SOURCE FILTER MODEL FOR EXPRESSIVE GU-QIN SYNTHESIS AND ITS iOS APP

Pei-Ching Li, Wei-Chen Chang, Tien-Min Wang, Ya-Han Kuo, Alvin W. Y. Su*

SCREAM Lab., Department of CSIE,
National Cheng-Kung University
Tainan, Taiwan
bff@csie.ncku.edu.tw

ABSTRACT

Gu-Qin as a venerable Chinese plucked-string instrument has its unique performance techniques and enchanting sounds. It is on the UNESCO Representative List of the Intangible Cultural Heritage of Humanity. It is one of the oldest Chinese solo instruments. The variation of Gu-Qin sound is so large that carefully-designed controls of its computer synthesizer are necessary. We developed a parametric source-filter model for re-synthesizing expressive Gu-Qin notes. It is capable to cover as many as possible combinations of Gu-Qin's performance techniques. In this paper, a brief discussion of Gu-Qin playing and its special tablature notation are made for understanding the relationship between its performance techniques and its sounds. This work includes a Gu-Qin's musical notation system and a source-filter model based synthesizer. In addition, we implement an iOS app to demonstrate its low computation complexity and robustness. It is easy to perform improvisation of the sounds because of its friendly user interfaces.

1. INTRODUCTION

Playing virtual musical instruments is a fashionable application since the multiple-point capacitive touch panel technique has been widely used in mobile devices in the last few years. The music synthesis techniques behind this sort of application software are mostly wavetable-based synthesizers [1]. Wavetable-based synthesis requires lots of storage space for various timbres. In addition, most synthesized sound generally shows little expression. In order to pursue a flexible control of synthesized sounds, parametric approaches, such as physical model or linear-predictive-based (LP-based) model, seem more suitable than wavetable-based approaches. Parametric approaches have larger order of freedom to design suitable control parameters corresponding to processing and combination of different excitations.

Gu-Qin is a Chinese plucked-string musical instrument that consists of a rectangular wooden chamber and seven strings. When Gu-Qin is played, the performer's right hand fingers can pluck the string either inward or outward, while the left hand fingers press the strings heavily to produce notes or touch them lightly to produce overtones. The performer is asked to use the fingers or fingernails to pluck, which produce very different timbres. In addition, the left hand fingers can glide along a string to produce vibrato or portamento effects. Pitch can change over an octave after plucking a string. Physical models for plucked-string instruments [2] and Gu-Qin [3]-[5] have been studied and built in the last decade. We have also proposed a series of techniques which focused on building the physical model of Gu-Qin and automatically learning its synthesis coefficients [6]-[8]. The pitch-changing mechanism of the model was also devised. Although the synthetic results sound perfect in the single pluck cases, they couldn't faithfully reflect the dynamics produced by successive Gu-Qin's performing skills. Such kinds of dynamics are the essential part of Gu-Qin music but are hard to model comprehensively [9]. Hence, the Gu-Qin physical model alone is not so applicable if the corresponding interactive performance model is absent.

Instead of attempts to fully model the physical structure and all possible performance skills in one single physical model, we proposed a modified source filter model which is capable of reproducing most performance atoms and their combinations. The performance atom here is defined as specific phases in a music note, such like, attack, sustain, release, glissando, portamento and so on. In our experience, an expressive Gu-Qin synthetic sound mostly depends on the fricative resulted from the pressure or sliding movement between the string and the performer's finger.

This paper also presents an iOS app software including a Gu-Qin's notation system, a notational symbol (also called JianZi described in the next section) parser, a synthesizer and an interactive interface to change the characteristics of synthesized notes. The source filter synthesis model has been adequately mapped its control parameters to Gu-Qin's special performing techniques. The synthesized results can not only sound similar to the original but also cover most of the possible variations due to various performing techniques. One of the authors, Alvin W.Y. Su, played his Gu-Qin and recorded the database used in this paper. A famous piece of Gu-Qin music called "Liang Shiau Yin" (Song of Beautiful Night) was recorded. Then, every note was played and recorded separately. The music and the synthesized results can be heard at [10].

The organization of this paper is as follows. The relationship between Gu-Qin's performance and its analysis/synthesis is discussed in Section 2. Detailed flowchart and processes of the proposed synthesizer are described in Section 3. We introduce the iOS app and demonstrate several synthesized results of different playing techniques in Section 4. Finally, our conclusion and future work are given in Section 5.

