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ASPECTS ON PHYSICAL MODELING OF A CHINESE STRING INSTRUMENT - THE GUQIN

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ABSTRACT

This paper discusses aspects regarding the physical modeling of the guqin which is a Chinese string instrument. First the instrument will be described, then the physical modeling of the guqin will presented, and finally control issues regarding the complex system will be discussed. The guqin is a seven stringed ancient musical instrument and it is the oldest Chinese string instrument still used in modern time. The long history of the instrument is well documented and the guqin has a crucial role in Chinese musicological studies. Its acoustics and playing technique, on the contrary, have not so far attracted great attention. The guqin synthesizer discussed here is going to be used for rule based synthesis of guqin music. The physical sound synthesis algorithm is based on digital waveguide modeling. It uses the commuted waveguide synthesis method, hence, an inverse filtered excitation signal is inserted to a string model. The features of the proposed synthesis method are able to reproduce the important characteristics of the instrument, i.e., inharmonicity, glides, friction sound, and flageolet tones.

INTRODUCTION

The purpose of this paper is to present the guqin synthesizer we have produced in this collaborative project where the goal is to digitize existing guqin music. We discuss the instrument, the way it is played, synthesis of flageolet tones, and aspects of controlling the synthesizer.

The guqin has a crucial role Chinese musicological studies and because of its rich documentation of its long history and precious old musical notation its function in the cultural is understood quite well [1]. In contrast, its playing techniques, acoustics and, hence, sound synthesis have attained far less attention. Transforming the large body of traditional guqin tabulature into music has been a very difficult task. The breadth of the material and the very specialized skills (understanding and playing) create a great challenge. With a computer system and suitable software this task could be partly automatized and the work would be much faster and easier than manual labour. This collaboration has dealt with both the acoustics and synthesis of the instrument and the notation system. Our approach is to use physically inspired sound synthesis models that are efficient enough to run in real time with a musical score that controls the synthesis model. This way flexibility, precision, repeatability is gained for creating rule based guqin music, ancient and why not modern too.

The commuted digital waveguide synthesis technique is the basis of the discussed synthesizer [2-3]. It has been successfully used for many traditional and ethnic instruments [4-6]. Previously, a neural network based technique has been proposed to synthesize guqin tones [7]. A deeper insight on the acoustics of the guqin and extensions to the synthesizer discussed here are presented in [8].

DESCRIPTION OF THE GUQIN

Guqin (pronounced ku-ch'in) is a fretless Chinese string instrument. It has seven strings and is the oldest Chinese string instrument still used in modern time [1]. The current structure of the instrument has stayed the same for about 1500 years. The structure stabilized between the 5th and the 7th century, and the most significant change since then has been the replacement of silk strings with steel-nylon strings. In the following, we briefly describe the construction and playing style of the guqin. Figure Play displays the side of the instrument while one of the authors Henbing Li is playing the instrument in the listening room at TKK.

Figure 1. Typical playing position of the guqin, the right hand plucks the strings and the left hand presses the strings against the top-plate.

Construction, playing technique, and tuning

The guqin is a hollow box made from two pieces of wooden board, the shape is long and narrow. The top board is carved into an arch while the bottom is flat. For the top board soft wood is usually used (such as tung), while the wood for the bottom board is hard (catalpa or fir).

The bridge is made from hard wood, and the strings are attached to it with a sophisticated twisting-rope system, which allows fine-tuning of the strings in a limited range. The other ends of the strings are bent over the end (tail) and are finally tied up to the feet on the bottom. There are 13 marks inlayed on the roughcast at the side of the first string, which indicate the positions of the first to the fifth and the seventh overtone. These marks also function as a reference for stopped strings, i.e., when the string is pressed against the top board. Each part between two contiguous marks is divided into ten parts, for example, mark 2.5 indicates that the tone is played halfway between the second and the third mark.

The guqin is usually played on a table with its two feet standing on the table and the neck laying on the right edge of the table (see Fig. 1). Two anti-slip mats between the contact points of the table and the instrument keep it in place. In ancient times the instrument has also been held in the lap. The right hand is used to pluck the strings between the bridge and the first mark (see Fig. 2), and the left hand presses the strings against the top plate of the body. The instrument is fretless, which enables smooth sliding tones. Guqin music also incorporates substantial use of harmonics or flageolet tones.

