California Institute of the Arts

# The Considerate Evolution of the Haegeum in Today's Technological Context

by
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# Abstract

This thesis addresses extensive research on how to augment the haegeum, a traditional Korean instrument, while also keeping in mind and respecting the decades of history, culture, religion, politics, and performance practice. It documents and explores each component of the haegeum individually and suggests ways to evolve the instrument by enhancing its natural distinctive characteristics to fit today's technological and social context. A large part of this thesis studies the history of not only the instrument itself but also of Korean history, traditional music, class systems, religions and cultures that helped shape the musical practice and traditions. The Korean Peninsula being a small geographical area connected to many other East-Asian countries, much of its culture was imported and modified from neighboring and distant countries. This thesis also tracks how and when these ideas and objects traveled into Korea and their significance in both Korean traditional music and the haegeum. The lack of augmented or technologized research on eastern traditional instruments, compared to western instruments, required this thesis to explore augmentation elements previously applied to western string instruments. If these western approaches respected and fit the original haegeum's culture, unique characteristics, and performance styles the thesis suggested how it could be re-applied on the haegeum. The final proposed project gathered all the research and aimed to target crucial issues in the traditional haegeum that may be resolved through incorporating technology.

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# Chapter 1

# Introduction

The haegeum itself derives from an ancient nomadic zither. Since its arrival to Korea, the instrument has been immensely adapted and modified to fit the Korean culture and traditions. Many iterations of this nomadic zither[1] were created in various sections of across Manchuria. However, although these instruments derive from the same origin, they have distinctively different characteristics and performance practice. One characteristic feature of the haegeum is its string bending method for playing ornamentation. By griping and releasing the pressure of the flexible silk strings, it is standard practice to add these quick and dynamic ornamentations during performances. This feature is also causes one of the prominent on-going problems with the traditional haegeum of fluctuating pitch. The constant aggressive pulling and releasing of the strings shifts the tuning and peg tightness making this traditional instrument very hard to collaborate with other instruments. Ensembles such as multiple haegeums, western strings, brass, woodwinds and more. Since on the haegeum, a common tuning for the strings does not exist, it is considered "tunned" if the two strings are tuned to the correct perfect 5th interval when the finger is horizontal across the two strings. This is one of many characteristic elements and factors needed to be considered when creating a conscious augmented haegeum.

Since the 1960s, the traditional haegeum modifications have been experimented to fit the cultural, social, and technological needs. Although South Korea has a very conservative attitude towards modification of traditional instruments, compared to countries such as China, Japan, and North Korea, a lot of modification were made within the last decade to fit to contemporary music and stages. The traditional haegeum was reshaped to increase its volume to suit the larger performance spaces and ensembles. Adapting to the growing standardization of western music, it also adapted to equal temperament pitch and notation. New versions of the haegeum such as the treble haegeum and bass haegeum were created to fill the need in orchestration and wider range of pitches required in piece. The electronic haegeum and four-stringed haegeum were also created with the same idea of maintaining the evolution of musical styles. Although these new iterations of the traditional two-stringed haegeum introduced new

[1] The term zither is often used to describe the haegeum. This is not the correct terminology as zither refers to a class of stringed instruments that are stretched across a thin, flat body and are played through plucking or strumming the strings. The haegeum is more accurately classified as a fiddle. Fiddles being the class of stringed instruments that are bowed. This misclassification comes from the confusion between the haegeum and ajaeng. Even native Koreans often misidentify the two instruments. The ajaeng, considering its shape and structure, would be classified as a bowed zither. However, in this thesis, haegeum will be labeled as a fiddle rather than a zither while instruments such as the ajaeng, gayageum and geomungo will be labeled as a zither.

elements and technology, all of them followed the principle of maintaining the characteristic features of the original haegeum.

It is only after taking account of all decades of history, culture, tradition, practice, and performance techniques of an instrument that a considerate and relevant augmented or hyperinstrument can be built. Through this knowledge, understanding and perspective the most significant questions can be addressed. If we do not have personal experience with the instrument, how can we ensure we are not making mistakes? Are there certain elements or characteristics so unique to the instrument, either culturally or physically, that cannot be altered? Could our new augmented instrument mistakenly remove an element that would make the instrument loses its purpose? How much change can you make to an existing instrument before it's classified as its own thing? A completely different instrument rather than an evolved version of the original. Especially if the instrument is being designed to be physically performed with, how do we convince collaborators who have the knowledge, background, and willingness to learn this augmented instrument work with us?

This thesis aims to explore each component that makes up the traditional South Korean instrument, haegeum. The first chapter briefly summarizes of the decades of history behind South Korean traditional music and the migration of ideas, religion, politics, and sequentially instruments within Eastern continents. In addition to any relevant information that may assist in understanding the instrument with decades of history and generations of common practice. The second chapter references the previous works of augmentations using sensors, creative engineering, mechatronics, and material research that may effectively apply to the haegeum. This chapter consists of six sections for the six components that make up the physical haegeum. Each section will be dedicated in exploring ideas specific to its instrument component. An in-depth description of the component's role and materials will be explained in each section. Possible challenges and limitations that may occur for the suggested works are then addressed in the conclusion. A final augmentation project is proposed using ideas from the previous works to resolve a major problematic element of the haegeum.

# Chapter 2

# Historical Context

To fully understand the frameworks, limitations, requirements, and approaches in making a conscious augmented Korean instrument, one should be aware of the decades of history and changes in culture the instrument surpassed to be what is it today. This chapter of the thesis will outline important historical periods, covering politics, culture, and music, as well as lay a foundation for future exploration of tradition Korean music also known as *Gukak.*

Over the centuries, the Korean Peninsula has been involved in a rich intertwining history with its neighboring countries. Due to the proximity of countries such as China, Japan, Mongolia, and other Eurasian countries, many elements of Korean culture, politics, governing systems, and religion have originated from outside of the Peninsula. One of its heaviest influence and cultural similarities comes from the Han Chinese. Staring from the 2$^{nd}$ century BCE until 1895, deliberate imitation and emulation of the Chinese culture was present in Korea. [1, 2] Before establishing their own systems, for example in 1443 with the invention of the Korean alphabet, Koreans created their own adaptions from what existed in the current Chinese culture. [2] Unlike the Sinitic language of Chinese, the Korean language is a branch of the Altaic language family. This classifies Korean closer to languages like Turkish, Mongolian, and Japanese than to Chinese. The Korean language being distinctively different than of Chinese, adaptions were made to fit the language. By creating Sino-Korean vocabulary and writing system, some words were directly borrowed from the Chinese dialect while others consisted of new Korean words created from Chinese characters that supported the Korean grammatical patterns. [2]

The land itself has reshaped their country boarders and regional divisions numerous times over the duration of history. Although today's Korean Peninsula covers a small section of Northeast Asia, throughout history the country boarders had often expanded north into Manchuria or what we know as China today.

## 2.1 Overview of Kingdoms

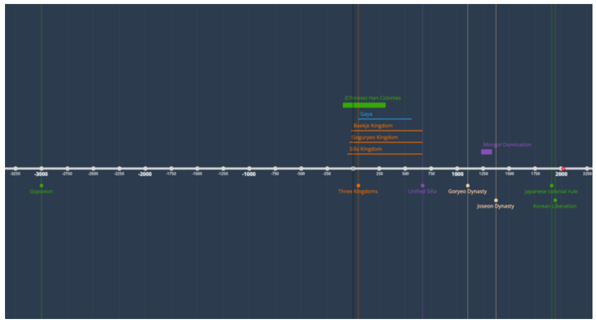

*Figure 1 Timeline of Kingdoms and Dynasties*

### 2.1.1 Gojoseon Kingdom (3,000 BCE)

According to the book *Samguk Yusa* (Memorabilia of the Three Kingdoms)[2] written in the 13th century by the Buddhist monk *Il-yeon*, the Gojoseon Kingdom (also referred to as Ancient Joseon) was reportedly founded by the somewhat mythical king *Dangun Wanggeom*. Although it is hard to fully prove this first rule, the tale of this first king was a crucial part of the Korean creation story and legitimizing the line of succession.

*Dangun* is thought to be the grandchild of the supreme deity *Hwanin*. When *Dangun*'s father, asked to descend and inhabit earth, *Hwanin* allowed his son to descend with 3.000 followers and sent him to Baekdu Mountain (in northern Korea where *Dangun* ruled) to form the city *Sinsi* ("city of god").

*Figure 2 Map of the Korean Peninsula During Gojoseon Kingdoms*

The story of *Dangun* is thought to have many symbolic references to historic events. His birth is seen to symbolize the arrival of the Bronze age culture in Korea. In this mythology, his mother was transformed from a bear into a human after diligently completing 21 days of solitude set by *Hwanung*, *Dangun's* father. This element of the myth supports the shamanistic beliefs and animal totems nomadic tribes brought with them when migrating to the Korean

[2] This book is a sequel to the more popular historical reference *Samguk Sagi* (History of the Three Kingdoms), and covered materials such as origin mythology, Buddhist focused legends and folk tales. Both books are frequently referenced when refereeing back to the Korea Peninsula's ancient history and culture.

Peninsula. Others claim this transformation myth represent one of the tribes who sought favor of the prince. *Dangun*, being the son of a supreme deity and bear, is often considered to link spiritual, animal, and human worlds. This further supports the claims of ancestorial link and direct descendants of an actual deity that has assisted many kings in justifying their divine right to rule.

Starting from 11th century BCE, Gojoseon becomes increasingly intermixed with the Chinese culture and people. In 1122 BCE, the rule is taken over by Gija, a prince from the Shang Dynasty. It is thought that during this period, Chinese government, administration, and high culture were first introduced. In 3 BCE, after constant war with the northern Chinese states, Gojoseon was eventually usurped by the Chinese general, Wiman. Wiman took advantage of the confusion that occurred the founding of the Han Dynasty in 206 BCE, but it was not long until the Han Dynasty take over the Korean territory in 108 BCE. It was during this time the indigenous Korean people were exposed to many political and cultural influences from the Han Chinese. Elements such as the ideographic writing system, Confucianism, centralized monarchy, and government were adopted and integrated into the culture over the four centuries of Chinese rule.

The music during this period consisted mostly of ritual festivities for seasonal agriculture activities such as planting and harvesting crops. These festivities involved loud music and dance performed over several days. This tradition thought to be carried on in later genres such as *pungmul* (farmers music) and *gut* (shaman music).

### 2.1.2 Three Kingdoms: Goguryeo, Baekje, Silla (50BCE-668)

The Three Kingdom period consisted of three main separate states. Goguryeo to the north and extending to Manchuria, Baekje to the southwest and Silla to the southeast. Gaya was a collection of small kingdoms and was never managed to form a unified state like others. It was eventually absorbed by Silla in 562.

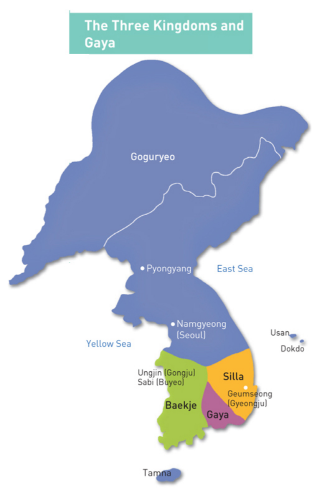


*Figure 3 Map of the Korean Peninsula During the Three Kingdoms*

Goguryeo, positioned north of the Peninsula had the most access to the Chinese high culture. It considered the most political and culturally advanced out of the three kingdoms.

Goguryeo was the first out the three kingdoms to officially adopt Buddhism from China. Although all three states eventually adopted the same Chinese culture elements such as Confucian teachings, exam system, government administration, and Buddhism (arrived in China in 68 from India) Goguryeo was often the origin of many culture adoptions that spread throughout the Peninsula.

Baekje, on the other hand, had close relations with both China and Japan. While Baekje still adopted many elements from imported from China, there was a prominent culture transfer with Japan. The Three Kingdom highly influenced Japanese court music, cultural elements, and political systems. In Japanese court music, the same instruments used in Korean music were adopted in performance. The strong ties with Japan also benefitted Baekje when Japan assisted with reinforcements during Silla-tang Invasions. Due to ethnic differences between ruling class and public, Baekje was not considered a strong state.

However, Silla's bone-rank and democratic system allowed them stability within the rulers and public. This state possessed a strong military standing due to their paramilitary educational system. In 648, Silla and the Tang Dynasty formed an alliance to take over the remaining states of the Three Kingdom. Silla was the smallest, weakest and most isolated state, but it used strategic alliances to build its strength. Forming an international diplomacy with Tang was not straightforward due the position of the state and needed to communicate across the Yellow Sea. Ultimately this small state absorbed both Baekje and parts of Goguryeo to form the next period suitably called Unified Silla.

During this period, each state had differentiating musical practice along with their own favored state instrument. Like mentioned before, due the northern position of Goguryeo, Chinese cultural elements were easily accessible. This extends to music and instruments as well. Many Chinese instruments and music were commonly used in this state but also a lot of Goguryeo music was found prominent in Sui and Tang Dynasty music. The Goguryeo state instrument was a six-stringed zither called the geomungo. Various aspects of this instrument can be seen in the qin. A similar Chinese seven-stringed zither instrument.

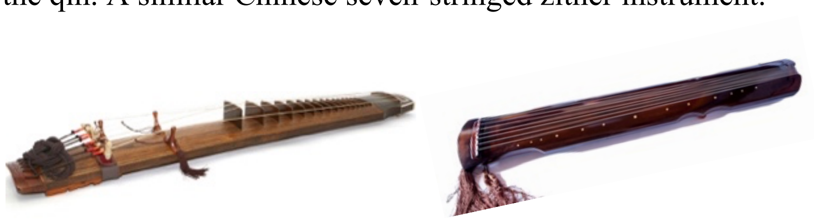

*Figure 4 Geomungo and Qin*

The Baekje state instrument was, the now no longer used or existing, vertical angular harp called the gonghu.

*Figure 5 Gonghu*

The Silla state instrument was the twelve-string zither called the gayageum. This instrument is related to the Chinese cheng, a sixteen-stringed zither, and the thirteen-stringed Japanese koto.

*Figure 6 Gayageum, Cheng and Koto*

### 2.1.3 United Silla (676- 935)

After the fall of Goguryeo in 668, the Tang Dynasty had established a strong presence and attempted to absorb the entire Korean Peninsula under its rule. Due to this, the Silla-Tang allegiance broke, and the Silla-Tang Wars began. The outcome of this war established new boarders and independent rule of regions. In 676, the Tang had moved north of the newly established Balhae while the new Unified Silla ruled the south. Balhae was established in 698 by a former Goguryeo general in attempts to regroup the Goguryeo people. Relations between the Tang and Unified Silla stopped until reconciliation between the states in the $8^{th}$ century.


*Figure 7 Map of the Korean Peninsula During United Silla*

The Tang Dynasty was known to have the most influence on its neighboring countries out of all the Chinese Dynasties. Korea, Japan, and Vietnam had elements of Tang civilization and culture in their own respective cultures. Out of the three countries, Korea was most faithful to the original Chinese model.

United Silla period was seen to be the golden age of culture and economy. With flourishing trade routes, United Silla established itself into a wealthy country. Buddhism during this time gained great momentum and many Korean Buddhist rose to comparable ranks and reputation as Great Chinese Buddhists. However, by the end of the $8^{th}$ century, Unified Silla started to undergo political troubles. The element that allowed the small Three Kingdom

Silla state to be a stable and strong state also unraveled this entire kingdom. Due to nepotism in the bone-rank system, new intellectuals not from prominent families were excluded from holding higher positions in society. This led to revolting against the Unified Silla royal house and rebellion from descendants of the Three Kingdom Baekje and Goguryeo states which reestablishes the three separate states again during 892-935. These states were called Later Baekje, Later Goguryeo and Unified Silla.

Many of the distinctive characteristics and musical tradition of Goguryeo and Baekje survived the turmoil of unification. However, the emergence of hybrid and new instruments weaken the existing musical characteristics of both Goguryeo and Baekje. The new wind instruments daegeum, junggeum, dogeum were developed during this period. While all three of these instruments are transverse bamboo flutes, they vary in size and key. They are also part of the six most popular instrument used in Unified Silla along with the gayageum, geomungo, bipa. These six instruments were labeled as *Samhyeon Samjuk* (three string, three wind).

*Figure 8 Daegeum*

Also due to this period's flourishing culture, many musicians were sent abroad to learn new instruments from foreign masters. With increasing spread of Chinese Buddhist culture in Korea, a new classification system appeared to distinguish between native Korean music and imported Chinese music. Although this classification system was set to separate Korean and Chinese music, most traditional Korean music at this point of history derived elsewhere. *Hyang-ak*, the label for native Korean music, is used to classify all music or elements, no matter what origin, that arrived before the Tang Dynasty. While *dang-ak* describes music or elements that arrived and are used in Korea after the start of the Tang Dynasty.

### 2.1.4 Goryeo (935-1392)

Goryeo was established when Wang Geon, a prominent general of Goguryeo descent, overthrew the unstable Later Goguryeo. Wang Geon went on to fully unify the Korean Peninsula in 936 when he conquered the remaining states of Unified Silla and Later Baekje.


*Figure 9 Map of the Korean Peninsula During Goryeo*

Although Goryeo still maintained close relations with the Song Dynasty that formed in 960, Koreans started branching out on their own by individualizing and forming their own cultural elements. Establishing their own centralized bureaucratic system, codified laws and expanding education through civil service examinations that allowed even lower birth candidates from non-prominent families to become bureaucrats and scholars. Due to the expansion of land under a single rule, they needed capable officials in provincial areas to control and regulate under the rule of Goryeo. This civil service examination was built on the model used by the Chinese but not a complete imitation of the system. During this period, many Korean scholars frequently traveled to Beijing and brought back with them new Chinese and European ideas such as Neo-Confucianism. The Song Dynasty was known to be a central trade hub for its neighboring countries, and this allowed these scholars to be exposed to not only new ideas but also technology such as the Tripitaka Koreana printing press. This led to the influx production of arts, pottery, and literature in 1018.

