Time

Between-subject one-way ANOVA was utilized to analyze the data between groups. The results illustrates that there is no significant difference between two pieces of music on the basis of learning time both in reading reduced notation ($F(1, 14) = 0.872, p = 0.366$) and in using MRGuqin ($F(1, 14) = 1.039, p = 0.325$). This suggested that the level of difficulty of the two pieces were similar.

Within-subject one-way ANOVA was utilized to analyze the data between methods. There are significant improvement of learning time between two methods both in two groups (see Table.4):

(1) In Group A ($F(1, 14) = 10.081, p = 0.007 < 0.05$), the average learning time decreased from 32.25 seconds (Reading reduced notation) to 15.63 seconds (with MRGuqin), leading to a 51.60% improvement;

(2) In Group B ($F(1, 14) = 9.670, p = 0.008 < 0.05$), the average learning time decreased from 26.38 seconds (Reading reduced notation) to 13.13 seconds (with MRGuqin), leading to a 50.23% improvement;

The result indicates MRGuqin system can help students learn faster. This is because that the symbols translated from the reduced notation relieved the cognitive burden of novices. Rather than understanding the character and finding the target location of fingers, MRGuqin is easier for users to follow the instruction of symbols displayed in the HMD. MRGuqin can overcome the difficulties in reading reduced notation and quickly find the corresponding location of fingers.

Performance

The performance was evaluate in two ways:

1. Teacher will score the performance of the participant considering of rhythm, intonation and expressiveness. One-way ANOVA was also utilized to analyze the data. There is no significant statistical difference between two groups on the basis of teacher's score both in reading reduced notation ($F(1, 14) = 0.090, p = 0.769$) and in using MRGuqin ($F(1, 14) = 0.706, p = 0.959$).This suggested that the level of difficulty of the two pieces were similar.

The result of both groups showed that the performance of the participants with MRGuqin got higher average score (91.00 of Group A and 91.13 of Group B) than that learned with traditional learning method (72.13 of Group A and 76.00 of Group B), and the improvements were 26.17% and 19.90% respectively (see Table.5). There are marginal significant difference between two method in Group A ($F(1, 14) = 3.805, p = 0.071$) and Group B ($F(1, 14) = 2.880, p = 0.112$).

2. The similarity between the ground truth (audio recording from teacher) and the audio recorded from participants is computed by measuring the difference between rhythm and intonation. The similarity in rhythm is calculated as the inverse of the sum of the difference in time for each tone between the ground truth and the record from a participant. The time for each tone is the time from start when a tone is produced. Whereas the similarity in intonation is calculated as the inverse of the sum of the difference in pitch for each tone. The pitch is determined by the main frequency from the Fourier Transform at each tone. The overall similarity is a weighted sum of the similarity in rhythm and similarity in intonation. Minim library[39] was used in processing the audio data.

Table 6: Scoring by system. Standard deviation was in bracket.The result of both groups showed that the performance with MRGuqin got higher average score(86.13 of Group A and 87.00 of Group B) in similarity than that learned by traditional learning method(66.50 of Group A and 73.50 of Group B), and the improvements were 29.51% and 18.36% respectively.

Group	Reduced Notation	MRGuqin	Improvement
A	66.50 (33.53)	86.13 (9.29)	29.51%
B	73.50 (30.28)	87.00 (5.60)	18.36%

There is no significant statistical difference between two groups on the basis of system's score both in reading reduced notation ($F(1, 14) = 0.342, p = 0.568$) and in using MRGuqin ($F(1, 14) = 0.052, p = 0.523$).This suggested that the level of difficulty of the two pieces were similar.

The result of both groups showed that the performance with MRGuqin got higher average score (86.13 of Group A and 87.00 of Group B) in similarity than that learned by traditional learning method (66.50 of Group A and 73.50 of Group B), and the improvements were 29.51% and 18.36% respectively. There is a significant difference between two methods in Group A ($F(1, 14) = 9.755, p = 0.007 < 0.05$) and marginal significant in Group B ($F(1, 14) = 1.537, p = 0.235$).