2. PERFORMANCE OF GU-QIN

Gu-Qin, one of the oldest Chinese instruments, has around 1500 frequently used combined performance techniques [11]. Many of them are exaggerative effects such as various vibratos and wide range portamento. The uniqueness of Gu-Qin music also comes from its special notation system. Different from western music notation, the notation of Gu-Qin did not directly indicate what notes were played. Instead, it described detailing tuning, finger positions, stroke technique and so on. This unique form of tablature, called JianZi Pu (literally “reduced notation”), was well-developed and formulated after the Tang dynasty in ancient China. JianZi Pu is a simplified version of the much older tablature which was used to write down all the performance details in Chinese. JianZi preserves only the important parts of Chinese characters to represent which string number is played, how to pluck and so forth. Though Gu-Qin music was introduced to the western world for more than 100 years, literatures about the relationship between JianZi Pu and Gu-Qin synthesis first appeared only in the decade. For example, Wang has presented a synthesizer to produce vibrato or portamento in Gu-Qin music [12] and Chang has proposed a JianZi Pu parser to fully digitalize these reduced Chinese notations [13]. Recently, Laurson et al. have presented a Gu-Qin synthesis system which provides basic score-based controls for JianZi Pu [14].

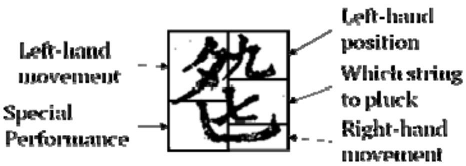

Figure 1: *Example of the JianZi notation.*

According to Chang’s thesis [13], a simple example is shown in Fig. 1. The left-upper character「夕」means the ring finger of left hand. The right-upper character「九」 means the ninth *hui* position. There are 13 *hui* positions of a string, which are related to the pitches. It means the left-hand movement is putting the ring finger of the left hand on the position of the ninth *hui*. The right-middle character「七」means the seventh string. The bottom character means plucking the string using the index fingernail outward. Therefore, the whole performance is to ask the player to use his/her index finger of right hand to pluck the seventh string outward while using his/her ring finger of left hand to press on the position of the ninth *hui* of the seventh string.

In a Gu-Qin tablature, time information such as beat and tempo is either absent or not strictly defined. Moreover, there is usually no time information for ornaments which often come with every pluck of a string even though these ornaments are not explicitly written down in the tablature. This gives the players lots of freedom to develop styles. Hence, it is important to allow a user to improvise on the aspects such as vibrato, portamento, intensity and so on. In [15], an expressive synthesis for the violin was reported. However, it failed to model large range portamento which is essential in Gu-Qin music. In the next section, a new analysis and re-synthesis method derived from true envelope estimation [16] will be described to solve the problem.

3. HARMONIC PLUS NOISE SOURCE FILTER MODEL

The proposed source filter model is a modified version of the frame-based linear predictive model [17] presented by Chen et al. There are two major modifications. First, the analysis/synthesis frame size is adaptive to the pitch period which may be varying with time. Specifically speaking, the frame size is the multiple of the local pitch period. For the transient phase, the frame size could be equal to one pitch period. For the sustain phase, the frame size could be ten times as large as the pitch period. Secondly, we include true envelope estimate proposed in [16] to analyze the harmonics’ spectral envelope so that the timbre could be extracted better than the traditional LPC coefficients estimate. Besides, both temporal envelopes are estimated as the filter gains of harmonics and noises as shown in Fig. 2.

F. Villavicencio et al. [18] proposed an accurate spectral envelope extraction method for LPC coefficients and this method had been applied in some music applications [19]-[21]. Two major problems of spectral envelop modeling were considered by the true envelope estimator [16]. One is the model mismatch problem caused by the incorrect order of the all-pole model used in LPC. The other is that the perceptively more important information around the first few partials is affected. If most harmonics couldn’t be modeled precisely, the timbre of synthesized sound is different from the original. Hence, the true envelope estimator is adopted in our Gu-Qin synthesis system.