The string is pressed against the top-plate with the nail of the left thumb or at the first joint. When pressing the strings with the other left hand fingers, the fleshy top part of the finger or occasionally the left side of the first ring finger joint is used. The right hand pluck the string from either the fleshy or the nail side. These variations and combinations bring a small variety in the tone quality as discussed in the analysis section.

The seven strings are tuned basically as a pentatonic scale. The basic tuning of the open strings is C2, D2, F2, G2, A2, C3, and D3 from the lowest string (no. 1) to the highest (no. 7). The pitch range for so called stopped strings is from 65.2 Hz (open string no. 1) to 787.5 Hz (string no. 7, mark 2.6) which roughly correspond to notes C2 and G5, respectively. The highest harmonic or flageolet sound is played on string no. 7 on marks no. 1 or no. 13 f_0 = 1174.7 Hz, D6. The guqin used in this measurement was made by Zhang Jianhua in Beijing in 1999. The boards are made of fir, and the roughcast is deer horn powder and raw lacquer. Shangyin steel-nylon strings are used.

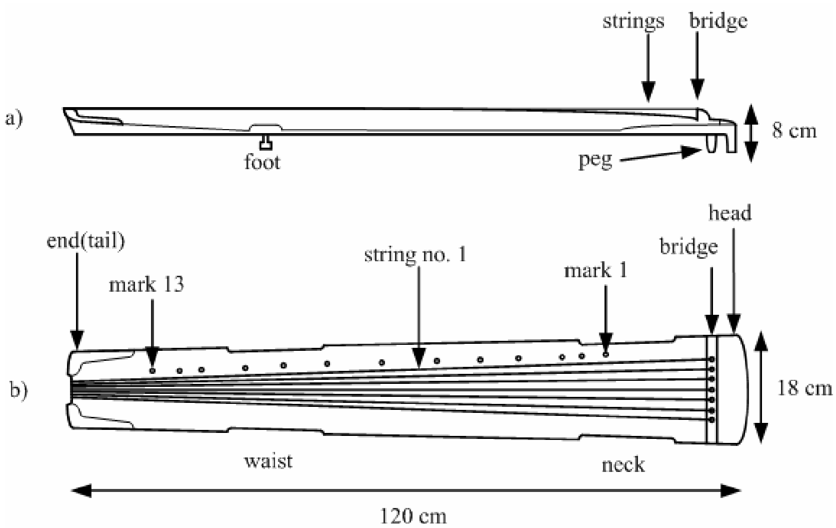

Figure 2. Side and top-views of the construction of the guqin.

PHYSICS-BASED SOUND SYNTHESIS OF THE GUQIN

The basic block diagram of the guqin synthesizer is shown in Figure 3. It has a excitation sample data-base with a timbre control for equalization, a string model *S*(*z*), a friction model, and a body model filter *B*(*z*). The string model is a single-delay loop (SDL) [9] digital waveguide and creates the decay partials of the string. The friction model generates the friction noise emanating from the sliding finger-string contact. The friction model is a set parallel resonators and designed in the same style Cook's model-based synthesizers [10]. In [8] the extension of the synthesizer to facilitate the synthesis of phantom partials, the friction model, the body model are discussed in more detail. Here we focus on the synthesis of flageolet tones.

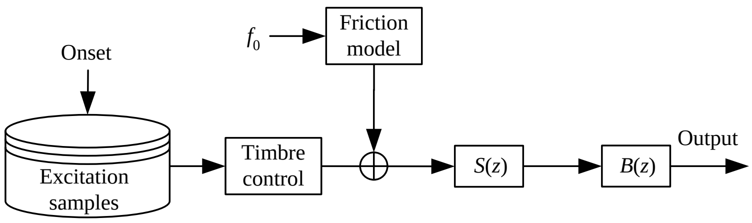

Figure 3. Block diagram of the guqin synthesizer.

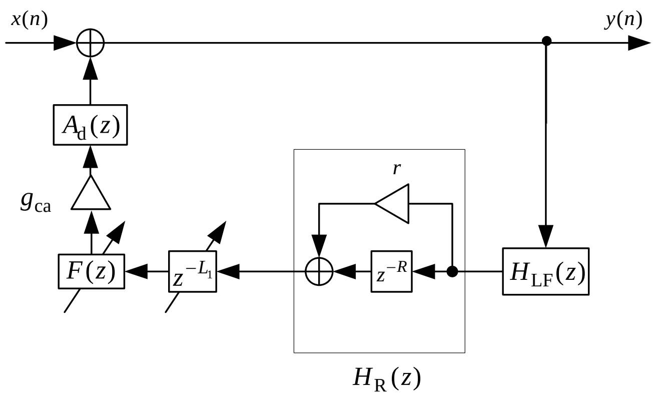

Figure 4. Signal flow diagram of the string model.