We can learn from the result that our MRGuqin could help users performance a little better. As we learned from the investigation, for most people who is new to Guqin (usually less than half a year in learning), understanding reduced notation is a huge challenge. In one case, a participant in Group A could barely finish the piece of

music by reading the reduce notation, let alone perform excellently. However, MRGuqin avoided this problem and the participant can finish with plausible accuracy. Because novices were hardly to find the target location of fingers quickly, the pieces of music played by participants were usually slower than the ground truth. MRGuqin system could help them conquer this problem by adding symbols to guide users and progress bar with different heights to indicated rhythms.

Feelings

According to the result of questionnaire we collected after experiments, all the participants (100%) thought the symbols were easy to understand. 14 participants (87.5%) felt it interesting in using interactive technology to learn Guqin. 13 participants (81.3%) said the virtual scene we created could help them understand the Guqin music better. 13 participants (81.3%) thought that faster learning speed and higher accuracy could enhance their learning confidence.

6 DISCUSSIONS

6.1 Comparison

We developed VirGuqin and MRGuqin to make Guqin more accessible to the general public. As mentioned in Section 1, there are some other interactive applications of Guqin which have different research goals. Reference [17] aimed at acquiring the physical gesture when performing Guqin by wearing specialized gloves, while our system is low-cost and all devices are off-the-shelf. Some works are cross-modal, trying to combined Guqin music with dancing[23], or painting[7, 20], while our work focus on playing Guqin and its education. Reference [51] proposed a teaching system, but symbols were projected on the Guqin instrument. Users could not see a virtual scene related to the Guqin music and still need to imagine it by themselves.

6.2 Contributions to HCI

We surveyed 1,006 Chinese worldwide and found the promotion of Guqin is faced with a number of challenges. To overcome these problems, we developed (1) VirGuqin for people who have little knowledge in Guqin art, making performing Guqin music without physical instrument possible; (2) MRGuqin for Guqin beginners to ease the learning process and increase their confidence. In our work, HCI methods and technology have been used to promote Guqin, and a good result has been achieved. We think HCI methods and technology could also be used in other dying arts. Our work helps broaden the application scope of HCI.

6.3 Limitations&future work

Our work still has some limitations. Firstly, in MRGuqin and VirGuqin (Teaching mode), users can only choose Guqin music from several candidate pieces stored in the system. Our future research will investigate methods to automatically generate instructions for arbitrary input music. Secondly, MRGuqin lacks feedback, which means MRGuqin cannot judge whether user's fingers are at the right place or not. Appropriate feedback may help build user's confidence and correct their fingering. We will add feedback to our system in future work. Thirdly, we believe the impact of our system on people's understanding and perception of Guqin will go beyond museums and the institutes that specialized in Guqin, but such an impact takes time to measure. More qualitative methods will be used to stronger our belief in further study. Last, how can Guqin music affects people's behavior thinking needs rigorous analysis and justification for significant future study. This can also be an interesting research direction.

7 CONCLUSION

Guqin is a representative Chinese traditional music instrument and was included in "Representative List of the Intangible Cultural Heritage of Humanity", but currently it is in danger of extinction. This motivated us to investigate the reasons that hinder the promotion of Guqin and developed VirGuqin and MRGuqin to make it more accessible to the general public. VirGuqin uses a low-cost motion tracking device (Kinect) to capture the motion of user's hands to perform without a real Guqin. A field study conducted in a museum showed 89% of 308 participants expressed an increase in interest in learning Guqin after using our system. MRGuqin is a mixed reality learning environment to reduce the entry barrier for learning Guqin. It was tested on 16 participants. Experimental results show the participants learnt Guqin significantly faster and performed better than the current practice.

Our work presented the current challenges in the promotion of Guqin and proposed two solutions which are proved to be effective according to our empirical study. The proposed solutions demonstrated how modern interactive technology can be used to support the inheritance of Guqin art and provided insights to solve some of the pressing issues in other endangered arts.

ACKNOWLEDGMENTS

This work was supported by the Natural Science Foundation of China (62002258) and National Key Research and Development Program of China (2019YFC1521200).