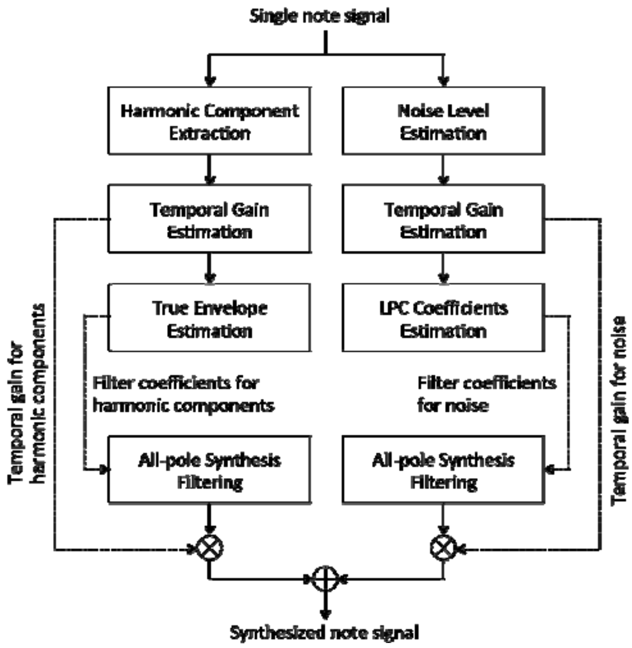

Figure 2: *Harmonic plus noise source filter model overview.*

When a Gu-Qin performance command is assigned, the synthesizer synthesizes both the harmonic part and its corresponding noise part. When the sound is re-synthesized, the impulse train fed into the all-pole synthesis filter creates the perceived pitch. Meanwhile, the white noise source feeds into the other synthesis path, also an all-pole synthesis filter. As modified by the captured noise characteristics, this noise part becomes quite audible especially in the attack or glissando phase of the sound. Many players consider such noise as an essential part of the Gu-Qin music. The corresponding temporal envelopes are applied to the outputs of both filters. These two components are combined together to get the synthesized sound in the end.

Even if part of Gu-Qin performance techniques is only analyzed in advance, the database is still practically applicable as long as enough performance atoms are well prepared. We can produce any possible or interesting Gu-Qin sound by manipulating two parameters, pitch and length as Fig. 3 shown. The pitch can be raised, lowered or even changed from straight to vibrato/glissando and vice versa. It can be achieved by setting the impulse train with the corresponding pitch periods along the altered pitch contour at any time instant. Next, the signal can be stretched or shortened by insertion or deletion of frames. Interpolation of filter coefficients for the additional frames in the sustain phase can keep the timbre perception unchanged. In theory, these two transformations can be employed in the whole signal or any small segment of signal. The noise part not shown in Fig. 3 can be produced in a similar way except that there is no pitch information to adjust.

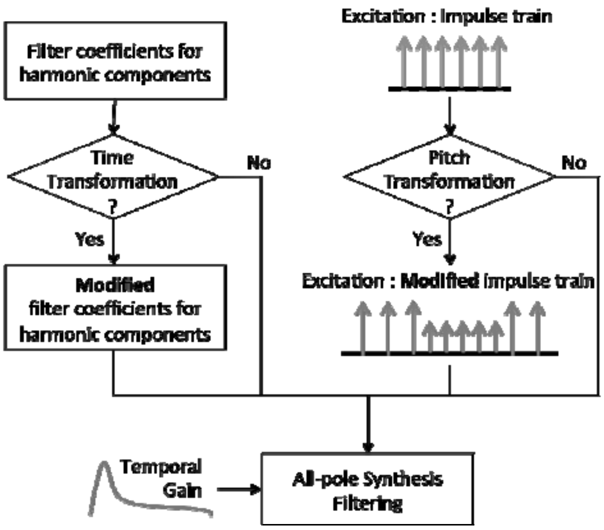

Figure 3: *Transformation processing overview.*

4. iOS APP AND SYNTHETIC RESULT

Figure 4: *Gu-Qin JianZi creation interface.*

We implemented the JianZi notation parser on an iOS APP based on Chang's work [13] and replaced the synthesis procedure with the proposed algorithm. Gu-Qin sounds were recorded and analyzed to get their synthesis parameters offline. Fig. 4 shows the visualized user interface for a JianZi notation. We built up most of basic JianZi elements as templates for users to choose. Most basic JianZi elements are divided into right-hand and left-hand parts and users can choose them by clicking "Roots" button. When they drag templates in the bottom of the screen to the desired positions, the accomplished notation will be verified by internal JianZi parser. A reasonable notation will be synthesized to the corresponding Gu-Qin sound when users press the loudspeaker icon in the upper left corner.

Users can perform sound transformation by clicking the "Transform" button. The corresponding pitch contour, the note name expressed in Western notation and the duration are shown in Fig. 5. The transitions among dominant pitches are marked in red dots on the pitch contour. Users can draw a desired curve to modify the pitch by pressing the pencil icon or key in the desired musical notes in the text field below. The numbers in seconds in the lowest text field indicate the durations of the segments of this JianZi. The example "Da Zhi Qi Hui Cuo Gou Liou Shuan Tui Fu" in Fig. 5 has a total of five segments. Users just need to alter these numbers for the time transformation.