Figure 4 shows the flow diagram of the used string model with the loss filter $H_{LF}(z)$ that implements the frequency dependent losses, the fractional delay filter $F(z)$ for tuning the string, and the dispersion filter $A_d(z)$ for simulating the inharmonicity [10]. The length of the string is varied, hence, the energy is scaled with g_{ca} [11]. The ripple filter [12] $H_R(z)$ enables efficient modeling of different decay times of partials.

To produce flageolet tones filter $H_{LF}(z)$ and $H_R(z)$ are parametrized in the following manner. The starting point is to have an open string model and alter the parameters of the ripple filter properly. At first, the *a* parameter for $H_{LF}(z)$ is computed for a flageolet tone as described in [13]. After this the loop gain *g* is calculated for a desired fundamental frequency f_0 and target decay time T_{60} as

$$g = e^{-(1/f_0 T_{60})}. \qquad \text{(Eq. 1)}$$

The ripple rate $R = 1/n$, where *n* is the harmonic index, determines the places of the ringing resonances in the frequency domain. Furthermore, the harmonic index *n* determines the f_0 of the flageolet tone, i.e., the f_0 of the flageolet tone is one of the harmonics of the open string. Then the ratio of the ringing partials and the radically fast decaying partials is described with the ripple depth as

$$r = e^{-(1/f_0 T'_{60})}, \qquad \text{(Eq. 2)}$$

where $T'_{60} = T_{60}/200$. This way the harmonics of the open string that are not multiples of *n*, i.e., the f_0 of the flageolet tone, decay about 200 times faster than the ringing harmonics. To compensate for the ripple filter's radical decay change and to maintain the target decay time, *g* is compensated by $1/(r+1)$. Therefore, the transfer function of the ripply loss filter is

$$H_{LF}(z)H_R(z) = \frac{g(1+a)}{r+1}\frac{r+z^{-R}}{1+az^{-1}}. \qquad \text{(Eq. 3)}$$

Stability for the string model is assured when the overall loop gain remains smaller than unity. This is the case as long as $g < 1$.

RESULTS

Due to the brevity of this article the results concentrate on the synthesis of flageolet tones. Figure 5 displays the decay times of the synthesized string model (o) and the analyzed target times (x), and the overall response of the loop filter (dashed line). The x-axis indicates the harmonic number and the y-axis the decay times of the fourth open string and fifth harmonic. The ripple filter succeeds very well in reducing the decay times of the harmonics between the ringing partials. Therefore, a flageolet like tone is synthesized with an open string model which is parallel what occurs in the real instrument. The advantages of this kind of technique are that no separate excitation signals are needed for flageolet tones and a ringing open string can be changed to a flageolet tone by changing simply the filter parameters and not by changing the f_0

of the string model. Additionally, with a time varying string model also flageolet tones can be slided or vibrato could be added even if it is not possible in the real world.

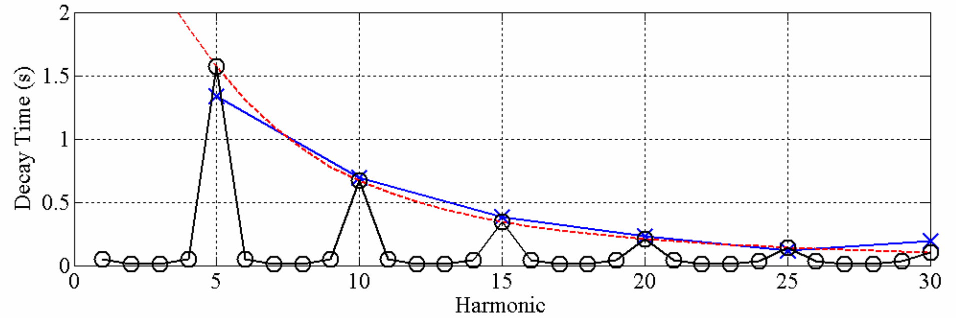

Figure 5. Decay times of a synthesized flageolet tone (o), target times (x), and loop filter (dashed) as function of harmonic number.