REFERENCES

[1] Activision. 2019. Guitar Hero. http://guitarhero.com/.
[2] Amanotes. 2020. Magic Tiles 3. https://play.google.com/store/apps/details?id=com.youmusic.magictiles&hl=en.
[3] Nick Bryan-Kinns and Zijin Li. 2020. ReImagining: Cross-cultural Co-Creation of a Chinese Traditional Musical Instrument with Digital Technologies. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*. ACM, New York, NY, USA, 382–387.
[4] Liangyu Cai. 2007. *A Chinese-English Bilingual Dictionary of Guqin Art.* Shanghai Conservatory of Music Press, China.
[5] Pedro Camacho. 2008. AudioSurf. https://www.audio-surf.com/.
[6] Changlin Chen. 1989. Preliminary application of the computer technique to guqin music research. *Journal of Computer Science and Technology* 4, 1 (1989), 85–96.
[7] Tong Chen, Yan Wang, and Qi Zhao. 2014. Research on the interaction design of Chinese guqin sound and painting based on Leap Motion(In Chinese). *Literature and Art Criticism* 1, 9 (2014), 77–81.
[8] Jonathan Chow, Haoyang Feng, Robert Amor, and Burkhard C Wünsche. 2013. Music education using augmented reality with a head mounted display. In *Proceedings of the Fourteenth Australasian User Interface Conference*. Australian Computer Society, AUS, 73–79.
[9] Franceli Cibrian, Oscar Peña-Ramírez, Deysi Ortega, and Monica Tentori. 2017. BendableSound: An Elastic Multisensory Surface using Touch-based interactions to Assist Children with Severe Autism during Music Therapy. *International Journal of Human-Computer Studies* 107 (2017), 22 – 37.
[10] Matthew Cox, Andrew Hollenbach, and Joe Geigel. 2016. A Dynamic 3D Performance Space for Control of Virtual Musical Instruments. In *Proceedings of the ACM International Conference on Interactive Surfaces and Spaces*. ACM, New York, NY, USA, 477–480.
[11] Marta del Rio, Jorge Martin-Gutierrez, Vicente López-Chao, Rodolfo Parra, and Mario Sosa. 2019. AR Graphic Representation of Musical Notes for Self-Learning