Figure 5: *Pitch and time transformation interface.*

Moreover, users can combine some saved JianZi into a piece of music and set up the onset times that associates with the previous JianZi's start time as shown in Fig. 6. For instance, the first JianZi, read as "Fan Zhong Zhi Qi Hui Gou Yi Shuan," starts at 0.27 seconds and the second JianZi, read as "Fan Ming Zhi Qi Hui Gou Erh Shuan," starts at 1.49 seconds after first tone has been played.

Figure 6: *Gu-Qin JianZi Pu: the first sentence of Liang Shiau Yin.*

The Gu-Qin database is performed by Alvin W. Y. Su who is an amateur Gu-Qin player and also the author of this paper. It is noted that the instrument was not tuned to the standard pitch level because the rare silk strings were easily broken. We choose a song named "Liang Shiau Yin" to be our example. Gu-Qin has a plentiful timbre and the playing style varies from person to person. We demonstrate three cases from simple to complex and the whole phrase in Fig. 6 is also synthesized. The following figures will use spectrograms from 0 to 1200 hertz to illustrate the changes in frequency domain so that one can observe the pitch, intensity and duration variation clearly.

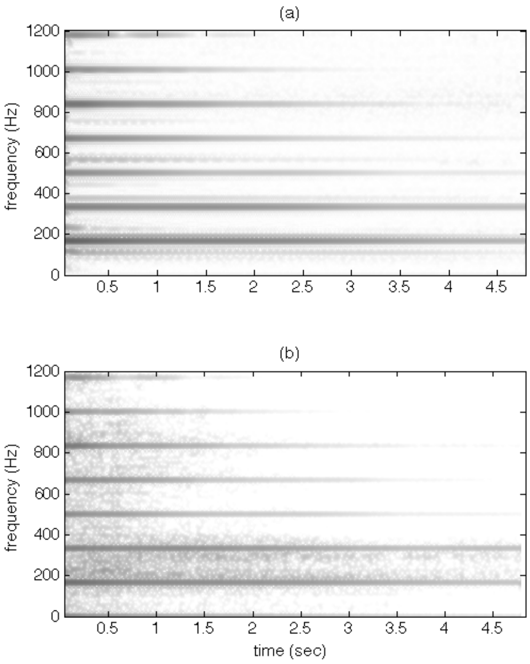

Figure 7: *Normal synthesis case: (a) An original Gu-Qin overtone with pitch equal to 167Hz. (b) The synthesized result.*

Fig. 7(a) is the origin of “Fan Ming Zhi Qi Hui Tiao Sz Shuan” with its pitch at 167Hz and its corresponding synthesized sound shown in Fig. 7(b). Fig. 8(a) shows a portamento of “Cuo Da Zhi Liou Hui Erh Tuo Qi Shuan” with its pitch varying from 253Hz to 307Hz and Fig. 8(b) shows the result derived from the above note with one more synthesized glide. Its pitch variation starts at 253Hz to 307Hz and after 0.32 seconds it glides again from 307Hz to 363Hz. Hence, we acquire a new Gu-Qin sound that the database doesn’t have.

A complex case is shown in Fig. 9(a). Its original notation is described in Fig. 5 and read as “Da Zhi Qi Hui Cuo Gou Liou Shuan Tui Fu”. The pitch contour starts with a portamento from 180Hz to 226Hz and glides back to 194Hz after 0.91 seconds then quickly returns to 226Hz in 0.1 seconds. As one can see, this note can be divided into five segments. We try to stretch the segments and the re-synthesized sound is shown in Fig. 9(b). The lengths of the five segments are multiplied by corresponding factors of 0.75, 1, 2, 3, and 1.5. These actions can simply symbolize that players can play with different styles; someone will glide quickly or have longer sustain and the other one may do in an opposite way. Fig. 10 shows the overall synthesized result of the first sentence of Liang Shiau Yin and each JianZi’s onset time is indicated by the corresponding number in Fig. 6. These sounds can be heard at [10].