During the latter half of this period, due to several coup d'etats, Mongolian invasions, and foreign rule had Goryeo on the decline. After 39 years of shielding off numerous Mongolian attacks, Goryeo eventually folded with an allegiance to the Mongol-ruled Yuan Dynasty and for the following 80 years existed under its rule. It was only in 1392, when Confucian Scholar General Song-gye Yi overthrew the Goryeo Dynasty in another coup d'etat.

Goryeo music adopted the Unified Silla musical tradition a cultural continues without much change. Continuing the Unified Silla music classification system of *hyang-ak* and *dang-ak*, the new class ***a-ak*** was created during the Goryeo period. The term *a-ak* was developed to classify music and instruments used in court ritual performances imported from China. In 1114, the Song Dynasty emperor sends a set of *a-ak* instruments and court banquet instruments as a gift to Goryeo introducing a new genre of music to traditional Korean music. During the latter half of Goryeo, the classification *dang-ak* (Tang music) is modified. The gonhhu, the instrument popularly used in Baekje, disappears form *dang-ak* ensembles and is replaced with zither-type instruments. During this period, the *dang-ak* orchestration was consisted with more wind and percussion-based instruments than stringed instruments. An iron slab set, end-blown notched flute, transverse flute, double-reed pipe, lute, bowed zither, large zither, hourglass drum, barrel drum, and wooden clapper made up the *dang-ak* ensemble. *Hyang-ak*, on the other hand consisted of a sparser orchestration based on stringed instruments. 6-string zither, 12-string zither, 5-string lute, 3 sizes of transverse flutes, hourglass drum, and wooden clapper were commonly used in *hyang-ak* music performances.

*Figure 10 Dang-ak ensemble*

### 2.1.5 Joseon Dynasty (1392-1910)

Throughout Korean history, there have been many kingdoms but the one and only imperial dynasty that have ever existed in Korea was the period of unfathomable growth as a country. The Joseon Dynasty, also referred as the Yi Dynasty, was founded, and ruled by the Yi family ideology for over 518 years. Founded with the neo-Confucianism ideology, this is also the first time that a religion other than Buddhism was promoted as the majority religion of the Peninsula.

Over this long duration of time, the Joseon Dynasty was able to flourish as a country. It maintained strong ties to the Ming Dynasty, but it relied less on foreign influences and began to develop new cultural elements on its own. During the 15th and 16th centuries, the rulers of the countries pushed for more education and science amongst the people. After developing their own alphabet system[3], aristocracy system, bureaucracy and government administration, the Joseon Dynasty saw immense cultural and scientific advancements in the form of printing, astronomy, military technology, geography, cartography, medicine, and agricultural science. Due to the rise of the country's agricultural success, the economy was also flourishing during this period.


*Figure 11 Map of the Korean Peninsula During Joseon*

[3] Developed by King Sejong the Great called Hangul.

With the main religion of Buddhism replaced with Neo-Confucianism, Buddhist music was eventually modified to fit the standard instrumentation, tuning and pieces of the period. During the early Joseon Dynasty, the *a-ak* (Chinese court ritual music) system is modified and perfected. Pak Yeon, the Royal Music Director under King Sejong, recalibrated how *a-ak* is played and prepared. Instruments were re-tuned to the circle of fifths[4] with the initial principal pitch based on the tuning of the hwang-chung. a bronze bell from the Ming Dynasty.

*Figure 12 Hwang-chung*

This process of systematically re-tuning was initiated due to the need of standardized tunning. Since each Chinese dynasty had its own characteristically different musical systems, too many instruments used in *a-ak* had contrasting tuning systems. These *a-ak* instruments were imported from China at different times over the centuries and the variations of system made it impossible to all the instruments to be performed as an ensemble.

Alongside the process of developing a standardized tuning system, *a-ak* repertoire went through re-organization and modification. All *a-ak* repertoire with uncertain or questionable origin were abandoned completely and replaced with new *a-ak* music from the Yuan Dynasty. Through all these processes, it is sometimes thought that *a-ak* performances became too elaborate and inappropriate for ritual purposes.

*Hyang-ak* (native Korean music) during this period flourished. With new compositions written in the new Korean alphabet system along with the newly developed notational system, *hyang-ak* became more accessible. The notational system, *jeongganbo*, was the first notational system to accurately notate pitch and time values required for the characteristically unregular traditional Korean music.


*Figure 13 Example of Jeongganbo*

[4] A system that organizes pitches in a sequence of perfect fifths. A perfect fifth interval consists of seven semi-tones apart.

Also, during the early Joseon Dynasty, there were several attempts to find suitable alternative materials readily available in Korea to sustainably manufacture new instruments. Especially for instruments such as the bronze bells and stone chimes. Many experimentations with interchanging materials had been made to most existing instruments.[5]

### 2.1.6 Late Joseon Dynasty and Japanese Occupation (1910-1945)

With the Manchu tribe invasions and Japanese Occupation, many cultural heritages were lost during the wars. Musical instruments and artifacts were completely lost and forgotten during this period. Later in history, there was a big endeavor to revive these lost elements. However, due to the lack of documentation and gaps in culture, it was almost impossible to replicate them exactly to what it was during the golden ages. With the country preoccupied by the numerous wars and political fragility, there was an obvious lack of importance for music and musicians. While *a-ak, jeong-ak,* all korean culture, costumes, language was abolished until 1945, *dang-ak* and *hyang-ak* ensembles were merged to form a single ensemble that played both genre of music. This ensemble was called the *Hyangdang Gyoju* (Korean-Tang form).

*Figure 14 Example of Hyangdang Gyoju*

The use of *hyang-ak* instruments in *dang-ak* music ultimately koreanized the Chinese-origin music and pieces. Many of the performance and instrument techniques were changed to fit the standard Korean ornamentation and metric structure present in *hyang-ak.* With this merging of genres, the already flexible distinction between *hyang-ak* and *dang-ak* for the most part disappeared.

By the 18th century, Korean traditional music staggered away from *Jeong-ak*, the general classification of music that included *hyang-ak, dang-ak, and a-ak,* and started to favor aristocrat and folk music. Subgenres of *minsogak* (folk music) that only required one person performances, such as *pansori* (solo singer) and *sanjo* (solo instrument), flourished during this period. Along with the domination of Confucianism, Buddhist performing arts declined in the public. However, they were still occasionally performed in secluded Buddhist temples and managed to resist the immense number of modifications made to the existing musical system.

[5] Refer to section 2.3.1

### 2.1.7 20th Century Gugak

As more European ideas and culture were introduced to Korea, new elements of western culture were widely adopted into Korean culture. European music was introduced with the appearance of Christian hymns and western-style military bands. Soon after, wealthier families encouraged the learning of western instruments, specifically the piano and violin. In the process of adopting the western culture, attempts to transcribe traditional Korean pieces in western notation were made. Unlike western music, Korean traditional music does not possess the concept of a single composer and completed composition. All truly traditional pieces do not have a single definite version of the piece and it hard to notate all the variation of oral tradition and ornamentations required of traditional Korean music. Yet in today's traditional Korean music practice, for the ease of accessibility, the western musical notational system is often used alongside *jeongganbo.*[6]

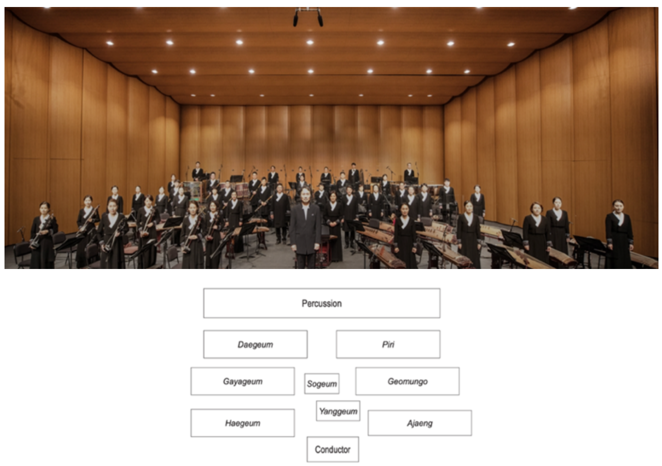


*Figure 15 Contemporary gugak ensemble following western orchestration seating layout*

The 1960 marked the early development of electronic and digital music culture in Asia. This included practices such as performing electronic works of contemporary western music composer as well as using techniques such as sampling of tape recordings and processing acoustic instruments. Most of the electronic music created were through sampling acoustic Asian instruments, manipulating the recording and playing alongside that recording with an acoustic instrument. The instrument playing with this back track features both Asian and Western instruments. [3]

In 1989, the first electric *gugak* instrument was created for Jin-Hi Kim and her performances shocked the older traditional masters of *gugak* and initiated the electric and electronic instrument culture[7] in Korea. Jin-Hi Kim is considered one of the main and important figures in early Korean electronic music. This traditionally trained geomungo performer and composer worked along with other artists and engineers to create the first electronic geomungo instrument as well as perform multimedia performances. Her work is heavily inspired by Buddhist aesthetics and Korean Shamanistic rituals as well as the cross-

[6] See Figure 13

[7] The Korean music culture defines 'electric instrument' as instruments that amplify their original acoustic sounds while 'electronic instruments' refer to instruments used as synthesizers and controllers for other sounds, timbres, and effects.

cultural approach to fusing Korean philosophy[8] and mythology with Western technology. One of her past works adopted the 4th century Korean mythology about the creation of the geomungo[9] as a reflection of emerging presence of the Western culture and technological elements in traditional elements in traditional Korean elements.

Due to the lack of technology present and accessible during this time, this instrument did not look or sound much like the traditional geomungo. The first electric geomungo was reduced to half the size of its original length and the strings were changed from silk strings to metal guitar strings. The switch of string material was due to the embracement of magnetic pickups to increase the acoustic sound. However, this electric geomungo limited traditional *gugak* playing techniques such as string bending and sounded more like an electric guitar than the instrument itself. However, in 1998 and almost a decade later, Ji Hi Kim worked with Joseph Yanuziello to co-design a new electronic geomungo. With the technological advances with pick up systems, this model was able to revert to its full acoustic soundbox size and silk strings. The instruments sound was processed through the software MaxMsp that was controlled by a MIDI foot pedal. By reverting to its more traditional layout, Kim can interweave between the traditional and contemporary display of the instrument. [4] [5]

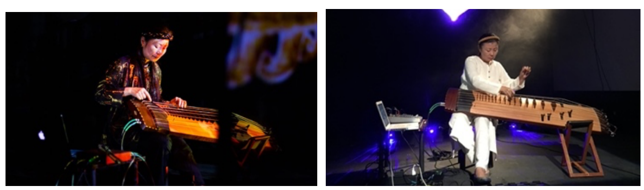
*Figure 16 Jin-Hi Kim's electronic geomungo*

Another key historical event of Korean electronic music is the December 1996 KBS Open concert[10]. During this nationally broadcasted TV concert, Eugene Park[11] performed on his ZETA electric violin[12] shocking the audience. Before this point, the general Korean public had not heard the timbre and characteristics of any electric instrument[13]. Although Jin-Hi Kim had developed and was experimenting with technologies, her projects were very niche and known by only a few in the field. It was Park's performance that opened Korea to the culture of electric classical and traditional instruments. [6]

*Figure 17 Eugene Park performing in the KBS Open Concert 1996*

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[8] Jin-Hi Kim's compositions around the *gugak* concept of 'living tones'. As each tone in *gugak* are considered as having its own individual life and shape, expressive ornamentations are added. This idea also follows the Buddhist ideology of 'life of a tone'.

[9] The myth tells the story of a black crane that flew into this ancient instrument and adopting the name of 'black zither'. (*geomun* meaning black and *go* meaning zither)

[10] Korean Broadcasting System is one of the main TV stations in Korea.

[11] Eugene Park is a Korean-American electric violins born in New York to Korean parents. As a child he had studied classical violin at Julliard's pre-college program but later in his career focused on electric violin performances.

[12] USA electric instrument manufacturer.

[13] KBS Open Concert performance by Eugene Park: https://youtu.be/MyALV4N-Oho

Until this point, Korean electrical instrument manufactures such as Daewon Instruments were creating electrical components such as pickup attachments to bridges of acoustic classical instruments but not full electric instruments. However, with the popularization of electric violins in Korea, the demand of these instruments escalated and assisted in creating the first domestic electric violin. The Strauss Electric Violin DVFE-505 developed by Jae-Eop Yoo at Daewon Instruments included several collaborators. In Korea, this was not a widely known field with specialized professionals to create an instrument like the Strauss. Yoo himself did not come from an electrical engineering background and needed help to create a whole electrical instrument from scratch. He went out to search for talented unconventional electrical circuit professionals working out of Nakwon Shopping Street[14]. These collaborators needed to be technically talented but not restrained to a certain field of electrical engineering. The individuals from Nakwon Shopping Street had both the skill and knowledge of acoustical and electrical instruments. With additional support from the electric guitar and amplifier company Seoho, the Strauss electric violin was created within a year since the project started. This instrument was designed to look like the f holes on the acoustical violin. This design was also thought to represent the entire Korean peninsula and suggested a unified Korea[15]. It was popularized by Eugene Park due to its significant reduction of noise compared to the ZETA. [6] [7] [8]

*Figure 18 Strauss Electric Violin DVFE-505 by Daewon Instruments*

Later in 1999, during the Daegu KBS 60th anniversary performance and Daegu Culture and Arts Center performance, Eugene Park played alongside six electric violins, two electric violas, two electric cellos and one electric contrabass all developed under the Strauss line. These electric instruments not only performed popular classical pieces but also used the Western instruments to sound traditional Korean instrument timbres through sound processing systems. The violin was altered to produce timbres of gayageum, ajaeng, and piri digitally. [7] [9]

*Figure 19 Strauss electric Cello*

In 2001, the globally sensational professional performing group 12Girls Band started a new chapter for Chinese traditional music. This group was the first internationally recognized to combine western musical styles like pop, classical, and jazz with Traditional Chinese music and instruments. [10]

[14] A street in Seoul known for collection of shops that sell, fix, maintain both acoustic and electrical instruments as well as other electrical musical gear.

[15] An attempt to secretly donate this instrument to North Korea fell apart due to Yoo's family troubles.

*Figure 20 12Girl Band*

Following this trend, the development of electric and electronic *gugak* instruments and the genre Fusion Gugak was constructed in Korea. Fusion Gugak features Korean traditional music crossed over with other musical genres such as ballad, hip-hop, dance, rock and more.


*Figure 21 The haegeum in Fusion gugak performances*

The performance group GongMyoung[16] illustrated the early period of Fusion Gugak while groups like sEODo[17] and Leenalchi[18] represent development of traditional *gugak* and pop culture. [11] [12]


*Figure 22 Fusion Gugak groups GongMyoung, sEODo, and Leenalchi*

[16] GongMyoung performance video: https://youtu.be/2fqVv1RHMzI

[17] This group consider themselves as Joseon Pop. Although they do not use *gugak* instruments and only utilizes the *pansori* style of singing, they fuse together multiple genres of music from both Korean and Western music. Performance video: https://youtu.be/YS2PVgNBYJM

[18] This group also uses the mix of western genres with *pansori* style singing. They also focus on both singing and dancing in their performances like true *Minsok-ak* performances. Performance video: https://youtu.be/SmTRaSg2fTQ

| | |
|---|---|
| Dangun founds Gojoseon: **3000 BCE** | |
| | **1500 BCE:** Founding of Shang Dynasty |
| Gija (from Chou Dynasty of China) rules Gojoseon: **1122 BCE** | |
| | **1046 BCE:** Founding of Zhou Dynasty (1st culture flourish. Writing, coinage, philosophical schools) |
| | **563 BCE:** Birth of Buddha |
| | **221 BCE:** Founding of Qin Dynasty (standardization currency, writing, legal code) |
| | **206 BCE:** Founding of the Han Dynasty (develop strong government, silk road, poetry, literature, paper) |
| **: 194 BCE** Usurped by a Chinese general, Wiman, during the confusion of the Han Dynasty founding | |
| Fall of Wiman and established Han colonies (Northern Korea): **108 BCE** | |
| Three Kingdoms in south of Korea: **57 BCE** | **68**: Buddhism introduced to China |
| End of Han colonies: **313** | |
| Official adoption of Buddhism/Confucian teaching (Goguryeo): **372** | |
| Official adoption of Buddhism (Silla): **527** | **552**: Buddhism introduced to Japan from Korea |
| | **581**: Founding of Sui Dynasty (Confucianism no longer dominant religion, Taoism/Buddhism, literature flourish) |
| Goguryeo armies win against Sui invading forces**: 612-618** | **618**: Founding of the Tang Dynasty (major achievements in tech, science, culture, art, literature) |
| Goguryeo repulsion of Tang invading forces**: 645-662** | |
| Silla-Tang alliance formed: **648** | |
| Silla-Tang takes over Baekje: **663** | |
| Silla-Tang takes over Goguryeo /form Unified Silla: **668** | |
| Silla wins Silla-Tang war: **676** | |
| National Confucian Academy establish United Silla Kingdom: **682** | **907**: Fall of Tang Dynasty |
| Founding of Goryeo Kingdom (Wang Geon): **918** | |
| Fall of last Silla king (Wang Geon): **935** | |
| Fall of Baekje (Wang Geon): **936** | |
| Adaptation of Chinese civil servant examination system: **958** | **960**: Founding of Song Dynasty (gunpowder, printing, paper money, compass) |
| Invasions of Khitan (Liao Dynasty): **993** | |
| Invasions of Nuzhens: **1104** | |
| Silver developed as currency: **1101** | |
| General Jeong Jungbu coup d'ete of King Myeongjong: **1170** | |
| First Mongol invasion: **1231** | |
| Peace with Mongols and accept Mongol domination: **1259** | **1275**: Marco Polo visits China |
| Mongols overthrow Choe family: **1270** | **1279**: Fall of Song Dynasty |
| | **1279**: Founding of Yuan Dynasty (Mongols/Kublai Khan - the grandson of Genghis) |
| | **1337**: Start of the 100-Year-War |
| | **1368**: Founding of Ming Dynasty |
| General Yi Seonggye coup d'ete: **1388** | |
| Founding of Joseon Dynasty (General Yi Seonggye): **1392** | |
| Invention of the Korean alphabet (Kim Sejong): **1443** | |
| **: 1470** Publication of the National Code (Gyeongguk Daejeon). The creation of a new bureaucratic system/government administration by King Seongjong: | |
| Japanese invasion of Joseon: **1592** | |
| Invasion (northwest) by Manchu tribes of Manchuria: **1627** | |
| | **1895**: End of Sino-Japanese War (Japan victory with China) |
| Japan annexed Korea. End of Joseon: **1910** | **1905**: End of Russo-Japanese War (Japan and Russia) |

## 2.2 Gugak[19]

The term *gugak* is used to describe the overarching class of traditional Korean music genres and subgenres that was solidified during the Joseon Dynasty. *Gugak* is also used as a classification system to differentiate between the various types of music and instruments. Previously throughout history, there had been multiple classification systems introduced. However, *gugak* only refers to the updated musical systems since the Joseon period and on. This period is often considered very important in Korean history because it is when Korean culture had finally individualized from foreign cultures and standardized their whole society.[20] In most cases, when talking about traditional Korean music, it usually disregards any musical elements that existed before the Joseon Dynasty and refers exclusively to *gugak.*[21]

*Figure 23 Examples of different gugak*

[19] This summary is not in any means a complete overview of the whole genre of gugak. Since this thesis is exploring a stringed instrument, gugak concepts will be explained with a bias towards only stringed instruments. Most vocal, wind and percussion concepts and instruments will be omitted.