on Guitar. *Applied Sciences* 9 (2019), 4527.
[12] Emmanuel Dubois and Laurence Nigay. 2000. Augmented Reality: Which Augmentation for Which Reality. In *Proceedings of DARE 2000 on Designing Augmented Reality Environments*. ACM, New York, NY, USA, 165–166.
[13] Nicholas Gillian and Joseph A Paradiso. 2012. Digito: A Fine-Grain Gesturally Controlled Virtual Musical Instrument. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*. ACM, New York, NY, USA, 39–42.
[14] Dick Ranch Glen Johnson, Dominic Chennell. 1996. Piano Magic. https://www.piano-magic.co.uk/.
[15] Yi Gong. 2002. *Guqin playing method*. Shanghai Education Press, China.
[16] Yin Guan and Changle Zhou. 2011. Machine Transcription of Guqin Tablature and Automatic Music Rhythm Tagging. *Journal of Information & Computational Science* 8, 11 (2011), 2165–2176.
[17] Jingyin He, Ajay Kapur, and Dale A Carnegie. 2015. Developing a physical gesture acquisition system for guqin performance. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*. ACM, New York, NY, USA, 187–190.
[18] Penttinen Henri, Jyri Pakarinen, Vesa Välimäki, Mikael Laurson, Mika Kuuskankare, Henbing Li, and Marc Leman. 2006. Physical modeling of the guqin - a Chinese string instrument. In *Nordic Music Technology Conference*, Vol. 250. NoMute, Trondheim, Norway, 12–14.
[19] Mu-Hsen Hsu, WGCW Kumara, Timothy K Shih, and Zixue Cheng. 2013. Spider King: Virtual musical instruments based on microsoft Kinect. In *Proceedings of the International Joint Conference on Awareness Science and Technology & Ubi-Media Computing*. IEEE CS, Los Alamitos, CA, USA, 707–713.
[20] Michael Xuelin Huang, Will WW Tang, Kenneth WK Lo, Chi Kin Lau, Grace Ngai, and Stephen Chan. 2012. MelodicBrush: a novel system for cross-modal digital art creation linking calligraphy and music. In *Proceedings of the Designing Interactive Systems Conference*. ACM, New York, NY, USA, 418–427.
[21] A.H. Jantan H.Y. Leng, N.M. Norowi. 2018. Virtual kompang: mapping in-air hand gestures for music interaction using gestural musical controller. *Journal of Fundamental and Applied Sciences* 10, 2 (2018), 24–34.
[22] Alexander Refsum Jensenius and Michael J Lyons. 2017. *A NIME Reader: Fifteen Years of New Interfaces for Musical Expression*. Vol. 3. Springer-Verlag, Berlin.
[23] Eng Tat Khoo, Roshan Lalintha Peiris, and Matthias Rauterberg. 2011. 3D Guqin: Digital playground to explore music that embodies Chinese culture and philosophy. In *2011 Second International Conference on Culture and Computing*. IEEE CS, Los Alamitos, CA, USA, 145–146.
[24] Konstantin Klamka, Jannik Wojnar, and Raimund Dachselt. 2019. ScaleDial: A Novel Tangible Device for Teaching Musical Scales and Triads. In *Proceedings of CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI'19 Extended Abstracts)*. ACM, New York, NY, USA, 1–4.
[25] Tap Lab. 2020. Dream Piano. https://play.google.com/store/apps/details?id=com.eyu.piano&hl=en_US.
[26] Xiangting Li. 2014. *Gu Qin Zong Yi(Survey of Guqin)*. China Renmin University Press, Beijing, China.
[27] Hui Liang, Jin Wang, Qian Sun, Yong-Jin Liu, Junsong Yuan, Jun Luo, and Ying He. 2016. Barehanded music: real-time hand interaction for virtual piano. In *Proceedings of the 20th ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games* (Redmond, Washington). ACM, New York, NY, USA, 87–94.
[28] Huanhuan Lu, Bingjun Zhang, Ye Wang, and Wee Kheng Leow. 2008. iDVT: An interactive digital violin tutoring system based on audio-visual fusion. In *Proceedings of the 16th ACM international conference on Multimedia* (Vancouver, British Columbia, Canada). ACM, New York, NY, USA, 1005–1006.
[29] Lanlan LV and Changle Zhou. 2011. Improved Affective Computing Fuzzy Model of Guqin Music. *Journal of Information & Computational Science* 8, 14 (2011), 3063–3073.
[30] Markus Löchtefeld, Sven Gehring, Ralf Jung, and Antonio Krüger. 2011. guitAR: supporting guitar learning through mobile projection. In *Proceedings of CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI'11 Extended Abstracts)*. ACM, New York, NY, USA, 1447–1452.
[31] David Holz Michael Buckwald. 2010. Leap Motion. https://leapmotion.com/.
[32] Microsoft. 2010. Kinect. https://developer.microsoft.com/en-us/windows/kinect/.
[33] Will Molloy, Edward Huang, and Burkhard Wünsche. 2019. Mixed Reality Piano Tutor: A Gamified Piano Practice Environment. In *2019 International Conference on Electronics, Information, and Communication (ICEIC)*. IEEE CS, Los Alamitos, CA, USA, 1–7.
