Physical Modeling Synthesis of the Stone Chime Instrument "Pyeongyeong"

Jae hyun Ahn
CREAMA
Hanyang University
Seoul, Korea
wooddoll@gmail.com

Richard Dudas
CREAMA
Hanyang University
Seoul, Korea
dudas@hanyang.ac.kr

ABSTRACT

*This paper is about the creation of a physical model of the traditional Korean stone chime instrument known as a "*pyeongyeong*" using Ircam's* Modalys *software. This research focuses on creating a physical model that can be used in musical ways. In order to build the physical model, the instrument itself must be researched so its physical details can be used as a foundation for the construction of the model. The goal is to create a virtual instrument that can be used for creative purposes in the context of contemporary/electronic music, in addition to being able to be used for compositions using traditional instruments, recording sessions and sound design for film scoring. The development of this model provides a good opportunity to allow the* pyeongyeong *– an instrument that is not easy to transport due to its physical size and weight – to be used in a wider international musical context.*

1. INTRODUCTION

This paper describes the creation of a physical model of the stone chime instrument known as a *pyeongyeong* that can be used as a virtual instrument. This model is based on both analysis of sounds recorded specifically for this project, as well as on existing research about the historical shapes, sizes, and vibration patterns of a variety of stone chime instruments. In addition to designing a physical model that can be used in the context of musical projects such as compositions, installations or sound design, the secondary purposes of this project are to understand the reasons for the unusual shape of the stone chime itself, to be able to virtually modify this shape in the model and to be able to apply different sets of physical material properties to it.

2. BACKGROUND

2.1 The *Pyeongyeong*

The traditional stone chime percussion instrument – known as a *pyeongyeong* in Korea – has a long history throughout East Asian countries. This instrument was important during ancient times because the tuning of stone instruments was not as greatly affected by temperature or humidity, compared with instruments made from other natural materials such as wood and fiber. This made it an excellent tuning reference for other musicians.

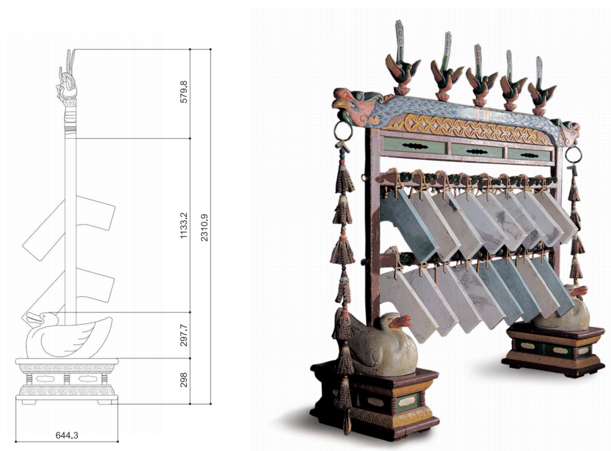


Figure 1. The *pyeongyeong*.[1]

The instrument (shown in figure 1) is constructed with two rows of 8 stone slabs of different thicknesses, giving it a 16-note range. The instrument is performed by striking the stone slabs with a bone mallet, and was traditionally used in performances of Korean court music. (A similar instrument called "*pyeonjong*" uses a set of 16 metal bells sounding an octave lower than the *pyeongyeong*.) Both instruments were brought to Korea from China during the Goryeo Dynasty (918~1392). A much smaller single-chime instrument known as a "*teukgyeong*." The chime of the *teukgyeong* is identical in shape and size to the chimes of the *pyeongyeong*, but the instrument is more portable because of its heavily reduced size. It traditionally had a ceremonial function at the Confucian Shrine and the Royal Ancestral Shrine Ceremonies.

The type of stone used for the *pyeongyeong* (and *teukgyeong*) initially could only be found in China, but during the reign of King Sejong (1418-1450), the appropriate kind of stone was discovered in Gyeonggi Province in Korea,

[1] Image reproduced from *Korean Traditional Musical Instruments Measurement Series 1*, ISBN 978-89-85952-09-5

from which time the instrument could finally be constructed locally. Modern chromatic instruments were only developed in the past quarter of a century, notably by Hyung-gon Kim in the 1990s.