[20] Refer to section 2.15

[21] From this point on, any mentions of "traditional Korean music" will refer to musical element pertaining to *gugak*.

### 2.2.1 Gugak Genres Classes: Proper-Music and Folk-Music

During the Joseon Dynasty (1392-1910), there was a clear separation between the educated-officials and lower commoners. This is manifested in all aspects of society and culture creating a prominent gap between the two classes. Although cultural elements such as literature, drama, painting, music, and dancing existed in both the lower and higher classes, the way in which they viewed and executed these cultural elements were contradictory. Music of the educated officials sought out to mimic human morals and culture as close as they can get to loftiness of deities,[22] while music of the common class focused their musical intentions on expressing intense human emotion. These contrasting lifestyles and ideals created a need to subcategorize the two forms of music the existed simultaneously during this period.

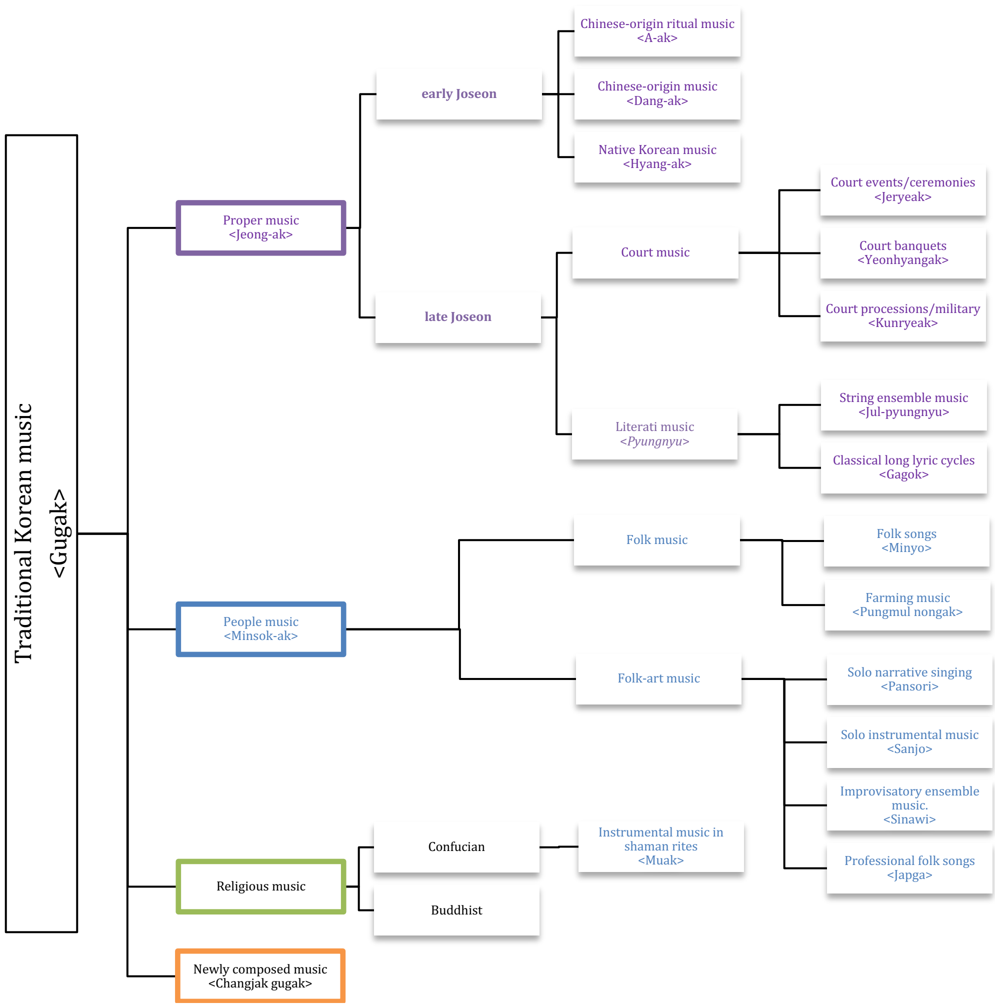


*Figure 24 Gugak classification system*

[22] As seen in the Dangun mythology. Refer to section 2.1.1

***Proper-Music (Jeong-ak)***[23]

Thanks to the detailed accounts written by educated nobles, the history, and specifics of *Jeong-ak* are easily examined. According to ***Samguk Sagi*** **(History of the Three Kingdoms)** published in 1145, *Jeong-ak* music needs to be meet with moderation of emotions. Music that expressed too many emotions was thought to be low-born and rejected in this genre of music. Other musical elements in *Jeong-ak* are closely tied to notions of Confucian practice, etiquette, and ethics. Its main features include slowness over speed, moderation than overly decorated, solemnity rather than joyfulness as well as peacefulness and gracefulness.

*Jeong-ak* consists of three main subgenres that organizes all *Jeong-ak* music by origin. Although the definitions and classification systems of these subgenres have changed multiple times throughout history[24], the most recent and common sub-classifications of *A-ak, Dang-ak and Hyang-ak* are defined as such:

*A-ak* refers to Chinese-originated ritual music used formally in Korean courts. This subgenre did not base their music directly from Chinese ritual music, but rather re-purposed popular or folk music originating from China. Currently the ***Munmyo Jeryeak*** is the only *A-ak* classified repertoire.

*Dang-ak* refers to koreanized Chinese-originated music used in Korean courts. This sub-genre, like *A-ak*, uses popular or folk music originated from China but is used. '*Dang'* in *Dang-ak* meaning the Dang-Dynasty (or more commonly known Tang-Dynasty).

*Hyang-ak* refers to indigenous Korean music used in Korean courts. Since most Korean music derived from Chinese music, there are still some elements in *Hyang-ak* that draw from other Chinese-originated music. What sets *Hyang-ak* apart from the other subgenres is that these pieces do not in any shape or form exist in any other land.

***Folk-Music (Minsok-ak)***

Unlike *Jeong-ak*, *Minsok-ak* does not have much written history. The vary little written documentation *Minsok-ak* has is largely written by someone outside of this particular social standing. Since the authors lack first-hand experience in this genre, the documentations are not considered as overarching or reliable references. Also, unlike *Jeong-ak* who favors the moderation of emotions, *Minsok-ak* expresses all the mundane emotions from grief to pleasure. This genre of music brings extreme addictive joy and fascination into audience. In fact, the audience is welcomed to outwardly express reactions to performances. In some performances, the music requires the audience to show their enthusiasm and engage in a rhythmic exclamation at certain sections of the piece.[25] [13]

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[23] The literal translation of Jeong-ak in English is "proper music". Although many previous English-written papers and references on *gugak* label this genre as 'court music', the term is often misleading. *Jeong-ak* is not limited to music played only in the royal courts but also extends to the genre of music enjoyed by the educated-official population. In this thesis, Jeong-ak will be referred to according to its literal translation: Proper-Music.

[24] Refer to sections 2.1.3- 2.1.6

[25] In *pansori,* the audience show their enthusiasm and encourage the *pansori* singer with *chuimsae.*

Most *Minsok-ak* history, techniques and repertoire rely on oral transfers. With the introduction of professional folk musicians, isolated regional styles[26] began to become blended together. As these professional folk musicians traveled across the country, they brought with them their folksongs from their regional home. In each new region they performed in, they rearranged their songs to fit the regions popular tastes and styles. Aside from performing folksongs, they also created complex pieces called *jakga* to promote artistic development in this genre. They are not normally transcribed in any form.[27] For example, in the southwestern region, the musical form *kwangdae* introduced popular musical forms and sub-genres such as *pansori* and *sanjo*.

While *pansori* and *sanjo* are a few of the existing subgenre in *Minsok-ak*, they both refer to the same virtuosic solo style of music often performed with a repetitive rhythmic pattern. Both subgenres are considered as professional artist music and need formal training to perform. The difference between the two subgenres is the instrumentation. *Pansori* refers vocal singers while *sanjo* is for all other instrument performers. The *sanjo* was influenced by *pansori* and *gut* (shaman music) and was created for instrumentalist to display and show off their instrument's unique characteristics through artistic techniques. Throughout a full-length *sanjo*[28], various scales, speeds, and rhythmic cycles are used progressively. Starting from the slowest rhythmic cycle, the *jinyangjo*, it moves on to faster and decorated patterns such as *jungmori, jungjungmori, jajinmori,*and *hwimori*. Unlike the other instrumental subgenres[29] , the melody may be improvised at times, but it is generally fixed and follows a certain musical flow.

### 2.2.2 Repetitive Rhythmic Patterns (Jangdan) and Melodic Progressions

Opposed to the western musical concept of linear harmony, *gugak* does not include this concept in its practice. In western music, whether an instrument is played on its own or with multiple instruments, the use of chord harmonic structures is constant within their music. This structure is created when several pitches are played at the same time, layering vertically on top of each other, to achieve the fullness of chord. However, rather than striving to creating a fullness in the music, *gugak* values[30] elements such as tonal thickness, changes in timbre and delicate phrasing of the melodic line. Each single tone played is considered as a living matter with its own individualistic spirit. It is through ornamentations and embellishments such as audible sliding, vibrating, shaking and other performance techniques that portrays artistic colour and charm, one can fully appreciate both the intentional harmonic scarcity and focus on the flow and uniqueness of the melody. With the lack need for linear harmony, the melodic line is often played as a solo by a single instrument. When playing in ensembles, strict union and alignment is not crucial during performances. Each instrument plays the same basic melody but add embellishments to accentuate their instrument's unique timbre in the melodic line. For some sense of collectivity within ensembles, a percussion drum will play a *jangdan*

[26] Refer to section 2.2.2
[27] Refer to section 2.1.6
[28] Also called *gin sanjo*. Lasts over 40-60 minutes long.
[29] Other instrumental sub-genres include *sinawi* (improvisational ensemble music), *nongak* (farmers music, mostly percussions), and *muak* (instrumental music in shaman rites).
[30] In *gugak* aesthetic features such as freedom, unhurriedness, silence, metaphor, emptiness, dynamic power, energetic vitality, and melodic lines are immensely valued and strived for in pieces.

(rhythmic pattern) guiding the flow of the irregular rhythm and signal the downbeats of the phrase.

### *Jangdan*

Out of the four types of rhythm available, *jangdan* a metrical rhythm, is the most used. Since in tradition Korean music, there are no equal length bars, the *Jangdan* audibly represents the weak and strong beats. The name *Jangdan* itself means long-short. Often performed on a janggu or buk, it is the drummer's job to give the pulse for the whole ensemble to follow. The rhythmic cycle is solely based on the drummer's interpretation of the mood and breathing. The rhythm is very flexible and is performed as like expressive breathing. On the janggu, an hourglass-shaped double-headed drum. Left side of the drum produces low tones and acts as the *jang* (long) giving the downbeats. The right side is responsible for the high tones and the *dan* (short) of the rhythm. The left side, made of cowhide, is played with the open hand while the right, made of horsehide, is played with a thin bamboo stick.

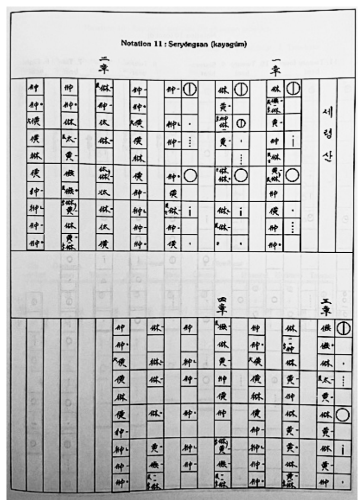

*Figure 25 Example of the Jeongganbo notational system*

### *Melodic Progressions*

In *gugak*, terms *jo* and *tori* are used to describe the characteristics of the melodic progressions. *Jo* is considered to represent the mode of the piece. A mode is an arrangement of tones that form a scale pattern. These tones are related to each other and often have specific features and roles. While most *jo* form a variation of the western pentatonic scale, they differ in where they start from. When a piece of music is labeled a certain *jo,* it refers to the lowest and starting point of the modal pattern. P*yeong-jo* is often used in *Minsok-ak* while *gyemyeong-jo* is more common for *Jeong-ak. Pyeong-jo* is based on the sol-mode. Its pattern is sol, la, do, re, mi. The *gyemyeong-jo* is based on the la-mode and consists of la, do, re, mi, sol. For *gyemyeong*-jo, emphasis with vibrato is applied to the re of the mode.

*Tori* is the regional styles used in *Minsok-ak*. During the beginning of Joseon Dynasty, most common people were tied to their home soil. This formed each region to have their own distinctive musical styles. Characteristically apparent melodic lines, and musical expression such as vibrato and other ornamentations separated how the music was played. Although later in the dynasty, with the influx of traveling musicians, the regional styles from each region were shared and spread across the land to expand performance variations.

The regions are as followed:

*Gyeong tori*, the most popularly used out of the five, is used in the central part of the Korean peninsula known as the Gyeonggi region.[31] *Gyeong tori* is often characterized as being cheerful and clear. It uses light ornamentations on the first and third notes.


*Figure 26 Gyeong tori {sol-la-do-re-mi}*

*Susimga tori* is used in the northwest in the Seodo region. This style uses a gentle vibrato on the tonic and very deep vibrato on the 4th note. The 3rd note of this mode is eliminated when playing this sorrowful, nasally, sticky style.


*Figure 27 Susimga tori {re-mi-sol-la-do}*

*Yukjabaegi tori* is used in the southwest in the Namdo region. Starting on la of the key, it uses a gentle vibration of the tonic (la) and deep vibrato on the 4th note of the mode (mi). This *tori* is characterized with being strong and mournful.


*Figure 28 Yukjabaeji tori {^mi-ra-do-(re)-mi/ v mi-(re)-dosi-la-mi}*

*Menari tori* belongs the Dongbu region of the east of the Peninsula. Like the *Yukjabaegi tori*, it starts on the la and uses deep vibrato on the 4th note of the mode (mi). It uses light vibrato on the tonic (la) and sol. This style is characterized with fast rhythmic patterns.

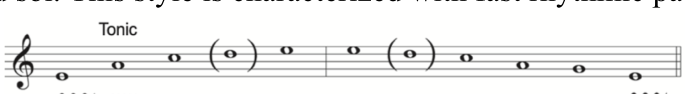


*Figure 29 Menari tori {^mi-la-do-(re)-mi/ v mi-(re)-do-la-sol-mi}*

The Jejudo region (an island off the coast of Korea), lacks stylistic similarities to other regional styles due to isolation. In this region, melodic lines move stepwise, there is more rhythmic flexibility and utilize more simple ornamentation. They base their mode on the *Gyeong tori*.

[31] Today's South Korean capital, Seoul, is in this region.

### 2.2.3 Notation Systems/Aural History

Another western musical element not in tradition Korean music is the notion of "composers" and "compositions". Aside from *changjak gugak*[32] works, pieces are not created by one single person but by many people and performers over a long period of time. No matter what subgenre the piece belongs to, in some way of form, it went through alterations when handed down through history. The collective creation, creation through transmission, personalization of transmission-process, deviations through variations, melody-borrowing from other genres, and improvisation aspects are abundant in the construction and weaving of pieces.

There are several notation systems for written scores in *gugak*. *Yukbo* uses verbal notation of oral imitation of sound, *Yuljabo* uses a letter notation system, *Yeoneumpyo* uses a cipher notation system and *Hapjabo* uses a combination of ciphers and letter notations. Out of these systems, *jeongganbo*, a square notational system is the most used. Jeongganbo is the standard notational system for *Jeong-ak* (proper music) while *Minsok-ak* is often written in the western notational system. Unlike *Jeong-ak,* it was not common practice to notated music from *Minsok-ak*. It was only later, for educational purposes, *Minsok-ak* was notated. Before this, it was mainly transmitted aurally though community members.