IMPLEMENTATION AND CONTROL

The physical model is implemented and controlled within an environment called PWGL [14]. PWGL is a visual programming language based on Lisp, CLOS, and OpenGL. In the complete system the musical score gives the notes and other musical information which control the physical instrument model. The score-editor of PWGL utilizes internally the Expressive Notation Package (ENP) [15]. The ENP again is a music notation package with very flexible possibilities to define the score, hence, enables to create control signals for the physical instrument model. Often these control signals are very specific since all instruments are played in a unique fashion. Another challenge confronted when synthesizing the guqin is that the traditional score, or tabulature notation, which is more than a thousand years old and based on Chinese characters. The Chinese characters describe how a performer should utilize both hands to execute a musical expression. The challenge is that ENP is primarily designed to present Western musical notation roughly from the 17th century onwards.

JZP is a novel representation scheme, developed by one of the authors Henbing Li, of the ancient Chinese guqin Jian Zi Pu tabulature that allows to notate guqin music in a modern computerized system. The JZP notation is used here to find information dealing with the correct processed sample and the low-level synthesis parameters used by our guqin model. The rest of the expression markings found in the score describe vibrato gestures that in conjunction with the glides describe how pitch fluctuations should be performed by the system. Figure 6 displays the playing of the open strings, including Chinese symbols, in the ENP. Note that sliding an open string is practically a pure physical impossibility.

We have also developed a scheme how to dynamically control the depth of the vibrato during sliding events. When a player slides the left hand on the string to a note and leaves the note ringing, there is naturally no vibrato during the sliding event. Figure 7 (a) displays a sliding event and Figure 7 (b)-(c) show vibrato gestures added to the sliding event. Decreasing the vibrato during slides could be solved by manually going through the whole score and altering the required events manually. In contrast, we propose a control scheme were the vibrato depth is scaled dynamically based on the speed of the left hand movement. By making it automatic is very convenient for a composer. Figure 7 (b) and (c) show how the automatic depth scaler affects the sliding event when it is mild and in full use, respectively. Moreover, in Figure 7 (c) the vibrato disappears completely during the slides.

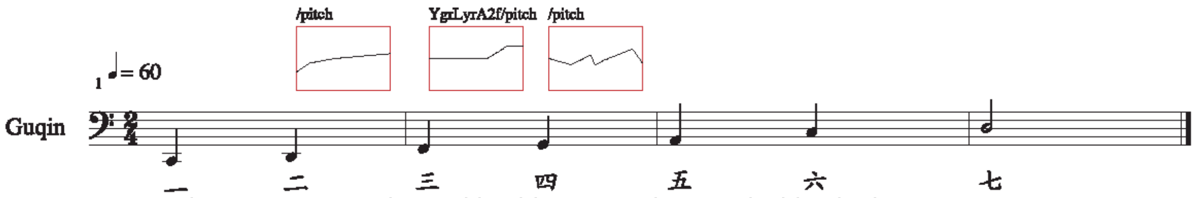

Figure 6. Open strings with Chinese symbols and slides in the ENP.

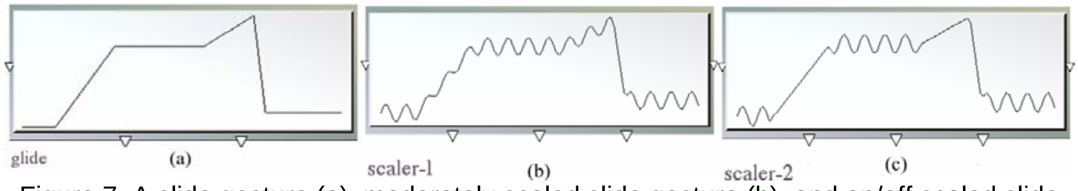

Figure 7. A slide gesture (a), moderately scaled slide gesture (b), and on/off scaled slide gesture (c).

CONCLUSIONS

This paper has discussed one of the instruments that was almost lost during the Cultural Revolution – the guqin. The guqin has a very important role in the history and present day of Chinese music. This paper presented shortly the construction of the instrument, the basic idea of a proposed guqin synthesizer and design of flageolet tones for the synthesizer. The notation system was briefly discussed and a manner to automatically scale vibrato gestures during slides was proposed. Future work will include rule based synthesis of guqin music with the proposed synthesizer in the PWGL environment.

ACKNOWLEGMENTS

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