One of the more interesting physical characteristics of the *pyeongyeong* is the stone itself. In Korean, the stone is called "*gyeongseuk*," and is composed of mixed geological materials, including limestone, jade, and andesite. The combination of these different materials contributes to its unique sound. It is worth noting that ceramic *pyeongyeong* chimes have occasionally been made, however the sound of these instruments is quite different from those made of stone, and the instruments remain equally cumbersome due to their large size and weight.

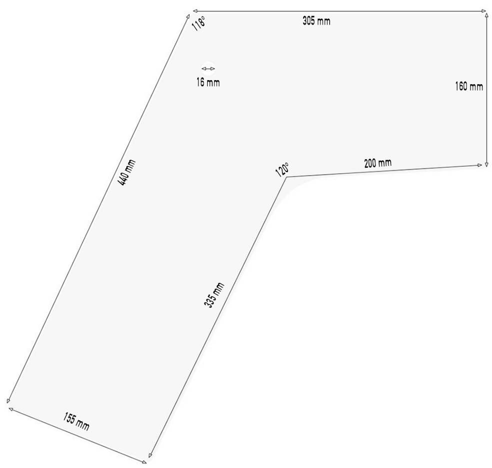


Figure 2. *Pyeongyeong/teukgyeong*: side view of a single chime.

Another important characteristic of the *pyeongyeong* is the distinctive L-shape of its chimes. The instrument was derived from the Chinese "*bianqing*," whose stone chimes originally had a different shape: the chimes of the oldest Chinese *bianqing* were almost square and evolved to be more triangular. Over the years, the stone chimes became L-shaped (see figure 2), the practical result of which was a longer vibration time. [1]

Figure 3. The 16 notes of the modern *pyeongyeong*, the Korean (and Chinese character) names of each pitch and the average thickness of each chime (in mm).

The 16 chimes of the modern *pyeongyeong* range between 528Hz and 1262Hz (see figure 3). All of the chimes are the same size when viewed from the side, but the thickness of each chime is different. The thickness of each stone is the key feature for tuning all 16 notes of the *pyeongyeong*. Seemingly paradoxically, thicker chimes sound higher in pitch than thinner ones (this is also shown in figure 3).

2.2 Virtual Instruments, Physical Modeling & Modalys

Virtual instruments can emulate a wide variety of instruments in addition to being used to create unusual sounds not associated with real-world instruments. The ability to creatively modify the sound of a virtual instrument depends on the synthesis technique used. Existing virtual instrument sets that include traditional Korean percussion often make use of sampling, thereby limiting the types of modification that can be applied to them. Physical modeling synthesis, on the other hand, is a viable alternative that results in seemingly "realistic" sounds that can be modified creatively at the synthesis stage, as opposed to post-playback.

Modalys is a physical modeling synthesis application developed at Ircam for research and musical use. The advantages of Modalys over many other physical modeling toolkits and frameworks are that it is easy for both developers and musicians to use, it has a large set of built-in tools, it is extendable via user-created objects, and it has a real-time playback engine compatible with Max/MSP. Furthermore, Modalys also allows users to create 3D meshes (or import 3D mesh files created in other software[2]) which can be used to calculate modal objects compatible with the rest of the Modalys toolkit. This conversion uses the finite element method (FEM)[3] so these objects are, quite logically, known as finite-element objects in the Modalys environment [2].

3. MODELS AND RESULTS

3.1 Analysis of the Original Instrument

As a first step towards making a model of a *pyeongyeong*, its 16 chimes and the single chime of the *teukgyeong* were individually recorded to serve as reference data. In the sonogram of the *teukgyeong* sound shown in figure 4, we can see that the instrument has an inharmonic spectrum composed of closely-spaced pairs of frequencies (roughly a fourth apart).