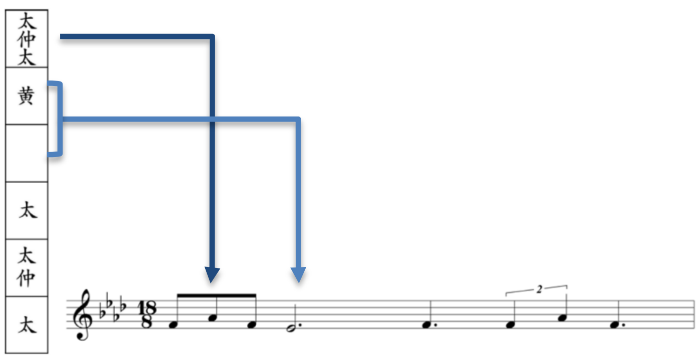

*Figure 30 Example of time and beat notation in jeongganbo*

Tones are represented in *jeongganbo* use the first symbol from Chinese words. Hwangjong (黃鍾) , daeryeo (大呂), taeju (太簇), hyeopjong (夾鍾), goseon (姑洗), jungnyeo (仲呂), yubin (蕤賓), imjong (林鍾), ichik (夷則), namnyeo (南呂), muyeok (無射), and eungjong (應鍾). The definition of these words does not hold great importance in *gugak.*

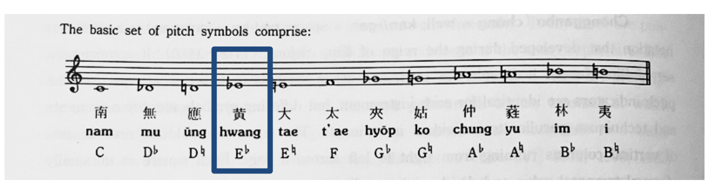

*Figure 31 Full 'scale' with the tonic as Eb*

[32] Newly composed *gugak* pieces dating back to 1940. See section 2.2.1

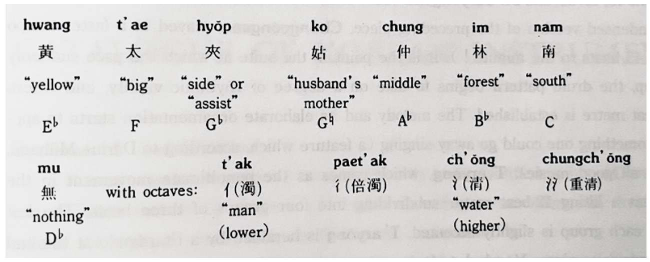

Figure 32 Definition of Chinese characters used as notes

In *jeongganbo*, each square represents one beat. If there is only one character in the square, that single tone should be held for a beat. If there are more than one character in the square, the beat should be divided equally amongst them. An empty square would old last written tone until new character introduced. This score is read top to bottom, right to left across the page.[33]

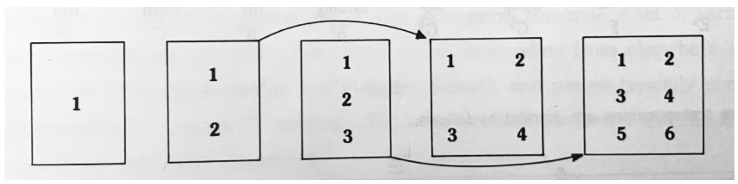
Figure 33 Jeongganbo square division

Recently there has been an increased use of western staff notation in *gugak*. With the ongoing standardization of western notation in most music from no matter what origin, many *sanjo* (solo instrumental) pieces have been transcribed for centralized education purposes. Of course, this introduces limitations in transcribing essential musical characteristics and diverse ornamentations present in these pieces. Custom symbols were created and added these western scores to indicate detailed tonal expressions and specific playing techniques. Due to the western music's concept of a singular and final 'composition'[34], to some, the notated versions of these pieces are not correct. Depending on the performer's teaching lineage (who they learnt from), and regional differences, not all ornamentations are notated on the western notation score.

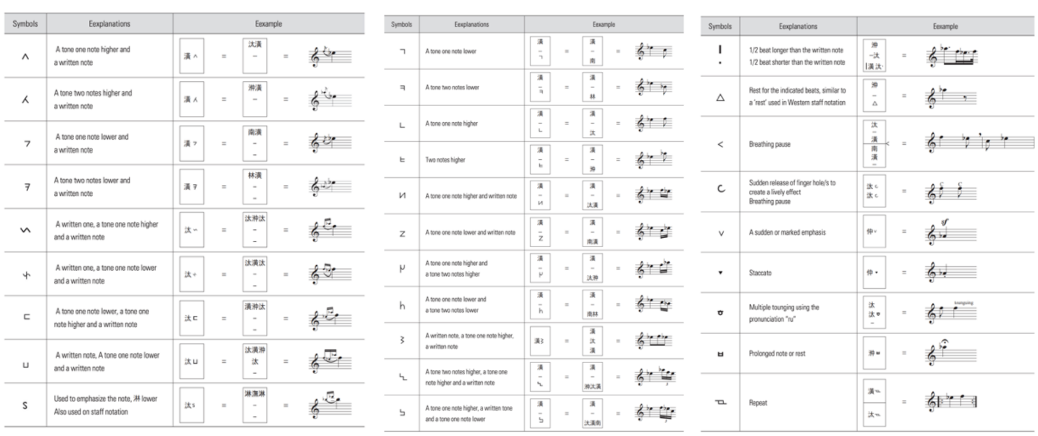
Figure 34 Western notation ornamentation symbols

[33] See figure18
[34] Refer to section 2.1.6

### 2.2.4 Ornamentation

In *gugak*, each note in the scale degree has its own unique characteristic ornamentation, phrasing, and mode progression. This system is closely followed unless in the rare circumstance it is taught or written otherwise. The rules are as follows:

1. The dominant, 4 steps below the tonic, is played with wide 'vibrato'.[35]
2. Tonic is to be played with light 'vibration'.
3. The supertonic, 1 step up from the tonic, is played with a slight 'appoggiatura' going a semi-tone down to the starting pitch following with some light 'vibration'.
4. The mediant, 4 steps up from the tonic, has a semi-tone downward curve at the end of the starting pitch.

The broad word for all ornamentation is *sigimsae.*[36] However, there are many specific forms and methods of ornamentations in *gugak*.

***Nonghyeon***[37]

*Nonghyeon* is the basic 'vibrato'. Depending on how far the fundamental pitch is bent up and down, it is described as light *nonghyeon* or deep *nonghyeon*. The symbol that represents this ornamentation also changed depending on the degree of the 'vibration'.

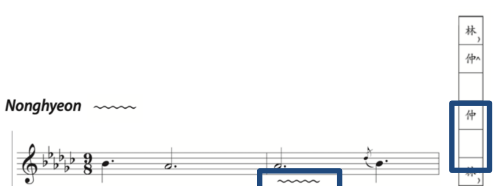

*Figure 35 Light nonghyeon*

*Deep nonghyeon*

*Nonghyeon* is used differently in *jeong-ak* (proper music) and *minsok-ak* (folk music). *Nonghyeon* used in *Jeong-ak* is not as deep compared to how it would be used in *minsok-ak*. On instrumental music scores, *nonghyeon* is not commonly notated.[38] There is no benefit to notating these 'vibration' ornamentation because each performer has their own version of *nonghyeon*, performance practice, and regional style. This opens the piece to be interpreted freely and respects the various versions handed down through oral transmission. Performers must often write in their own or their master's *nonghyeon* placements in the score.

[35] Almost a semi-tone ranges up and down from starting pitch. Vibrations for each scale degree is performed by scale. Meaning if the dominant is played with a smaller vibrato range, the tonic, supertonic and mediant ornamentation should accommodate. Depending on the amount of vibrato on the dominant, there may not be any vibrato used for the other scale degrees.
[36] *Sigimsae* was developed for instruments to replicate the unique characteristics of Korean vocal singing.
[37] *Nonghyeon* for stringed instruments and *nongeum* for wind instruments. (*hyeon* translates to 'string')
[38] See figure 28 + 29.

***Chuseong and Toeseong***

Chuseong and Toeseong are a bending ornamentation that gradually drop or raise the pitch height from the fundamental pitch. In some cases, *Toeseong* can be expressed as falling from a higher pitch to fundamental pitch. To perform *Toeseong* on the haegeum, one must release pressure to the strings from the starting fundamental pitch position, dropping the pitch height. *Chuseong* raises the pitch on the haegeum by adding pressure to the string.

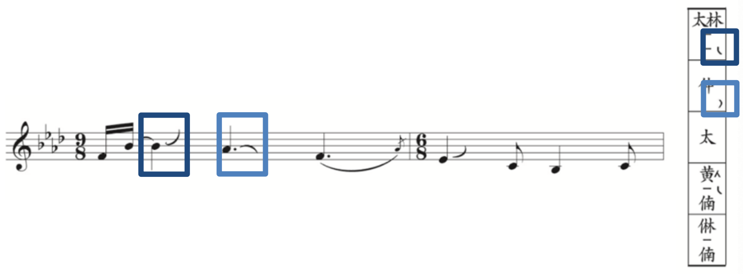

Figure 36 Chuseong/Toeseong in proper music

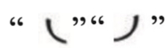

Figure 37 Chuseong and Toeseong symbols in proper music

Chuseong and Toeseong symbols in folk music

***Kkumimeum***

*Kkumimeum* is a 'turn figure' ornamentation used in both *Jeong-ak* (proper music) and *Minsok-ak* (folk music).

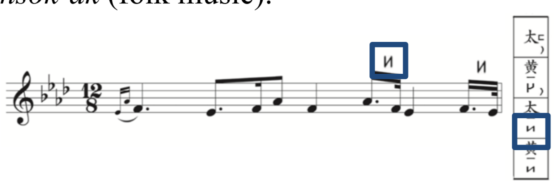

Figure 38 Kkumimeum in proper music

Kkumimeum in folk music

***Daruchigi***

*Daruchigi* is used in *Minsok-ak* (folk music). This ornamentation raises the pitch of the fundamental pitch higher. The amount of bending is not set and depends on the performer expression.


Figure 39 Daruchigi in folk music

***Breaking tones***

Breaking tones are widely used in *gyemyeong-jo* of a *sanjo* (solo instrumental) and southwestern region folk songs[39]. The fundamental pitch is subdivided by a fluctuating up and down semi-tone.

*Figure 40 Breaking tones in folk music* *Breaking tones in contemporary pieces*

***Yoseong***

*Yoseong* is the main ornamentation technique in *Jeong-ak* (proper music). The fundamental pitch is held then moved to the next highest note on the scale. This note, depending on the fundamental pitch, could be a semi-tone or whole-tone interval. This raising of pitch is repeated once or twice.

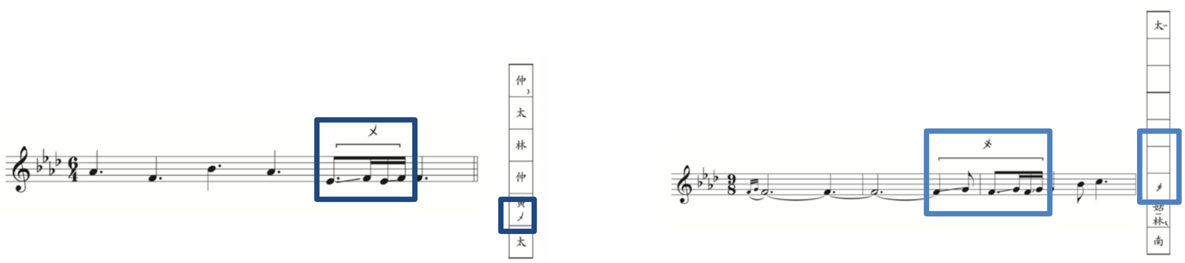

*Figure 41 Single yoseong in proper music* *Double yoseong in proper music*

***Jeonseong***

*Jeonseong* is an ornamentation that accents the fundamental pitch and then bends the pitch deeply downwards creating a 'di-yup' phrase. This ornamentation is used in in *Jeong-ak* (proper music), *Minsok-ak* (folk music) and contemporary pieces

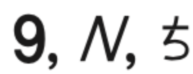

*Figure 42 Jeonseong symbol in (proper), (folk), (contemporary)*

***Ingeojil***

*Ingeojil* is a traditional technique that is used in *Jeong-ak* (proper music), *Minsok-ak* (folk music) and contemporary pieces. It is a very short ornamentation and is more bow technique than pitch orientated. While the pitch does become raised, the important technique is the changing of bow direction while connecting the pitch bend.

[39] Also called *yukjabaegi tori*.

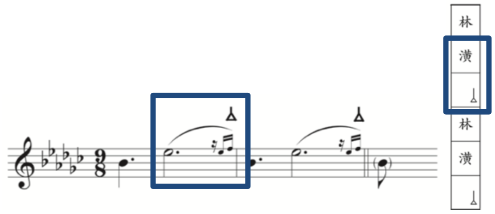


*Figure 43 Ingeojil in proper music*

***Contemporary ornamentation***

In contemporary *gugak* pieces, ornamentations such as double pitches[40], striking the soundbox with stick of bow, striking the soundboard with fingers, grazing pressure on strings. Also, western music techniques common in contemporary *gugak* are: glissando, double pitch glissando, tremolo glissando, harmonics, trills[41], tremolo, pizzicato, tenuto/ tenuto staccato, legato, detache, collegno tratto[42].

## 2.3 History of the Haegeum

The word 'haegeum' utilizes two borrowed Chinese characters, also known as hanja, to construct its expression. 'Hae' (奚) meaning servant and 'geum' (琴) meaning Chinese-originated lute. The haegeum is also informally called by its onomatopoeia of the instrument sound, kkangkkangi or kkaengkkaengi.

The haegeum is often considered as a pauper and commoner instrument. As a result of its unique piercing, nasally, and ripping timbre, this instrument can produce both bright and sandy sounds that allows for a large range of emotions needed for *Minsok*-ak (folk music). However, the haegeum is not only limited to *Minsok-ak* but is one of the most important instruments in all traditional Korean ensembles. Whether it is performing *Jeong-ak* (proper music)*, Minsok-ak* or ritual music, this instrument is almost never omitted from a *gugak* ensemble.[43] The haegeum's unique ability to play a continuous connecting sound makes this instrument essential in bridging gaps other *gugak* instruments create while they play. Although the haegeum consists of two silk strings and a horse-haired bow, it not classified as a real string instrument in *gugak*. This is due to the unique playing methods and characteristics of the haegeum. In *gugak*, all the other string instruments can be plucked or hit and produce aftertones[44] while the haegeum has more wind-like characteristics. The way it can connect notes effortlessly and its ability to bend pitches resembles more of *gugak* wind instrument than chordophones.

[40] Perfect 5$^{th}$ interval only due to the initial string tuning of strings by perfect 5ths.
[41] Whole tone intervals.
[42] Strike bow stick on string.
[43] Out of the 58 *tangakgi* (Chinese-origin instruments) that arrived to Korea during the *Goryeo* period, the only instruments to be included in both *Jeong-ak* (proper music) and *Minsok-ak* (folk music) are the haegeum and dangjeok (flute).
[44] String instruments like *gayageum* and *geomungo.*

### 2.3.1 Playing technique

Traditionally, the haegeum is played cross-legged on the floor with the haegeum resting on the left knee. More recently, the playing posture developed to accommodate various performance settings and cultural advances. Alternative playing postures include sitting on a chair while resting the haegeum on their left knee and performing standing with the haegeum on a stand or strapped around their waist.

*Figure 44 Playing posture*

The left hand controls the pitch and ornamentations on the haegeum. Since this instrument does not have a fixed tuning, the pitch range is not as limited as other instruments. Depending on what the initial tuning is set to, the haegeum can play up to three octaves. However, this does not mean the instrument hold unlimited pitch range. For the ideal timbre of the haegeum, it is common to tune the two strings that are stretch vertically along the length of the whole instrument to A3 and E4.

*Figure 45 Three octaves in the ideal timbre of the haegeum*

These two strings are quite close together from each other and this is so the player to press both strings at the same time. While the thumb wraps around the back of the neck, the four fingers are placed on the string. One should position their fingers, so the strings are resting in-between the first and second joint of their fingers. The four fingers controlling the pitch of the string should not be separated from each other. Each of these fingers controls the pitch by a semi-tone. The more fingers pressed on the string will raise the pitch. The haegeum's unique characteristics is its lack of fingerboard. The distance from the neck and strings are substantially far. This allows for the special performance technique of applying extreme pressure by gripping inwards on the strings. Haegeum players can freely bend notes very quickly and with a large range of possible pitches. Ornamentations and embellishments are therefore often used throughout the piece. On a single string, one can play a full octave without changing their hand position by pressing incrementally into the string.

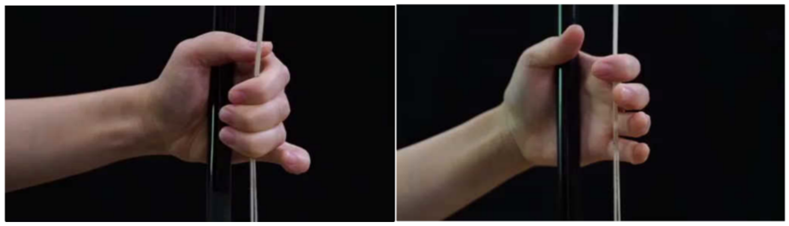

*Figure 46 gyeonganbeop and yeokanbeop[45]*

On the haegeum the right hand and arm oversees the bow movement. Unlike many bowed string instruments, the bow is held by an underhand. This bow is not tightened prior to playing but utilizes the performers shift in pressure against the bow. To be able to access both closely placed strings separately, the horsehair of the bow is threaded between the strings. The player underhandedly grabs the leather strap that connects the bow stick and hair with their middle, ring, and pinky fingers. The index and thumb comfortably sit on either side of the bow stick. To play the inner string, the performer must add enough pressure to the leather strap, so the bow hair angles itself to securely contact only the inner string. Like every other bow, the bow must move horizontally creating friction on the contacted string. To play the outer string, the same rules apply. The only difference being the pressure is added to the thumb.