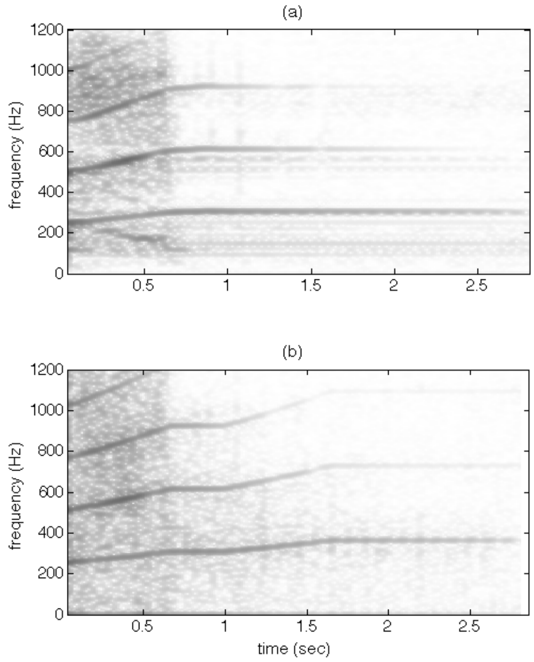

Figure 8: *Pitch transform processing case: (a) A portamento clip with pitch varying from 253Hz to 307Hz. (b) The re-synthesized result using pitch transformation to have an artificial gliding around 1 second.*

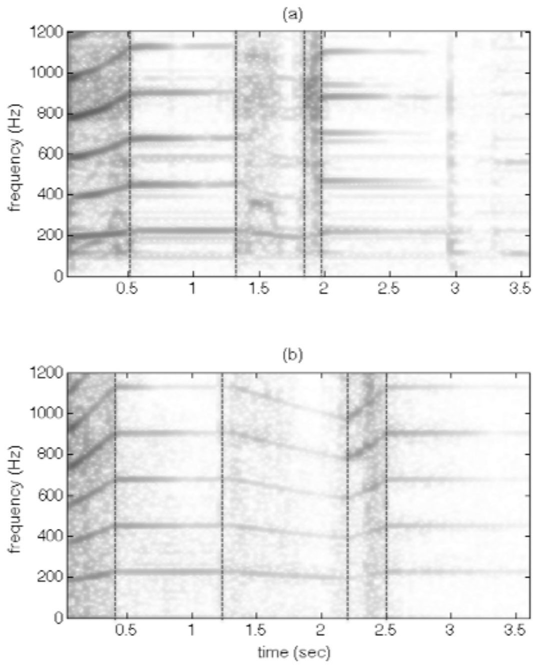

Figure 9: *Time transform processing case: (a) A complex Gu-Qin clip divided into five segments. (b) The re-synthesized result of time transformation. (dot line: segment boundary)*

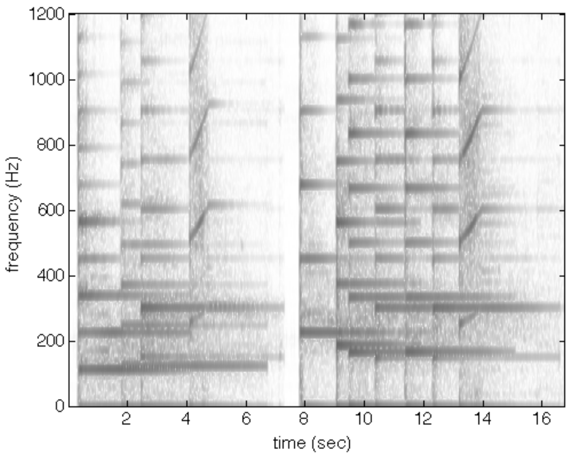

Figure 10: *Synthesized sound of the first sentence of "Liang Shiau Yin."*

5. CONCLUSION AND FUTURE WORK

In this paper, we proposed a Gu-Qin synthesis system that contains a JianZi Pu editor, a JianZi symbol parser and a source-filter model synthesizer. The source-filter synthesizer improved the synthesized sound quality by employing a true envelope estimator combined with the pitch synchronous analysis frame size technique. Furthermore, fine synthesis controls can be achieved by applying versatile and robust pitch and time transformation processing. Various expressive Gu-Qin synthesized sounds were presented in our demonstration. We also implemented the system on the popular iOS platform and created an interesting and human-friendly interface. One can easily have his/her own improvisation of the sounds.

In the future implementation, we will include more relationships between Gu-Qin's performance techniques and the proposed synthesis controls. We will try to support all the JianZi's in the system. The synthesis parameter database will also go through further modification based on users' experiences and opinions.

6. ACKNOWLEDGEMENT

The authors would like to thank the National Science Council, ROC, for its financial support of this work, under Contract No.NSC 100-2221-E-006-247-MY3.

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