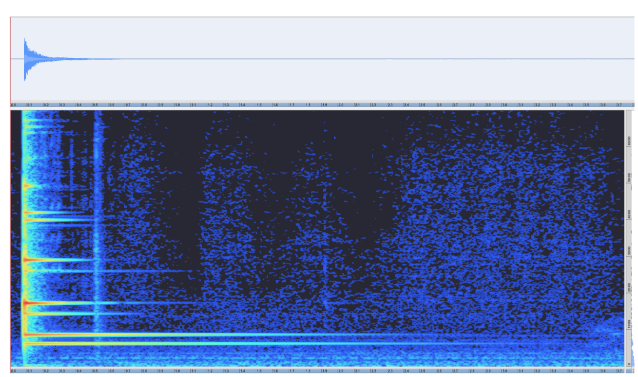
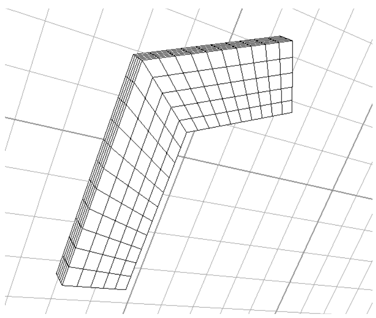


Figure 4. *Teukgyeong* waveform and sonogram (3.7 sec.).

[2] Modalys can currently only import "Mesh Version Formatted 2" files that use "hexahedral" (i.e., cube-based) meshes.

[3] The finite element method (FEM) is a mathematical technique for finding approximate solutions for partial differential equations.

The prominent frequency pairs shown in this sonogram are: (620 Hz, 870 Hz), (1440 Hz, 1727 Hz), (2610 Hz, 2910 Hz), and (4000 Hz, 4200 Hz). The higher frequency in each pair tends to be stronger in amplitude and thus generally dictates the sound's perceived pitch (this chime is tuned to an A). This is in line with similar data from existing research [3, 4], which confirms that this unusual combination of partials is a result of both the instrument's shape and materials.



```
(setq part1 (make-mesh 'single-point '(0.0 0.0 0.0)))
(duplicate 'translation part1 10 '(0.0 0.01 0.0))
(duplicate 'homothety part1 5 '(0.128 0.004 0.0) .945)

(setq part2 (make-mesh 'single-point '(0.06 0.13 0.0)))
(duplicate 'translation part2 8 '(-.0075 -0.00375 0.0))
(duplicate 'homothety part2 5 '( 0.128 0.004 0.0) .945)

(setq pyeo (make-mesh 'add (list part1 part2 )))
(duplicate 'translation pyeo 5 (vector 0 0 .002))
```

Figure 5. Simple mesh model and Lisp code example.

3.2 Designing a Simple Mesh

By simply using the physical measurements of the chime, a simplified mesh model can be built in Modalys as a finite-element object (see figure 5). This is certainly not a very detailed model – especially considering that a highly accurate mesh could be obtained using a 3D scanner – however, it is useful for creating an efficient synthesis in order to test different material parameters.

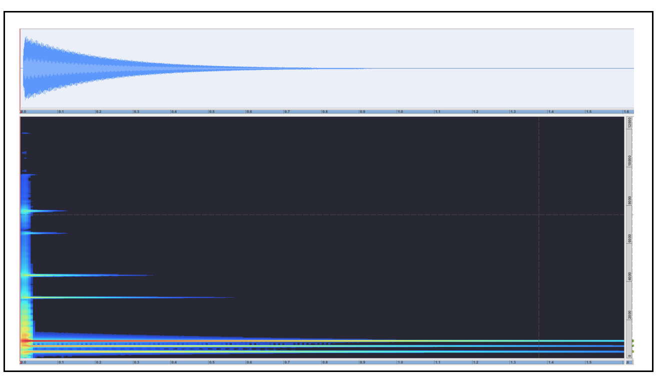


Figure 6. Simple mesh model: waveform and sonogram (1.6 sec.).

A sonogram analysis of a sound synthesized from this model shows an inharmonic spectrum similar to that of the actual instrument (see figure 6). It contains frequency groups of (334 Hz, 646 H, 904 Hz), (3186 Hz, 4348 Hz) and (6546 Hz, 7708 Hz). Although this is comparable to the sound of the actual instrument, it is not audibly similar. Some important details, including the curve at the underside of the "knee" need to be added in order to make a better, more accurate model of the instrument.