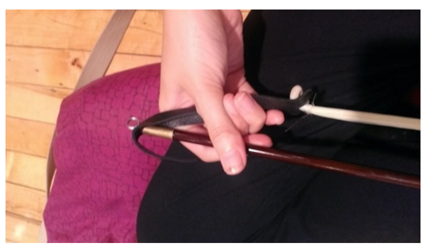

*Figure 47 ungungbeop[46]*

### 2.3.2 Origin of the haegeum

The origin and early history of the haegeum is relatively blurry. There is very little and scattered documentation about the haegeum, and an exact creation year or ancestry is hard to concretely define. The haegeum's earliest ancestor is believed to be an instrument created by the kumo xi nomadic tribe[47] in northeast Manchuria[48]. During the Tang Dynasty (618-907), influenced by the kumo xi instrument, the xiqin was popularly used in China. The xiqin was composed of a bamboo neck, small tubular resonator with a thin soundboard, two strings held by pegs and utilized a rosined stick[49] to create a creating sound. However, later in the Yuan

[45] The term for light pressure on the strings is *gyeonganbeop*. While increased pressure is called *yeokanbeop*.
[46] The term for pushing and pulling the bow.
[47] Due to this tribes' extensive travels, there are many East-Asian bowed spike fiddle instruments that look very similar to the haegeum. Chinese Huqin family (includes xiqin and erhu); Japanese Kokyu; Mongolian Morin Khuur; Thai Saw U/Saw Duang; Vietnam Dan K'ni/Dan Co. All these instruments are bowed vertical fiddles but have their own characteristic features that stands them apart. For example, the Vietnamese Dan K'ni does not have a soundbox but rather uses a cotton or hemp string connected to the string and plastic round component inserted into the mouth and behind the teeth. The players mouth becomes a soundbox for the instrument and its movement controls the ornamentations. [69]
[48] Currently the Xinxiang province in China.
[49] Not a bow and without horsehair.

Dynasty (1279-1368), the rosined stick was changed to horsehair. The xiqin is part of the huiqin[50] instrument family. In this family is the more popular *erhu* that was developed during the Song Dynasty (960-1279). The Cantonese pronunciation of xiqin is haikum and is very close to the haegeum pronunciation.

It is not certain how the haegeum arrived in Korea, but it is estimated to been used and quite popular since the 11th century during late Goryeo Kingdom (918-1392). In 1114, the king of the Song Dynasty (960-1279) sent a large amount of *a-ak* (Chinese-originated proper ritual music) instruments as a gift to Korea. Most of all the *a-ak* instruments were introduced at this time. Although the haegeum was not on the inventory list of this mass absorption of Chinese-origin instruments, it is widely believed that this instrument arrived in Korea during along with the other Chinese-origin instruments.

According to the main surviving historical record of the Goryeo Kingdom, ***Goryeosa* (History of Goryeo)- 1493**, the haegeum may have entered Korea under the name of 'hogum' in 1124 from the Song royal courts. This documentation also mentions that the haegeum was only played in *hyang-ak* (Korean-originated proper music) during the Goryeo period. In ***Hallim Byeolgok* (Song of the Confucian Academics)- 1216**, the term 'haegeum' appears in this early documentation on list of instruments for a *hyang-ak* piece composed during the Goryeo period. Finally, in ***Akhak Gwebeom* (Musical Treatise)- 1493**[51] written during the Joseon Dynasty, the haegeum was classified as a *dangbu akki* (instrument from Tang country). This classification led to limiting the haegeum to only *dang-ak* ensembles by the end of 15th century.

### 2.3.3 Materials of the haegeum (*Paleum*)

*Paleum*[52] is a concept that derives from the Chinese ba yin. These systems use the eight materials: metal, stone, thread, bamboo, gourd, soil, hide, and wood to classify the characteristics of objects by their material composition. These eight materials refer to Yin and Yang belief and individual essences of matter. In eight categories, specific characterization and symbolic representation are associated and corresponded to detailed materials, seasons[53], lunar year, and direction of the wind. [14] The collective of all eight of these materials represents the perfect union of everything that exist in the universe. [14]

[50] *Hu* meaning barbarian.
[51] This document also covers the production process of making the haegeum as well as outlines the playing techniques *gyeonganbeop* and *yeokanbeop* (refer to section 2.3.1)
[52] *Pal* meaning eight. *Eum* meaning tones.
[53] Examples: the sound of bamboo corresponds to the spring equinox/east wind, the sound of wood corresponds to the arrival of autumn/north wind, the sound of thread corresponds to the summer solstice/south wind.

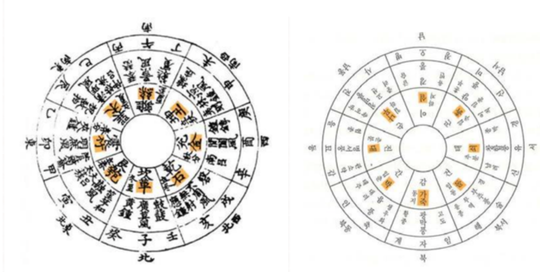

*Figure 48 Diagram of ba yin/paleum associations in Chinese and Korean*

This concept is used in both traditional Chinese and Korean music. Follwing ba yin, Chinese imperial orchestras were comprised of instruments that represent each of the eight materials. Stone chimes, vessel flute and tubular flutes representing stone, soil, and bamboo. Zhong bronze bells and bronze Tonggu drums representing metal. Drums representing hide. Stringed instruments representing silk. Percussive clappers and Yu (ridged washboard-like percussion) representing wood. Pipes represented bamboo. Sheng mouth organ representing gourd. Through this configuration, it is thought this ensemble could produce all the sounds in that exists and find harmonization in the universe. [14] The music they play would bring both the audience and performers closer to a balanced nature.

The haegeum is the only instrument to use all the eight materials in the *paleum* classification system. The soundbox and neck representing bamboo. The pegs representing wood. The rosin for the bow representing soil. The base plate representing metal. The strings representing thread. The bridge representing gourd. The leather strap representing hide. The crushed stone coating inside the soundbox representing stone.

| Name | Materials | Structural roles |
|---|---|---|
| *Jua* (pegs) | wood | winding strings; tuning |
| *Yuhyeon* & *Junghyeon* (strings) | silk | making sound |
| Hand grip | skin | connecting the bow and the horsehair |
| *Wonsan* (bridge) | gourd | Supporting the two strings on the soundboard of the resonator body |
| *Gamjabi* (metal plate) | metal | connecting the two strings with the instrument |
| *Jucheol* (metal rod) | metal | connecting the *gamjabi*, the resonator body, and *ipjuk*. |
| *Bokpan* (soundboard) | wood | resonating sound |
| *Gongmyeongtong* (resonator body) | bamboo, earth | |
| *Malchong* (horsehair) | Horse tail | making sound by rubbing the strings |
| *Hwaldae* (bow stick) | bamboo | |
| *Garakji* | stone | helping connect the resonator body and *ipjuk* |
| *Ipjuk* ("standing bamboo") | bamboo | fastening the strings with pegs |
| *Sanseong* (sound separator) | silk | gathering two strings |

*Figure 49 Paleum materials of the haegeum*

Akin to the Chinese imperial orchestra's configuration of instruments, the haegeum can represent all eight of the *paleum* materials in one instrument. It can synchronously absorb all the corresponding symbolic references behind each material and serve as everything that exists in the world. According to the *paleum* beliefs, the sound it produces would be considered flawlessly complete and nourishing.

### 2.3.4 Physical development of the acoustic haegeum

In the earliest available document that mentions the haegeum, ***Akseo* (Instrument Book)- 1104**[54] written by Jinyang of the Song Dynasty, the haegeum was being played by rubbing a thin bamboo stick between the two strings like the xinqin. Illustrations in this document shows the lack of *sanseong* (horse-hair)[55] and clear use of bamboo material[56] for the vertical neck. [15] [16]

*Figure 50 Haegeum illustrated in Akseo*

The next document that mentions the physicality of the haegeum was the **Wenxian Tongkao-1317**. It was written by Ma Duanlin during the Yuan Dynasty. This document did not illustrate any physical development of the haegeum and was very similar to what was described in ***Akseo* (Instrument Book)- 1104**. However, in ***Akhak Gwebeom* (Musical Treatise)- 1493**, the haegeum during this time developed into the instrument that we know today. Although there are still some differences such as the direction of the neck curvature, the decorative string attachment to the top of the neck, and materials it is composed of. However, the introduction of the horsehair bows and *sanseong* are a big development both the physicality of the instrument and the sound it produces. [16]

*Figure 51 Haegeum illustrated in Akhak Gwebeom*

With more technological, mechanical, and material advancements, the material used to produce the haegeum changed alongside these innovations. Almost all these new material substitutions follow the *paleum* system[57] and maintains the haegeum's rare qualities and timbre.

The soundbox, originally made from bamboo was altered to be composed from stronger and more resistant wood materials. The most common material became red sandalwood but other woods like yellow mulberry and mountain citron are often used. The soundbox lining was traditionally lined with paint made from crushed stone to adjust the sound of the soundbox. As a result of now being able to shape the wooden soundbox, this became unnecessary. By shaping the soundbox carefully, the maker can control the timbre of the sound. This does remove one of the materials in the *paleum* system, stone. However, even though the modern

[54] This document covers not only Chinese music history and theory, but also studies the Korean music history and theory during the early *Joseon* dynasty.
[55] Refer to section 3.1. Alters left hand playing technique and fine-tunes initial string pitch.
[56] The standard bamboo material was thought to have 3 nodes for the main vertical neck and 5 nodes for the bent top curve.
[57] Refer to section 2.3.3

haegeum no longer includes the stone material, the underlaying symbolic idea of morphing of *paleum* should still be valid. The sound and essence of the stone material is still produced in the haegeum through a different approach. The soundboard is now composed from a thin sheet of paulownia wood glued to lip and sanded to shape.

The neck, also originally made from bamboo stalks with prominent nodes, transferred to using hardwood from fruit trees such as pear or apricot. These hardwood dowels are heated and bent to form the iconic shape of the haegeum. Another material alteration made to the neck is the metal spike that connects the neck to the soundbox. Traditionally, the bamboo stalk would pass though the body of the soundbox and be secured by tension. Now, the metal spike is inserted into the neck, through the soundbox and secured to a plate at the base of the soundbox. The plate also acts as a secure place to attach the end of the strings. This allows for a more durable resonant material to pass through a small hole in the soundbox.

The bow, like the soundbox and neck, was also traditionally made of a flexible bamboo shaft. Because of the weak areas around the nodes, it was very important to harvest the perfect shaft with the nodes in the favorable placements of the bow. This is a laborious and imperfect process. With the switch to wood, the makers were able to carve the stick to the exact flexibility and balance they required. Carbon fiber bows were also introduced to make extra stable, consistent, and durable bows.

With the innovation of the flexible and adaptable materials, this gave rise to creation of new instruments. There are three modified acoustic instruments that was influenced by the haegeum. The Treble-haegeum and Bass-haegeum are essentially the same the haegeum but altered to produce a higher or lower pitch range. The Treble-haegeum has a shorter neck and thinner strings compared to the haegeum while the Bass-haegeum has a larger body and longer neck. The So-haegeum is a four stringed haegeum[58]. It consists of two pairs of inner and outer strings that are bowed two at a time. Due to the playing method and number of strings, the So-haegeum often sounds like two performers playing together. Correct tunning of the strings is very important due to the chord-like playing method.

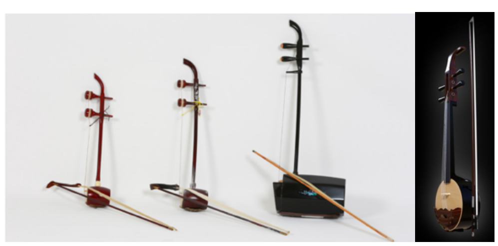

*Figure 52 Treble-haegeum, haegeum, bass-haegeum, sohaegeum*

### 2.3.5 Development of the Electric and Electronic Haegeum

Since the popularization of electric instruments performances lead by Jin-Hi Kim and Eugene Park[59], this sparked more interest in creating electric, augmented and hyperinstrument

[58] *So* (四) meaning four. This instrument is recently mainly played in North Korea.

[59] Refer to section 2.1.7

versions of the traditional *gugak* instruments. The Korean music culture defines 'electric instrument' as instruments that amplify their original acoustic sounds while 'electronic instruments' refer to instruments used as synthesizers and controllers for other sounds, timbres, and effects.

Around 2009, Young-Jun Choi and his company Oriental Express created the first electric haegeum called the iHaegeum. Although many prototypes were created, this instrument consisted of a piezo disk transducer pickup glued to the bridge of the instrument and a ¼ inch cable connected to the audio system. The iHaegeum did not consist of a soundbox but rather was a simple structure that stretched and fixed the two strings. Through using the amplification of the piezo, extended techniques such as pizzicato were able to be heard and incorporated into performances[60]. [17] [18]

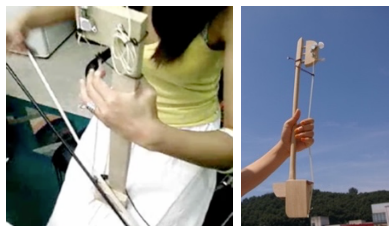

*Figure 53 Version 1 and 2 of iHaegeum prototype*

*Figure 54 Version 3 of iHaegeum*

Later, an electric bass haegeum project was also initiated in 2011 with the same approach as the iHaegeum[61].

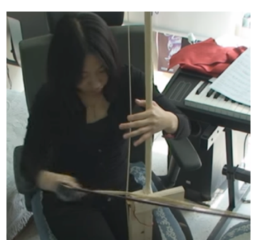

*Figure 55 Electric Bass Haegeum by Choi*

In 2009, the company Supersound and its CEO Dong-Hyun Kim experimented in creating electric *gugak* instruments. The goal of the company was to create a true *hallyu* group that reflects the unique identity of the long Korean culture and history. The girl group Proto,

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[60] iHaegeum performance video: https://youtu.be/48HPatsD-Ok
[61] Bass iHaegeum performance video: https://youtu.be/Kxp_GG76rFU

was created to represent this ideal. Along with singing and dancing, like any popular K-pop group, this four-member group[62] also had traditional Korean instruments strapped onto them. Since the gayageum, geomungo, haegeum were designed to be worn on shoulder and needed the performers to move effortlessly, they required each of these instruments to weigh less than 3kg. Over the three years of development, they were able to research that the composite of fiberglass and aluminum gave them the lightweight, yet sturdy[63] instruments needed for this group and type of performance. These instruments looked and sounded completely different from the traditional instruments. With steel strings and electromagnetic pickups[64], they sounded more like an electric guitar than the acoustic *gugak* timbre. This was a sign of respect to the original sound of tradition and culture around these instruments. [19] [20] [21]

*Figure 56 Supersound's electric gugak group Proto*

In 2013 as an awardee of the KOCCA (Korea Creative Content Agency) 2012 Global Experts Linkage Project Education Program, Dae-Hong Kim led the creation first ever electronic haegeum. This project produced a series of electronic *gugak* instruments called the eHaegeum, eJanggu, and ZiOm wearable controller. This project was started to produce sufficient instruments that could be performed in the multimedia performance 'Rabbit in The Moon'. This performance was based on one of the Buddhist Jataka tales that tells the story of a rabbit sacrificing itself for society. The rabbit is immortalized for its selflessness and his image is forever etched onto the surface of the moon. In this performance, the rabbit represents the traditions while the moon represented new emerging technology. At the end of the show, the merging of traditions and technology reflects the storyline, new augmented instruments, and other mixed artistic elements of the performance. [22]

*Figure 57 MK1 performed at the NIME'13 conference*

The eHaegeum's design was influenced by the need to maintain the familiarity of the traditional instrument for both the performer[65] and physical design. Due to the small size of the haegeum's soundbox, the number of electronical components were carefully deliberated in

[62] Min Ah Kang played the haegeum, Hyeon Ha Lee played the gayageum, Byul Nim Hwang played the janggu and CEO Dong Hyun Kim accompanied them with the geomungo.
[63] Sturdy enough to handle the tension of the strings.
[64] Kim previously tested using silk strings and piezoelectric pickup system housed directly inside the wooden bridges.
[65] eHaegeum performance video: https://youtu.be/HXuOLgADHKU

inserted into the final project. A couple sensors and physical controls were added to the traditional body of the haegeum to control the sound settings and effects. A pickup system was also implemented to increase the volume to adapt to the large performance space and other instruments. [22]

Figure 58 eHaegeum

CarbonPlay's Arang-e made in 2018 follow the design of the eHaegeum closely. The Arang-e was developed[66] by Jae-Eop Yoo with funding from Jeonbuk Creative Economy Innovation Center and K-ICT[67]. [23] [24] [25]It is similar in the way that it uses the traditional haegeum design and utilizes the empty space of the soundbox to implement the electronic components. This project does however have many different features. This electric instrument adopted new materials for its physical components that fit the electrical needs of the instrument. The Arang-e features a carbon fiber soundbox, wireless electrical body insert and a bluetooth amplifier case. [26] [27]

Figure 59 Arang-e and it's amplifier case.

In 2020, Dae-Hong Kim re-developed the eHaegeum into a new electronic called the AirHaegeum. With an unfamiliar structure and playing technique this completely digital instrument does not have a physical strings or haired bow. It was named as the AirHaegeum due to the physical strings being replaced with a laser and proximity sensor. The name was given due to the feeling of playing the air rather than a physical instrument[68]. [28]

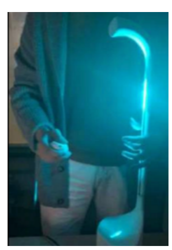


Figure 60 AirHaegeum **

[66] Footage of Yoo making the Arang-e: https://youtu.be/iLJ_ppbut7E

[67] During this 6- month start up mentoring program, Yoo developed and registered a patent in 2018 for his 'Dual-mode electronic haegeum using carbon fiber material

[68] AirHaegeum performance video: https://youtu.be/Auun9V_AZ68

# Chapter 3

# Exploration of the Haegeum

This section of the thesis will explore prior works on augmented instruments, hyperinstruments and other relevant research to explore feasible options for the technical evolution of the haegeum. Since the topic of this thesis was to create a culturally, historically, and technically relevant augmented haegeum, each of these prior works will be individually examined and carefully deliberated. If the technical evolutions presented in these works can be applied to the haegeum without disrupting the essence of the instrument, this chapter will serve as a theoretical prototype for future possible augmentation ideas.