[34] Enzhi Ni, Minjun Jiang, Xiaojun Ding, and Changle Zhou. 2011. Handwriting input system of chinese guqin notation. *Journal on Computing and Cultural Heritage* 3, 3 (2011), 1–22.
[35] Enzhi Ni, Minjun Jiang, and Changle Zhou. 2010. Decomposition of reduced character of Chinese guqin notation. In *2010 IEEE International Conference on Intelligent Systems and Knowledge Engineering*. IEEE CS, Los Alamitos, CA, USA, 384–389.
[36] Enzhi Ni, Changle Zhou, and Minjun Jiang. 2012. A Radical Cascade Classifier for Handwritten Chinese Character Recognition. *Journal OF Software* 7, 10 (2012), 2294.
[37] Ministry of Culture and Tourism of the People's Republic of China. 2018. Representative List of National Intangible Cultural Heritage Inheritors. http://www.ihchina.cn/representative#target1.
[38] Yan Peng. 2009. Reflections on the safeguarding and transmission of Guqin zither culture (in Chinese). *Musicology in China* 2009, 2 (2009), 89–92.
[39] Damien Quartz. 2014. Minim. http://code.compartmental.net/minim/.
[40] Zhimin Ren, Ravish Mehra, Jason Coposky, and Ming Lin. 2012. Designing virtual instruments with touch-enabled interface. In *Proceedings of CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI'12 Extended Abstracts)*. ACM, New York, NY, USA, 433–436.
[41] Katja Rogers, Amrei Röhlig, Matthias Weing, Jan Gugenheimer, Bastian Könings, Melina Klepsch, Florian Schaub, Enrico Rukzio, Tina Seufert, and Michael Weber. 2014. Piano: Faster piano learning with interactive projection. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*. ACM, New York, NY, USA, 149–158.
[42] Yong Shi. 2011. Guqin music on mass media (In chinese). *Huang Zhong: Journal of Wuhan Conservatory of Music* 2 (2011), 133–143.
[43] Qing Sun, Deyun Zhang, Yifeng Fan, Kaizhong Zhang, and Bin Ma. 2010. Ancient Chinese Zither (Guqin) Music Recovery with Support Vector Machine. *Journal on Computing and Cultural Heritage* 3, 2 (2010), 1–10.
[44] Scientific United Nations Educational and Cultural Organization(UNESCO). 2003. Text of the Convention for the Safeguarding of the Intangible Cultural Heritage. https://ich.unesco.org/en/convention.
[45] Scientific United Nations Educational and Cultural Organization(UNESCO). 2008. Guqin and its music. https://ich.unesco.org/en/RL/guqin-and-its-music-00061.
[46] Christina Volioti, Sotiris Manitsaris, Edgar Hemery, Stelios Hadjidimitriou, Vasileios Charisis, Leontios Hadjileontiadis, Eleni Katsouli, Fabien Moutarde, and Athanasios Manitsaris. 2018. A natural user interface for gestural expression and emotional elicitation to access the musical intangible cultural heritage. *Journal on Computing and Cultural Heritage* 11, 2 (2018), 1–20.
[47] L. Wikarsa, D. Paseru, and V. T. Pangemanan. 2015. The development of a cross-platform multi-player virtual application of Kolintang musical instruments using various controllers. In *2015 International Conference on Electrical Engineering and Informatics (ICEEI)*. IEEE CS, Los Alamitos, CA, USA, 600–605.
[48] Wikipedia. 2020. Contents of the Voyager Golden Record. https://en.wikipedia.org/wiki/Contents_of_the_Voyager_Golden_Record#Music.
[49] Nan Yao, Kaisheng Wang, Yue Cai, and Xuwei Zhang. 2015. Application of Somatosensory Sensor Kinect in Man-Machine Interaction Framework of Gesture Recognition. *Sensor Letters* 13 (2015), 1050–1054.
[50] Hong Zeng, Xingxi He, and Honghu Pan. 2019. FunPianoAR: A Novel AR Application for Piano Learning Considering Paired Play Based on Multi-Marker Tracking. *Journal of Physics: Conference Series* 1229 (2019), 597–602.
[51] Yingxue Zhang, Siqi Liu, Lu Tao, Chun Yu, Yuanchun Shi, and Yingqing Xu. 2015. ChinAR: facilitating Chinese Guqin learning through interactive projected augmentation. In *Proceedings of the Third International Symposium of Chinese CHI(Chinese CHI'15)*. ACM, New York, NY, USA, 23–31.
[52] Changle Zhou and Lanlan Lv. 2009. The fundamental frequency estimation of Guqin timbre based on wavelet transform. In *IEEE International Conference on Intelligent Computing and Intelligent Systems*. IEEE CS, Los Alamitos, CA, USA, 89–92.
[53] Athanasia Zlatintsi, Panagiotis P. Filntisis, Christos Garoufis, Antigoni Tsiami, Kosmas Kritsis, M. A. Kaliakatsos-Papakostas, Aggelos Gkiokas, Vassilis Katsouros, and Petros Maragos. 2018. A Web-Based Real-Time Kinect Application for Gestural Interaction with Virtual Musical Instruments. In *Proceedings of the Audio Mostly 2018 on Sound in Immersion and Emotion*. ACM, New York, NY, USA, 1–6.