3.3 Designing a Detailed Model

3.3.1 Scanned (Non-Flexible) Model

A more precise and detailed mesh model of the *teukgyeong* chime was initially created based on a high-resolution photo of the stone chime's profile which was used, together with detailed measurements of the chime itself, to create a 2D mesh. This mesh was created using standard image editing software and exported as a set of fixed coordinates defining the exact profile of the chime. These coordinates were imported into Modalys and extruded along the z-axis to create a 3D object, which could be saved as a hexahedral mesh and later edited using third-party 3D modeling software in order to create finer divisions of the mesh (see figure 7).

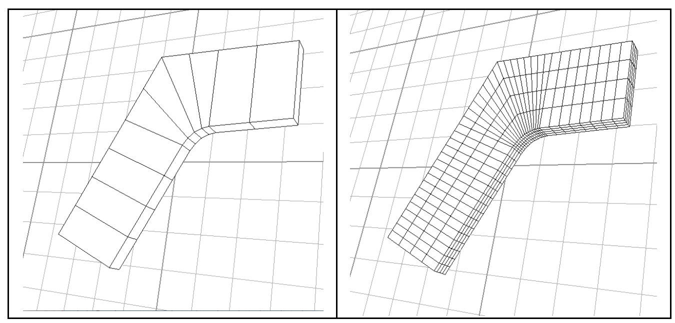


Figure 7. Scanned model: simple and subdivided mesh.

The resulting sound synthesis of this model (shown in figure 8), although slightly higher in pitch, is perceptually closer to the sound of the actual chime than the previous model, but the mesh has a fixed shape based on the scanned points, and therefore cannot be user-tailored to any great degree. Nonetheless, it could be used to create a fairly convincing 16-chime *pyeongyeong*, since each chime is tuned by varying its thickness (instead of scaling its overall dimensions). For this model, the material properties of the stone were approximated as nearly as possible to those of *gyeongseuk* using the available parameters for the Modalys finite-element object (density, young's modulus, poisson ratio and damping coefficients). An appropriate excitation point on the chime was chosen, based on both information from performers of traditional music and existing vibration research which has been written about the *pyeongyeong* [5]. The synthesis, shown in the sonogram analysis in figure 8, contains frequency groups of (431Hz, 383Hz, 1087Hz), (2622Hz, 3095Hz), (4738Hz, 4936Hz), 6545Hz, and (8182Hz, 8787Hz).

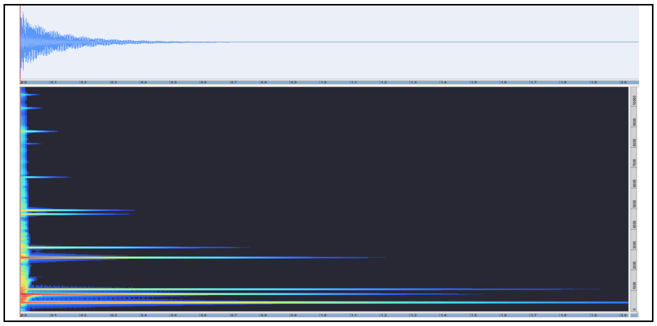


Figure 8. Scanned model: waveform and sonogram.

3.3.2 Semi-Flexible Model

An improved version of the model was made using the same coordinate data from the previous method, however all mesh processing (and mesh subdivision) is now done in Modalys. This lets the user control the detail of the mesh, as well as the overall dimensions and thickness of the chime. This version also more accurately models the hole in the chime, which is used for hanging it from its wooden frame with a rope. Since the rope and hole create a fixed point around which the chime vibrates, two points – one on each side of the model – are used as the "holding points." These are faces on the mesh that are considered fixed in space when the mode shapes of the finite-element object are calculated in Modalys. This subtle change causes the predominant frequencies of the model to be related by the interval of a 4th instead of 3rd, which corresponds to the sound of the actual instrument. The synthesis shown in figure 9 contains frequency groups of (11Hz, 201Hz, 370Hz), (900Hz, 1480Hz, 1860Hz), (2670Hz, 2990Hz), (3685Hz, 4255Hz) and (5465Hz, 6316Hz).