*Figure 61 Main components of the haegeum*

This chapter is organized to highlight the six main components of the haegeum. The strings, neck, soundbox, bridge, bow, and tuning pegs. Each component will be investigated separately to outline the numerous references and applicable possibilities.

Although some of the included references feature completed augmented haegeum projects, a large portion is targeted to Western music instruments, concepts, and performance techniques. Due the lack of research on East-Asian augmented instruments and hyperinstruments, this thesis is written to summarize and theorize the potential techniques utilized in the western setting and electively repurpose them to conform to *gugak* concepts and culture.

### 3.1 Tunning Pegs (*Jua*)

*Figure 62 Jua*

On the haegeum, there are two wooden pegs that fastens the strings to the instrument. The strings are wrapped around the head of the peg and the leg is inserted into a hole in the neck. The pegs are secured into place with tension and are positioned linearly to each other. Due to its linear position, the direction the strings are wounded on the peg heads mirror each other. The most top peg holds the outer (thinner) string and is tightened counterclockwise. The second peg is for the inner (thicker) string and is tightened clockwise. Also due to the position of the pegs, the outer (thinner) string fixed to the top peg leans on the second peg. To reduce friction between the strings, there often is a small thin piece of plastic tubing threaded through the outer string and positioned where it comes into contact with the second peg.

As the result of the pegs linear position, a small gap forms between the strings. The *sanseong* is a thin string that gathers the two strings together and reduces the gap between them. For proper left hand playing technique, it is essential that the two strings are a close as possible. This string is specially tied around the strings and fixed to end of the second peg. By adjusting the position of the string knot and tension of the peg fixture, the *sanseong* can be used to fine-tune the strings.

*Figure 63 Sanseong*

The wooden pegs on the current haegeum are one of the greatest physical challenges to the instrument. The tension-held pegs make it very hard to tune without laborious strength and is prone to slipping. The ornamentation technique required quite regularly when playing the haegeum, constantly adds and release extreme pressure to the strings. This also consequently affects the pegs causing it to move and slightly lower the initial tunning.

### 3.1.1 Mechanical Pegs

#### 3.1.1.1 Ulfarsson's Halldorophone (2008~) [29]

Due to the Halldorophone's use of feedback actuation and the inclusion of a whammy bar, the mechanical guitar pegs were used for extra stability. Also, the author's attempt to design a hyperinstrument that has its own clear visual identity, and the compact size of the mechanical guitar pegs may have aided in the decision to use these pegs over other options. The compact size of these pegs also come in handy when trying to find space for the extra four sympathetic string formation along with the four playable strings needed for this instrument.

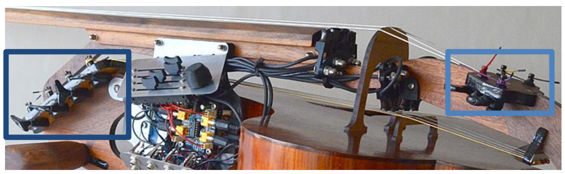


*Figure 64 Use of pegs for the 4 playing strings and 4 sympathetic strings (2014)*

*Figure 65 Alternate designs of the peg formation (2014, 2018)*

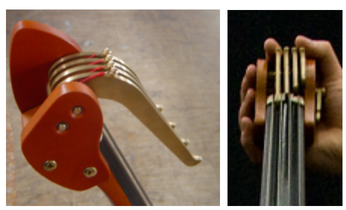


*Figure 66 Whammy bar design for the four playing strings (2008, 2018)*

#### 3.1.1.2 Overholt's Overtone Violin (2005) [30]

The Overtone Violin uses a custom-made mechanical peg as it's string fixture and tuning system. As a result of the immense use of sensors, this instrument needed to consider both the space and weight of each component. With twenty-four separate adjustable components, it was also important for the pegs to be secure enough to outlast accidental bumps and movements. With the instrument's design of placing the pegs near the shoulder-rest and using the space in the scroll for other effects controls, the compactness of the mechanical pegs makes sense.

*Figure 67 Position of the pegs*

#### 3.1.1.3 Yoo's Arang-e (2019) [26] [27]

The pegs on Yoo's Arang-e features the first custom-made gear method pegs used on a commercially available haegeum. On the traditional haegeum, the pegs use friction to hold the tension of the two strings. This presents certain limitations for both the instrument and player. The tight frictional force causes it very difficult to tune. Since the performance practice and techniques of the haegeum require constant tuning, the wooden friction pegs make it harder for beginners and children to learn the instrument without constant assistance tuning. The transition to the mechanical tuner allows for easier access to all levels and ages. These pegs also allow for more consistent tuning and very fine tuning possible.

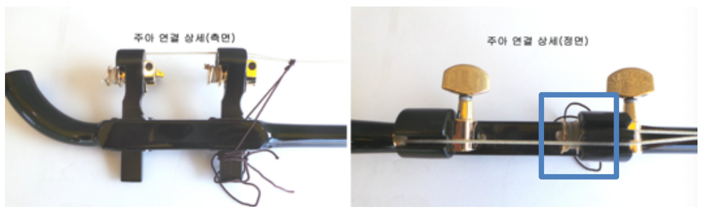



*Figure 68 Arang-e's bobbin mechanical pegs*

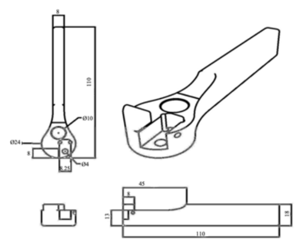


*Figure 69 3D-printed peg base design [31]*

Yoo's haegeum pegs uses 3D-printed peg base with a square post that is fixed onto the bore hole of the neck while the mechanical pegs are fixed onto the cut out of the base. The peg base is designed with a square post, compared to the traditional cylinder shape, to prevent any twisting of the base. The purpose of the base is to position the strings in the correct playing distance from the neck and each other while maintaining the haegeum's characteristic design. The string tension and tuning is held solely by the mechanical pegs attached to the underside of the base. Unlike any guitar or ukulele mechanical tuners, this tuner has a bobbin-like system that cleanly wraps and grips the remaining string.

#### 3.1.1.4 Oriental Express's Haegeum (2009) [18]

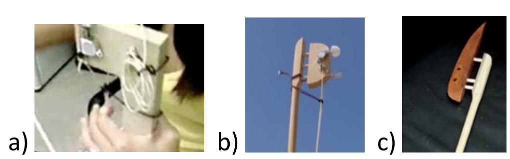



*Figure 70 Oriental Express's Haegeum pegs of iterations a), b), c)*

Oriental Express's electronic haegeum also features alternative peg system on their instrument. Using three dowels, a single attachment was permanently hammered into the haegeum's neck. Ukulele tuners were then secured horizontally facing each other onto the attachment block. This system allowed for easier tuning of the strings while also maintaining the correct neck-to-string distance and overall aesthetics of the haegeum.

## 3.2 Strings (*Hyeon*)

*Figure 71 Hyeon*

The strings on the haegeum consists of two strings of various thicknesses composed of sheep gut and silk. Recently developed use of chemical processing on the strings allow them to more durable and easier to play. The outer-string (*Yu-hyeon*) is slightly thinner and responsible for the mid to high range of the current left-hand position[69]. It is characterized as having a clear sound. The inner-string (*Jung-hyeon*) is the thicker string with a lower and richer sound. The strings float quite far from the neck of the instrument. This space allows for extreme pitch bends through pulling down on the string and releasing that pressure. Without the limitation of a fingerboard, the haegeum player easily pitch bend as far as they would like. This also allows a very large pitch range of almost two octaves to be played in a single left-hand position. Following the flexible in-and-out motion of the strings, ornamentations[70] and embellishment such as vibrato can be performed[71]. However, the frequent use of this motion gradually causes the pitch to fall from the initially tuned strings.

The tuning of these strings, like most *gugak* instruments, does not have a predetermined fixed tunning[72]. They are roughly tuned as perfect 5$^{th}$ intervals[73] between the two strings. For example, if the outer-string (*Yu-hyeon*) is tuned to Bb4[74], the inner-string (*Jung-hyeon*) must accommodate this and must sound a Eb4.

[69] For detailed performance techniques, refer to section 2.3.1
[70] *Gugak* utilizes many different forms of ornamentations in its performance technique and culture. Refer to section 2.2.4
[71] Rather than the limited up-and-down motion in western instruments or the similar spiked fiddle, erhu.
[72] Unlike western music instruments. For example, the cello is tuned to C, G, D, A.
[73] Refer to 2.1.5
[74] It is uncommon to tune below a Bb4 or higher than a C#5. If the strings are tuned too low, the strings will be too loose and therefore have no resistance against increased pressure or contact of the bow. Too high, the timbre will become sharper but lose the instrument's resonance. It will also be very hard to bend the strings and lose the large range of motion of an adequately tuned string.

| *Yuhyeon* | *Junghyeon* |
|---|---|
| $B^{\flat}_4$ | $E^{\flat}_4$ |
| $B_4$ | $E_4$ |
| $C_5$ | $F_4$ |
| $C^{\#}_5$ | $F^{\#}_5$ |

*Figure 72 Possible tunings of the outer and inner strings*

Because the strings are tuned using the index finger and not the open strings, some players prefer to tune the outer-string (*Yu-hyeon*) a little higher to a minor $6^{th}$ interval. This is to account for the upward angle[75] of the left-hand and therefore affecting the outer-string to be played slightly lower in pitch. It also considers the mechanics of pulling of the strings. Since the string is positioned between the first and second joint of the strings, the inward gripping motion favors most of its weight onto the inner-string. This causes the outer-string to pitch bend a little less compared to the inner-string.

### 3.2.1 Linear-potentiometer and Force-sensitive-resistor Sensors

***Linear-potentiometer***

Linear-potentiometer sensors detect the position of a contact point applied to the sensor material. Normally it is made of three layers of materials. A spacer placed between the top and bottom conductive material to create a gap between the two and form an open circuit[76].

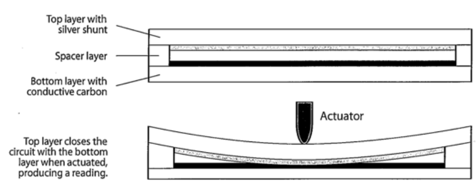



*Figure 73 An example of a linear-potentiometer from the commercial Softpot sensor*

The bottom conductive material is charged with a certain voltage[77] (point-A in fig. 56) running down the length of the sensor and grounded on the opposite end (point-B in fig. 56). When the sensor is pressed at a certain point, the top conductive material closes the circuit and alters the voltage of the bottom conductive material by adding resistance to it. The resistance will depend on the total length of the linear-potentiometer but the closer to the grounded end, the lower the resistance[78] will be. [32]

[75] See figure 39
[76] When the components of an electronic circuit are not completely linked together. A gap in one or more of the connections.
[77] The pressure of charge (amount of energy) between two points.
[78] The defiance/resistance to the flow of charge (amount of energy)

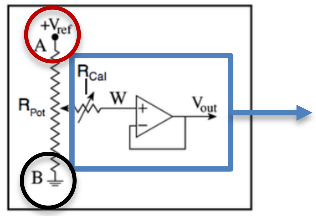


*Figure 74 Circuit diagram for linear-potentiometers[79]*

*Figure 75 The commercial Softpot sensor*

***Force-sensing-resistor***

Force-sensitive-resistor or FSR, works with the similar principal as linear-potentiometer. However, instead of sensing pressure linearly along a certain axis, the whole contact pad where the two top and bottom conductive layers is measured. Compared to the linear-potentiometer, the bottom conductive layer is in a grid formation. The more force that is applied the less resistance is measured.

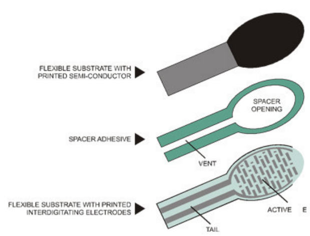


*Figure 76 An example of a commercial FSR*

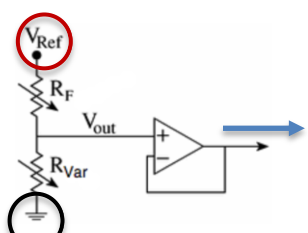


*Figure 77 FSR circuit[80]*

#### 3.2.1.1 Pardue's violin (2014) [33] [34]

Pardue utilizes the combination of resistive position sensors and pitch tracking to optimize their system. By creating a custom resistive position sensor overlay[81] on the fingerboard, the violin can track the position of the players fingers and therefore the pitches being played. These sensors are used to detect the range of what note is being played and limit

[79] The RCal is the adjustable reference resistor used to adjust sensitivity of sensor to position of contact. [41]
[80] The RVar is the adjustable reference resistor used to adjust sensitivity of sensor to position of contact. [41]
[81] Commercial linear-potentiometers have apparent heigh and edges that can alter the feeling of the instrument. [34]

the autocorrelation pitch tracking. The time-domain autocorrelation method of pitch tracking was chosen due to its adequate dependency and latency speeds[82]. Utilizing the sensors allow for the pitch analysis to be faster because of limiting the number of possibilities the played pitch can be. Also, the combination of aural and sensor data can minimize errors in the system.

In their 2015 study, the custom linear-potentiometer consisted of four printed conductive traces[83] made from 0.15mm polyimide, thin tape, and a strip of velostat that covers the width and length of the fingerboard. In this configuration, the conductive traces acted as the top conductive layer, the thin tape as the spacer and the velostat as the bottom conductive layer. When the finger pressed the string, the velostat closed the current-mirror circuit with the conductive traces under the tape. [33]

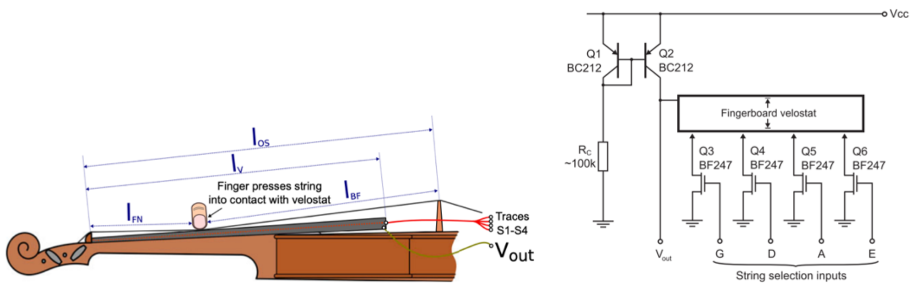


*Figure 78 Pardue's violin circuit diagram*

The sounded pitch is detected by calculating the distance between finger and nut ($I_{FN}$) by comparing the max string voltage ($V_{MS}$) to the voltage output created by the pressure location ($V_{out}$).

$$l_{FN} = l_V \left(1 - \frac{v_{out}}{v_{MS}}\right)$$

*Figure 79 Pardue's pitch tracking equation p.1*

After calculating the length from finger to nut, this data can be used to calculate the sounded pitch ($f_{HW}$). This equation compares the set tuned pitch of the open string ($f_{string}$) to the length of the oscillating section of the string ($I_{BF}$).

$$\hat{f}_{hw} = \frac{f_{string} \times l_{OS}}{l_{OS} - l_{FN}}$$

*Figure 80 Pardue's pitch tracking equation p.2*

#### 3.2.1.2 Ko's TRAVIS II (2020) [35]

The TRAVIS II was heavily influenced by Grosshauser's approach to creating a position sensing module that maintains the players tactile familiarness of the ebony fingerboard. Instead of adding a three-layered sensing strip directly on the fingerboard like Grosshauser or Pardue, Ko used the natural space between the fingerboard and strings as the spacer of the linear-potentiometer[84]. However, by creating a custom 3D-printed fingerboard that has conductive capabilities for the top conductive layer and electrifying the traditional metal-

[82] Although 20ms has a noticeable delay, latency under 10ms is acceptable for interactive audio systems. If a lower latency is desired, one must accept the low frequency resolution of the produced sound.
[83] Four sets of data channels for each string. Allows for multiple data streams simultaneously.
[84] Refer to section 3.2.1

wound strings for the bottom conductive layer, the TRAVIS II took a step forward for a more seamless and appeasing fingerboard.

The original ebony fingerboard of the acoustic violin was completely removed and replaced with a black 3D-printed fingerboard made from a PLA filament material[85] . This alternative fingerboard consists of small linear divots under each of the four strings to allow for a separately printed Conductive PLA filament material to be inserted and if need be, removed. These four conductive strips are modular to the fingerboard base to allow for easy replacement and troubleshooting. Due to the nature of the sensitive conductive sensing of the strips and electronics needed to gather the displacement in resistance, this approach is very sensible. Also with the four individual strips, TRAVIS can assign separate data channels for each string. This allows for all four string position data to be processed simultaneously. Unfortunately, the only downside of using a 3D-printed fingerboard is its lack of stability to pressure. When playing in higher positions, the PLA fingerboard is too flexible and bends with the application of pressure. Other filaments[86] were tested but held the same results. Ko solved this problem by adding external supports such as the wooden support under the fingerboard presented in the final version of the TRAVIS II.

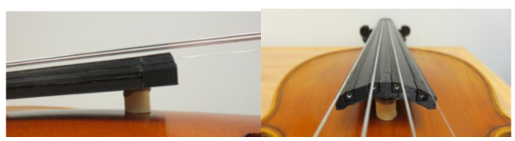


*Figure 81 TRAVIS fingerboard*

The strings of the TRAVIS II use the traditional violin strings with a twist. For these strings to act as the bottom conductive layer of the linear-potentiometer, the strings must have an electronic charge and be grounded. When the strings encounter the Conductive PLA printed strips, the displacement of the output voltage will illustrate the finger positions being played. Each of the ball-ends of these four strings are soldered to a single JST connector that routes the Arduino's 3.3v and ground into each string.

*Figure 82 TRAVIS string voltage/ground connection*

Unlike the Grosshauser projects, the TRAVIS opted for a wireless configuration for its data transfer allowing for more movement during performances.

[85] Non-conductive material. Unlike the Conductive PLA sensors strips also printed.
[86] Like PETG filaments.

### 3.2.2 Conductive Sensor

#### 3.2.2.1 Ehrhardt's piezoelectric strings (2020) [38]

Ehrhardt's piezoelectric string[87] are made from a piezoelectric polymer fiber material and is put through a bi-component melt spinning process so it can detect a wide range of vibrations[88]. This string is composed of two layers. A round braided shell made from PVDF (polyvinyldiflouride) [89] and an electrically conductive thermoplastic polyurethane inner string. Using the roll-to-roll method of polymerizing its fibers, the string can have active piezoelectric properties.

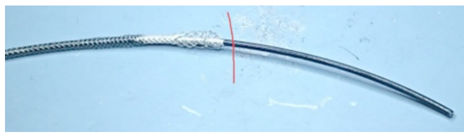


*Figure 83 Ehrhardt's piezoelectric string layers*

The downside with Ehrhardt's string is it cannot be used as instrument string on most instruments. Because the string itself cannot withstand the tension of most instruments and due to the outer layer being braided and not wound like typical instrument strings, it is very delicate to be bowed on. Also, with no ball-end or sensible mounting without additional connector components, this project is still in development and experimentation on how to apply this technology to existing instruments.

#### 3.2.2.2 Hwang's conductive silk yarns (2020) [40]

Comparable to Honnet's in polymerization of pyrrole, Hwang approached creating a highly conductive yarn sensor using the combination of Ag nanowires and PEDOT:PSS[90]. While dyed polymerization of fibers limited the conductivity to ~70 S /cm, Hwang's method allowed for higher conductivity at ~320 S /cm.

The process of combining the Ag nanowires with a conductive polymer such as PEDOT:PSS is more laborious than pyrrole polymerization. The first step is to prewash the degummed silk yarn in a polyol reduction solution process consisted of water, silk detergent, ammonia for around 30 minutes. The silk yarn is then air-dried at room temperature for 24 hours. After drying, the yarn is dipped in an Ag nanowire solution[91] of 0.5wt% isopropyl alcohol, baked on a hot plate for 5 minutes ate 180 degrees Celsius. The now Ag nanowire-coated yarn is dipped again into a PEDOT:PSS solution and dried with a heat gun at 100 degrees Celsius. Through dip-coating the silk yarn with the Ag nanowire and PEDOT:PSS solutions, it imparts conductivity to the fiber.

[87] The devkit created by the authors of this research: **https://discourse.chair.audio/t/piezoelectric-string-devkit/64/14**
[88] From sub-Hz to Mhz range of vibrations.
[89] As outer electrode.
[90] Polymer: polyelectrolyte complex poly(3,4-ethylene dioxythiophene):poly(styrene sulfonate)
[91] The silk yarn to Ag nanowire solution wt% ratio is ~2.9:1

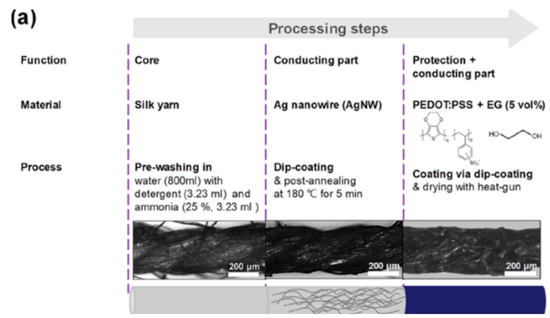


Figure 84 Ag nanowire and PEDOT:PSS polymerization

### 3.2.2.3 Honnet's Polysense (2020) [39],

The Polysense uses In-situ polymerization to create textiles that can sense pressure and deformation[92]. Without changing the feel of the material by using surface-level conductive tracks or layering conductive fabric, this polymerization technique integrates the piezoresistive properties directly into, onto and around the material. In-situ polymerization refers to the process where monomers are combined to form conductive polymer chains on, in and around each of the individual fibers in a textile.

Different to layered conductive sensors, this system uses conductive molecules inside the fabric to alter the measurable change in resistance. When pressure is applied it pushes the free-floating conductive molecules closer together causing the change in current and resistance.

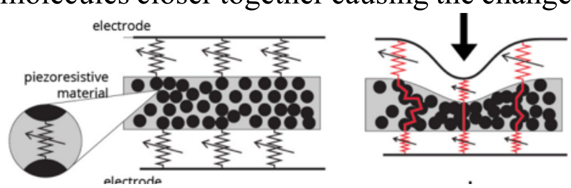


Figure 85 Polysense conductive molecules when pressed

Organic polymers like polyaniline (PANI), polypyrrole (PPy) and poly-(2,4-ehylenedioxythiophene) (PEDOT) has intrinsically (naturally) conductive properties and allows the flow of electrical energy. For materials not naturally conductive, one way to dope a polymer is to add extrinsic conductivity. This is done when a monomer or polymer is exposed to an oxidizing agent[93] such as Iron (III) chloride.

Honnet's work uses the simplest synthesizing compound for doping a polymer. By adding the Iron (III) chloride[94] to the monomer pyrrole[95] and polymerizes it to polypyrrole (PPy) and increase conductivity of the area both chemicals were added. The process of creating a polypyrrole fabric is quite simple. After soaking the desired fabric is a pyrrole and water solution around 10-15 minutes [96],add the oxidizing agent (iron chloride). After around 30 minutes the fabric will have evenly turned black from polymerization. The fabric is then washed with cold water, air-dried, and ironed.

[92] Although commercial piezoresistive fabrics such as Eeonyx are available, this project is cheaper and customizable.
[93] Oxidation occurs when hydrogen atoms weakened allowing for monomer molecules to bind to each other forming polymer chains
[94] Also known as ferric chloride.
[95] Pyrrole is used in manufacturing bio-compatible batteries
[96] For 3m2 of cotton fabric, there should be a 5:! ratio of water to fabric. The water to pyrrole volume ratio is around 1000:25 (1L water, 25ml pyrrole) and water to iron choride mass ratio of 100:1 (1L water, 10mg iron chloride)

With this technique, materials like polymerized yarn stretch sensors and pressure sensors can be created. This polymerized yarn can then be incorporated into other materials as sensors or patterns can be polymerized directly to the fabric. In this project, traditional resist-based dyeing techniques such as batik were used to block the dye in certain areas of the fabric. In this case, the batik or wax blocked out the iron chloride and other areas were free to be polymerized.

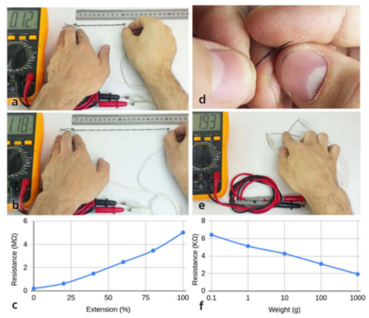



*Figure 86 Conductive yarn stretch and pressure sensors*

*Figure 87 Glove with pressure sensitive areas in knuckles and joints*

### 3.2.1 Virtual Laser String

#### 3.2.1.1 Kim's AirHaegeum (2020) [37]

Instead of two physical strings, like on a traditional stringed instrument, the AirHaegeum features a single laser[97] that is emitted through the length of the instrument and a proximity sensor embedded into the neck[98]. This laser functions solely as a visual representation of the strings and does not have any control of the sound production of the instrument. When played, the AirHaegeum's laser string visually displays the performer's finger position and degree of grip pressure detected by the neck sensor.

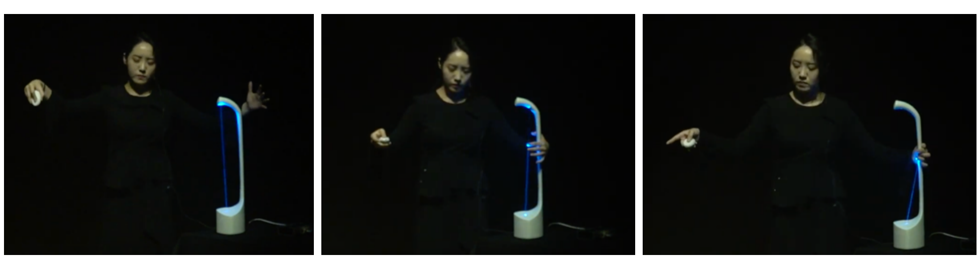


*Figure 88 Laser bends of the AirHaegeum*

[97] To achieve an aesthetic colour, a combination of the 450nm blue, 488nm sky-blue, and 520nm green lasers are merged to create a single stream of 100mW light. A laser diode module and driver allow for adjustable brightness when needed.

[98] See section 3.3.2.1

Figure 89 Specular reflection system of AirHaegeum's virtual string

This is achieved by implementing specular reflection using a brushless DC servo motor. Often used in camera gimbals, this type of servo motor allows for a quiet and responsive high-precision positioning control that provides velocity and position feedback sensing data.

Figure 90 Laser diode module and BLDC servo motor (RDM-S-4005)

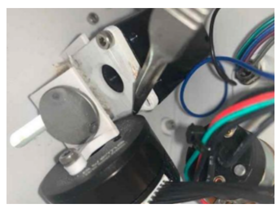


Figure 91 Motor, mirror, and laser diode module system

The internal magnetic encoder in the BLCD servo motor receives the position data from the neck sensor and moves the motor angle accordingly. This adjusts the 3D-printed mirror attachment and bends the reflection angle of the laser. Emitted out the base of the instrument, this laser bend is accurately redirected to the vertical and horizontal position of the left hand.

## 3.3 Neck (*Ipjuk*)

Figure 92 Ipjuk

The *ipjuk* or the neck of the haegeum sticks vertically up from the center of the soundbox. The neck is crucial to the overall build since it connects and fixes the other components of the instrument to itself. The total length of the neck, from the base of the soundbox to the curved top, is usually 62cm. However, the haegeum player has around 38cm of usable playing length of the strings. The neck diameter is quite thin, around 1.3cm wide, for the players thumb to wrap around and be supported against.

### 3.3.1 Linear Potentiometer Sensors

#### 3.3.1.1 Grosshauser's projects (2013) [41]

The finger position and pressure in Grosshauser's final violin project utilized custom-printed flexible sensors made based with 0.5mm thick conductive foils. This sensor combined the methods used to make linear-potentiometers and FSRs (force-sensitive resistor).

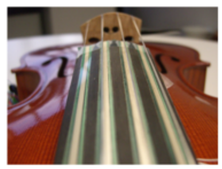


*Figure 93 Sensor placement on the violin fingerboard*

The design of this violin and placements of the sensors were carefully researched to make the sensors and it's following electronics to be as unobtrusive to the player and movements. To integrate additional capabilities without influencing the musician while they are playing. Grosshauser aimed to create an augmented instrument that had the right ratio of the fingerboard to sensor. These sensors should be wide enough to trigger the sensor but does not completely remove the familiar tactile of the fingerboard and therefore distract the player. By using thin sensors, both in width and thickness, only the small sections of under the string was covered. Since on a traditional violin, this small section is already sandwiched by the string when pressed upon, adding the sensor strips here does not change the tactile feeling of the metallic string on the finger. Yet, leaving the spaces between the strings empty allows for the player to have the familiar ebony fingerboard tactile texture.

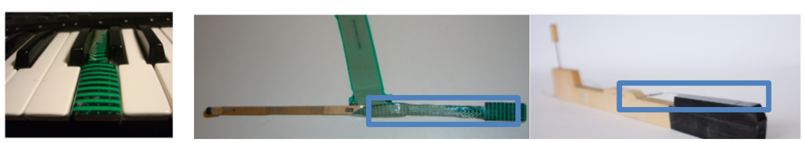


*Figure 94 Flexible PCB circuit with 4x28 sensor matrix on white and black keys*

A similar position sensing technique was applied to the piano. With a custom matrix-printed circuit made from a flexible PCB board, it can sense the pressure and position of the finger on individual white and black keys. This data is processed and presented to the user as a heat-map visualization.

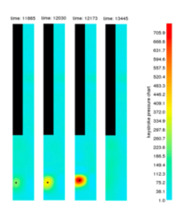


*Figure 95 Heat-map visualization*

The data from these sensors have average sampling rate of 300Hz and are used in MaxMsp to control audio processing of the acoustical violin sound produced by the instrument. This project opted for a wired data transfer from the sensors to the computer for lower delay rates of the real-time sound synthesis and output. Although this causes the performer to have limited mobility and have possibly distracting additional wires, it is understandable for the sake of the stability and speed of the data transfer.

#### 3.3.1.2 Schoner's cluster-weighted sampling (2000) [36]

This project built a model that uses recorded datasets of gestural input data of the violin bow, and finger positions for sound synthetization for any violin-family instrument though gestural input. Through cluster-weighted sampling, the augmented violin can generate sound output directly from the sensor inputs. The goal of this project was to create a model that appears to be following the same acoustical physical laws for the listener and performer.

The finger position was determined by a custom-made linear-potentiometer. By connecting a DC voltage to a resistive stainless-steel strip at approximately 1ohm, tape and a strip conductive foil. Unlike later works on resistive position sensors via custom linear-potentiometers, this project did not have separate data flow for each string but rather limited to just one position input.

#### 3.3.1.3 Goto's Superpolm (1996) [42] [43]

The Superpolm, created in 1996, was a completely virtual instrument that had no resonating body or actual physical strings. Instead of strings, position-measuring sensors on the fingerboard were used. Four Interlink FSR sensors were positioned asymmetrically to allow each of the 10cm by 2.5cm long sensors to be accessed. Since the Superpolm was a gestural instrument, many of physical elements of the violin were omitted and controlled digitally by measuring the gestures of the performer.

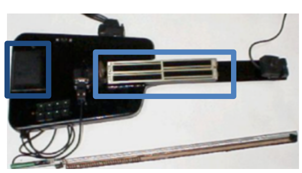


*Figure 96 Superpolm*

A traditional violin is held up between the players shoulder and chin. This component of the violin is referred to as the chin rest. On the Superpolm, an internal pressure sensor is embedded into the chin rest and covered with a flexible rubber layer. Depending on the intensity of the chin pressure, the player can change the audio or visual parameters of the performance.

#### 3.3.1.4 Moon's MIcelloDI (2020)

The MIcelloDI is a MIDI instrument built from a 6cm ABS pipes, 3D-printed bridge and pegs enclosures, and several sensors. This instrument, unlike the traditional Violincello it is modeled after, does not have a soundbox or full-length strings. Instead, it uses four Piezo

Vibration Sensors to represent the four strings of the cello and two 500mm Softpot Membrane Potentiometers used to track the finger position and pitch of the instrument. [44]


*Figure 97 MIcelloDI*

The Potentiometers are re-programable and flexible depending on the performance needs. The duality of the sensors allows for one to control pitch and another to control audio effects, foley, or visual processing. The length of both the ABS tubing, potentiometers, faux-vibrations strings, and 3D-printed base were measured to directly reflect the dimensions of a traditional cello. This was designed for traditional cellist to easily apply their techniques and experience to this instrument. Since the MIcelloDI is a completely virtual instrument, it can control and switch across multiple timbres of instruments using the cello playing techniques.

#### 3.3.1.5 Strohmeier's piezo-resistive kinesiology tape

In Strohmeier's work with kinesiology tape sensors, he refers to Honnet's formula for creating piezo-resistive fabrics by polymerization. By soaking kinesiology tape into a pyrrole solution, it can be used as an alternative HCI (human-computer interaction). As traditional HCI limit possible movements to a single plane and input, movements tracked by these kinesiology tape stretch sensors mimic the counteracting movements of the muscles inside the joints. [45] [46]


*Figure 98 Piezo-resistive kinesiology tape*

With the exceptionally flexible material of the piezo-resistive kinesiology tape, it can be cut and designed to fit any sensing needs. Depending on their placements on the body and shape of the sensor, they can be used as strain gauges, bending sensors, FSRs, linear potentiometers, x/y-axis position sensors or even component connectors. Depending on the amount of stretching of the tape and movement from the resting position, the sensor's resistance changes proportionally.

In Strohmeier's work in 2012, the WristFlicker was embedded into a wrist warmer to measure the wrist rotation (pronation/supination)[99], wrist tilt (ulnar/ radial deviation) and wrist bend (flexion/extension) of the user. By adding six strips of piezo-resistive kinesiology tape at different angles of the wrist, this system can measure all three motions of wrist movement simultaneously. Each of the movement direction consists of two counteracting sensors to reduce the delay in movement readings. Combining the readings of both counteracting[100] sensors, allows a faster and detailed reading. [46]

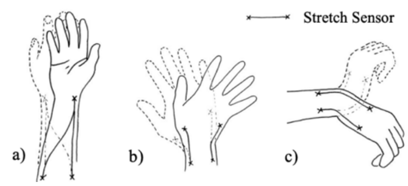


*Figure 99 WristFlicker's wrist rotation (a), wrist tilt (b), and wrist bend (c)*

Strohmeier connected these six sensors to an Arduino and Bluetooth module to link and control a music player application on an android phone. By sending the raw values of the sensors through a lowpass filter to reduce noise and threshold value system to select which two sensors work counteractingly with each other, this system was able to control various parameters of the music player application. It was able to control the selection of music, volume control, and play/pause controls with the movement of the user's wrist. [46]

### 3.3.2 Proximity Sensor

#### 3.3.2.1 Kim's AirHaegeum (2020) [37]

Before finalizing the AirHaegeum's last design and proximity sensor of the neck, multiple iterations and technology were experimented to find the most accurate fit. This instrument required several specific parameters such as the ability to detect four fingers simultaneously and in various positions both horizontally and vertically. Due to the constant ornamentations and pitch bends, the system also needed to be responsive enough and reach a wide area of detection to catch the nuances of the haegeum playing. The system also needed to be compact enough to fit inside the small cavity of the instrument. Basic infrared sensors in various positions and angles were tested in three prototypes[101] of AirHaegeum but they were not able to meet the criteria needed. External camera-based sensors were tested however it tested to be very unstable and limiting for the performer.