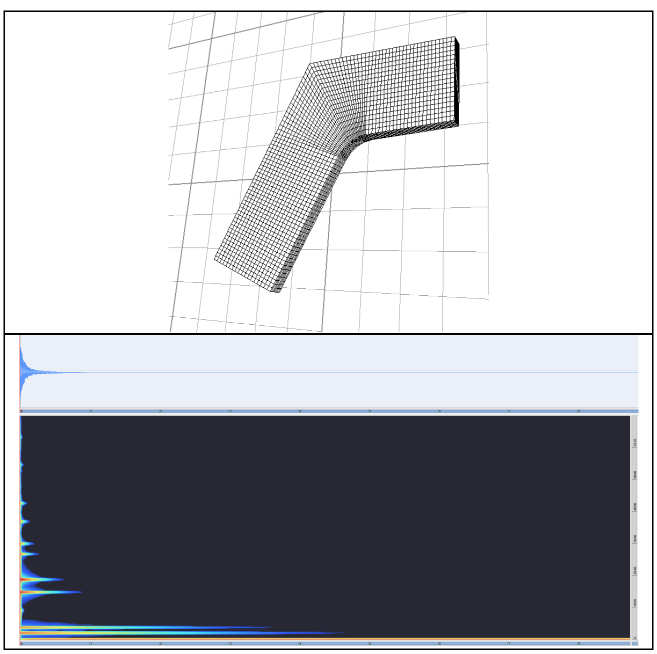


Figure 9. Semi-flexible model with waveform and sonogram.

3.3.3 Flexible Model

A more flexible user-editable version of the model was then created to allow the design of chimes with various shapes and dimensions (including I-shaped, L-shaped and rhombus-shaped chimes). This model lets the user define the angle in the middle of instrument, the angle and height of two sides as well as the sub-division of each section. The example mesh shown in figure 10 imitates the old Chinese stone *bianqing* chime.

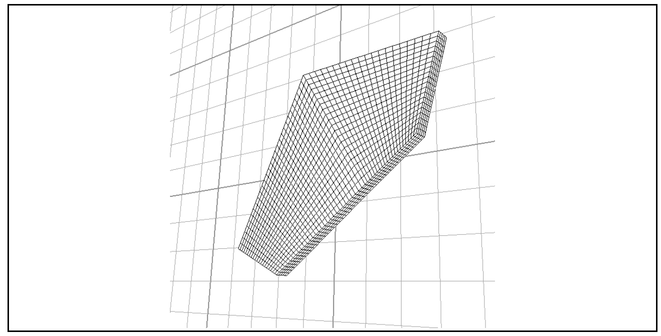


Figure 10. Flexible model imitating a *bianqing* chime.

Although the *pyeongyeong* is traditionally struck with a bone mallet, there is no existing model for that kind of striking interaction in the current version of Modalys. Fortunately, the parameters of the Modalys felt hammer connection can be adjusted in order to come close to simulating the attack of a bone mallet.

4. FUTURE DEVELOPMENTS

Although there is room for future growth with this model, it is already at the stage where it sounds natural and can be used practically and creatively. One potential future use of this model is that it could be used to synthesize historical or ancient stone chime instruments that are not easily accessible for performance.

5. REFERENCES

[1] Yoo, J., Rossing, T. D., "Geometrical effects on the tuning of Chinese and Korean stone chimes", *Journal of the Acoustical Society of America*, Vol. 120, 2006.

[2] Stegaru A., *Modalys Reference Manual Finite element objects,* Ircam, 2003.

[3] Han, K., Yoon, J., Kim J., "A Study on the Spectrum Analysis for the Sound Synthesis of Pyeongyeong", Dongguk University research report, 2009.

[4] Yoon, J., Kim J., "A Study on the Timbre of Pyeongyoung", *Journal of Korea Multimedia Society*, Vol. 13, No. 11, 2010.

[5] Lee S., Kang M., Lee J., "Optimal Shape Design of Pyeongyeong Considering Structural and Acoustical Characteristics", *Transactions of the Korean Society of Mechanical Engineers*, Vol. 38, Issue 3, 2014.