[99] The rotational motion of the forearm has three mounting points. This is to replicate the pronator teres and supinator muscles of the forearm.
[100] At a given time, one sensor is stretched and the other relaxed. This gives two values to register faster movement readings.
[101] All three prototypes and the final design used the same single laser virtual string in their systems. The laser string is only a visual component and does not have any effect on the neck's sensing. See section 3.2.1.1

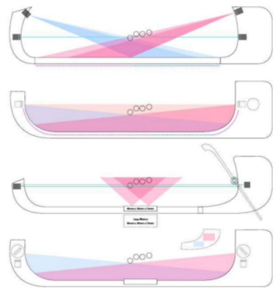


*Figure 100 AirHaegeum's finger position system design progression*

The final design eventually applied the zForce system, Neonode's patented optical sensing technology. The AIR touch sensor is a compact sensor module that can convert any screen or surface into a contactless touch experience. Inside a single sensor module, multiple pairs of light emitters and detectors, optical light guides, and a controller IC work together to retrieve position data of an object. As the light emitters project an infrared light, something that is invisible to the human eye, object placed inside the scope of the module cause intensity shifts in light captured by the detectors.

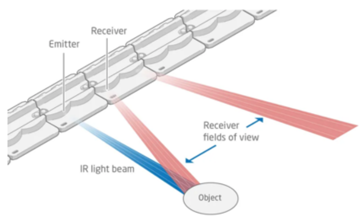



*Figure 101 Neonode's zForce system*

The Neonode sensor allows for eight separate accurate and responsive sensor parameters in each of their slimly packaged modules. Parameters such as touched, touch event, touchX, touchY, touch size, and touch ID all assist in precise position mapping needed to play the AirHaegeum's virtual string. The module's ability to sense up to ten objects with a range of 30cm x 20cm cover all the requirements needed for haegeum playing.

*Figure 102 Neonode's sensor module in the AirHaegeum*

## 3.4 Soundbox (*Gongmyeontong*)

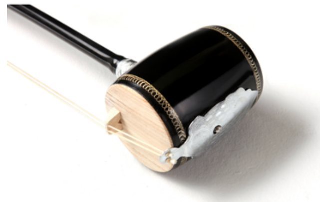


*Figure 103 Gongmyeongtong*

On the haegeum, soundbox is made of three components. The resonator, soundboard (*bokpan*), and metal plate (*gamjabi*). The main component, the resonator, is a round open-ended wooden tube that has an average diameter of 8-9cm and is around 10cm deep. On one side of the resonator, a thin circular piece of wood the same diameter as the resonator is glued to the rim of the resonator[102]. This acts the soundboard the haegeum. The metal plate sits at the bottom of the resonator. This component secures the metal rod that connects the soundbox to the instrument's neck. It is also responsible for acting like a tailpiece for the strings.

The construction of the soundbox requires multiple thin layers of material to be added to shape the sound the instrument produces and extend its lifespan. The soundboard is often shaved and sanded in aid of perfecting the sound. On the resonator, six layers of ocher[103] is applied on the exterior wall. Inside the resonator, several thin layers of *seokanju* [104] or ocher is also applied as needed. After this process, lacquer is applied on the exterior of the resonator. The lacquer is applied once, completely dried and repeated up to seven times to formulate a good sound. In some cases, decorative paintings are added to the sides of the soundbox. The makers often use mother-of-pearl or golden shells for these decorative elements.[105] [15]

*Figure 104 The process of making a soundbox for the haegeum*

### 3.4.1 Physicality of the Soundbox

#### 3.4.1.1 Noguera's MUUT electric violin (2010) [47]

The design of the MUUT electric violin came from the desire to build a lighter and functional electric violin. By implementing the hollowed-out truss bridge body the instrument was able to evenly distribute the pressure of the neck stressed by the string tension while also being lighter in materials.

[102] The edges are later sanded down to seamlessly connect the soundboard and resonator.
[103] A pigment containing ferric oxide. Typically, with clay.
[104] A pigment produced from red soil.
[105] Refer to section 2.3.3

Figure 105 Final MUUT violin

To build the intricate design with wooden material instead of the common plastic for electric violin, Noguera used laser cutter to create plank layers of the whole instrument. First, the MUUT was 3D-modeled and sliced into thin vertical 3D-model layers in the CAD software. These files were then laser cut onto red cedar plank. Red cedar was chosen due to their light weight and resonant characteristics. Taking the cut planks, each layer was stacked on top of each other and bonded together using a traditional luthier adhesive. After a couple hours of waiting for the glue to dry, Noguera had a precisely made outcome of their original design. Using a laser cutter decreases the chance for error and material waste due to its preciseness of the process. The MUUT was later sanded for smooth shaping and applied a high gloss coat of catalyzed urethane.

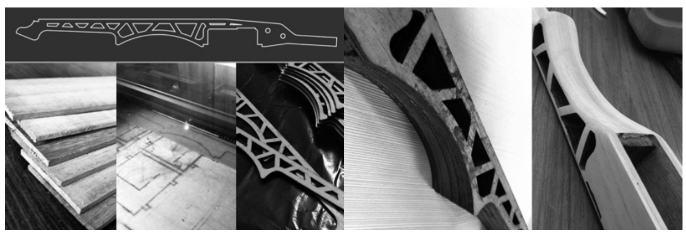


Figure 106 Laser cutting the MUUT layers, gluing and sanding

#### 3.4.1.2 Ulfarsson's Halldorophone (2008~) [29]

Ulfarsson's Halldorophone considered many factors in their soundbox's physical and social design. The Halldorophone was influenced by the design of the violincello. Although many other iterations and designs of this project were tested, Ulfarsson's switch to this classic string instrument also had social implications. The question of what happens to an augmented instrument when it is has a somewhat familiar design with unquestionably familiar instrumental features but is also mixed with new characteristic features. The essence of this classical string instrument also allows the subconscious association of virtuosic players, professional luthiers, and solo instruments. This allows the Halldorophone base its identity off this already existing instrument.

Figure 107 Design of the Halldorophone

Although the Halldorophone is based on the model of the cello, it was designed to have its own clear visual identity. With the oddly shaped soundbox, it separates itself slightly from the traditional cello structure. Acoustically, if following the "half-wavelength-rule"[106] this soundbox design is way too small to project good and full sounds. Therefore, the Halldorophone has a harsh and nasally timbre and many wolf-tones[107] throughout its range. The soundbox should be considered as characteristic filter than an acoustic amplifier.

*Figure 108 Inside the soundbox of the Halldorophone*

#### 3.4.1.3 Overholt's Overtone Fiddle (2011) [48]

The external soundbox design of the second iteration of the Overtone Fiddle[108] was designed with the proper Helmholtz-resonator dimensioning to maximize the volume of the resonating sound. This instrument consists of two soundbox structures. An external carbon fiber soundbox attached to the bottom of the violin and the 2 layered balsa wood main violin soundbox. In each of these structures, there are transducers that assist in the feedback actuation element of the instrument.

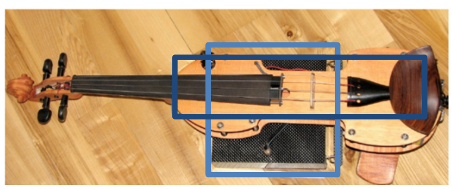


*Figure 109 Overtone Fiddle's 2 internal and external soundbox design*

The external soundbox follows the Helmholtz-resonator dimensions by having the total dimensions of 5.6" x5.6"x1.2" and the internal volume of 37.6 cubic inches. The 0.519" radius circular sound hole on the bottom of the external soundbox follows the equation for the optimum volume production.

$$R = \sqrt[3]{\frac{volume}{\frac{4}{3}\pi}}$$

$$R = \sqrt[3]{\frac{37.6}{\frac{4}{3}\pi}} = 0.519$$

*Figure 110 Helmholtz-resonator sound hole dimensions*

[106] For a good projection, the surface of the soundbox should be half the wavelength of the lowest frequency it can project. In case of the traditional cello and consequentially the Halldorophone, the lowest frequency is 65.4Hz.
[107] Sudden spikes in frequency responses at certain frequency spots.
[108] Not to be confused with the Overtone Violin by the same author.

#### 3.4.1.4 Oriental Express's Haegeum (2009) [18]

The minimalistic frame of Oriental Express's haegeum was created to be an electronic instrument. Without the need for any acoustic sound or resonant qualities, the soundbox of the instrument was re-configured to primary holding the string tension and knee support. Replacing the cylinder resonator of a traditional haegeum, a downwards L-shaped base was created so the instrument could be held upright between the players legs while playing.

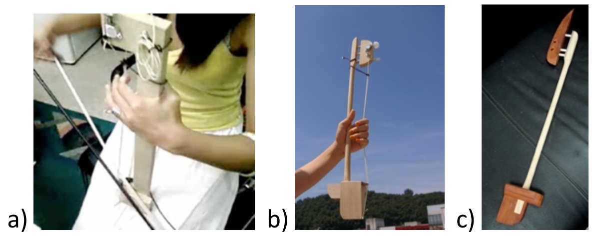


*Figure 111 Oriental Express's Haegeum soundbox of iterations a), b), c)*

#### 3.4.1.5 Arang-e (2019) [26] [27]

The electrical haegeum Arang-e features a custom electrical soundbox insert module to amplify the instrument's acoustic sound. Several knobs and buttons on the external face of the insert was developed to easily control the volume and tone while playing. Due to the 9-volt battery a part of this insert module, the whole electrical system can be charged and run wirelessly. The only wired connection needed for the instrument is to the speakers or amplifier[109].


*Figure 112 Arang-e's soundbox insert module*

The resonator the insert is housed in is also different from the traditional haegeum. With the addition of electrical components to the instrument, the issue of a floating ground became a problem. However, by using a 3D-printed carbon fiber soundbox, it can absorb the floating ground and reduce unwanted electrical noise [31].

*Figure 113 Arang-e's alternative resonator and soundboard materials*

Another material that differs the Arang-e to its traditional counterpart is the type of wood for its soundboard. Instead of the traditional paulownia wood, a material that has poor

[109] For ease of access, the case that comes with the Arang-e features a built-in amplifier the instrument can be plugged into. The case needs external power through a wall socket.

durability and uneven quality, spruce wood is favored. Spruce is commonly used in western instruments due to its uniform rings and consistent quality. By making this change, the Arang-e was able to naturally become louder and therefore assist with the amplification process.

#### 3.4.1.6 eHaegeum (2013) [22]

The eHaegeum, co-created by Ajay Kapur, Dae Hong Kim[110], Raakhi Kapur, and Kisoon Eom, was the first augmented haegeum ever created. This instrument was created to continue the traditional shape, configuration, and familiarity of the acoustical haegeum and its performer. This was achieved by installing all the electronics[111] in the small cavity of the haegeum's resonator. The eHaegeum utilized a traditional haegeum and added additional electronics and sensors to enhance the acoustic instrument.

*Figure 114 Augmented soundbox of the eHaegeum*

The eHaegeum implemented accelerometer sensors in the resonator in order map the movement of performer and instrument. A force-sensing resistor was fitted under the bridge to recognize the degree of pressure applied to the strings while playing ornamentations. Both the accelerometer and FSR connected to a computer program, via the Arduino, to control the live audio processing and effects. Additional buttons and switches were added to the top of the resonator for easy setting changes and triggers.

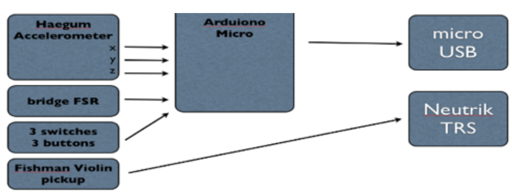



*Figure 115 Electrical component flow of the eHaegeum*

A Fishman Violin pickup was also embedded into the cavity of the resonator to amplify the acoustic sound and apply digital sound processing on the computer.

*Figure 116 Fishman Violin pickup*

Alongside the eHaegeum, the eJanggu was also created following the similar methods. Sensors, knobs, and buttons were embedded into the drum resonator of the Janggu[112]. Since this instrument's cavity is larger, it allowed for more embedded electronics and a larger

[110] Kim later developed another augmented haegeum project called the AirHaegeum in 2020.
[111] To fit all the electronics and sensor connections into the small cavity of the soundbox, an Arduino Micro controller board and two small custom shields for the sensors were used.
[112] The Janggu is a double-sided drum connected and used commonly in *gugak*. It is often considered as the key instrument of the ensemble and acts like the conductor by dictating the rhythm and speed of the pieces.

Arduino board[113]. Two IR sensors were also embedded into the instrument to track the movement of cross-hitting the drumheads.

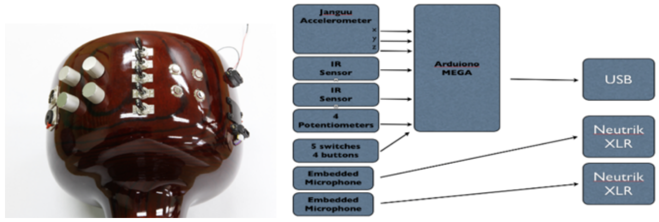


*Figure 117 eJanggu components and flow*

Unlike the pickup of the eHaegeum, the eJanggu utilizes a microphone in each cavity of the dual drumheads. To separate the sounds of created by each drumhead, a custom plug was created to be inserted in the middle of the instrument. Although it substantially effected the bass response of the drumheads, it was implemented into the eJanggu due to its ability to isolate the two sounds from each other.

### 3.4.2 Effects Controls with Knobs, Buttons and Sliders

#### 3.4.2.1 Overholt's Overtone Violin (2005) [30]

The Overtone Violin was created to maximize the violin's expressivity through both gestural and physical controls. Although the goal was to increase the control parameters of a violin performance, these controllers needed to be easily accessible and comfortable to use without any major technical changes to the traditional performance style. To achieve this, many of the main control parameters were imbedded into the scroll of the violin. This way, the left hand could quickly change the settings and control effects while still playing open strings.


*Figure 118 The top half of the Overtone Violin*

The front of the scroll of the Overtone Violin consisted of a 16-button matrix, a 2-channel sonar, and a mini video camera. While each of the 16-button matrix controlled programable effects, the 2-channel sonar was used to detect the distance between the violin and a solid object. This could be the closes wall, large object, or audience member. The mini camera was implemented to allow for a visual aspect to the performance. The images from the mini camera were taken, manipulated, and projected as part of the performance system. On the backside of the scroll, 2 linear potentiometer, 1 joystick, and a 2D accelerometer were housed.

[113] A bigger microcontroller board allows for more options such as analog-to-digital conversions and digital pins that allow output control as well as input data from sensors and mechanical elements.

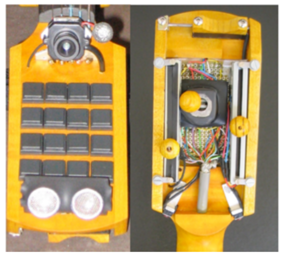


*Figure 119 The front and back of the Overtone Violin scroll*

#### 3.4.2.2 Goto's Superpolm (1996) [42]

The 8-button module on the bottom right side of the Superpolm is positioned in the most favorable and accessible spot of the instrument. These buttons are pre-programed to perform program changes, trigger pitches and sounds, and as well control visuals included in the performance. On this instrument, the buttons are to be controlled by the bow (right) hand. With the button module being right under where the bow is played, the performer can quickly trigger new buttons before starting their downbow stroke.

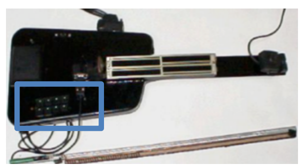


*Figure 120 Superpolm button module*

#### 3.4.2.3 Ulfarsson's Halldorophone (2008~) [29]

The four-slider module of the Halldorophone is used to control the mix of the pickup signal before it is sent to the embedded 50w amp and speaker cone. By having control of the mix, the feedback loop system can be somewhat manipulated. Each one of these sliders controls the velocity levels of the four playable strings. By raising or lowering these sliders, the player can control the range of the feedback actuation. The slider module is positioned on the right-hand side of the instrument to be controlled by the right hand. On Halldorophone, it is not crucial for the bow (right hand) to be constantly played. Due to its feedback actuation of both the playable strings and sympathetic strings, the instrument is continuously triggering new string vibrations on its own. This leaves the right-hand occasionally free to constant control of the sliders.

*Figure 121 Halldorophone slider module*

#### 3.4.2.4 Melbye's feedback bass (2020) [49]

Much like Ulfarsson's Halldorophone, this instrument uses a very similar feedback loop system. With the embedded amp and speaker cone, the player can re-vibrate the entire double bass along with the traditional physical excitation of the bow. Melbye's feedback bass also feature a four-slider control module on the top-right hand of the instrument. These four sliders control the volume of the four individual strings. On the side of the module other knobs and buttons were added to control additional DSP mappings. Like the Halldorophone, the placement of the slider module was selected for its quick accessibility with the bowing (right) hand.

*Figure 122 Melbye's slider module*

#### 3.4.2.5 Eldridge's feedback cello (2017) [50]

Although the Eldridge feedback cello follow a similar system as Ulfarsson and Melbye, this instrument does not feature a physical slider module. The design of this instrument was so that a portion of the components be removable from the instrument. This was to allow the instrument to also be used in more traditional, non-feedback loop performances. Instead of implementing an embedded slider control module, the player can control the individual volume of the strings through a commercial analogue mixer or pedal system.

### 3.4.3 Audio Feedback Loop

Through embedding both the audio input and output directly onto the soundbox surface of an instrument, this causes the audio phenomenon called feedback loops.

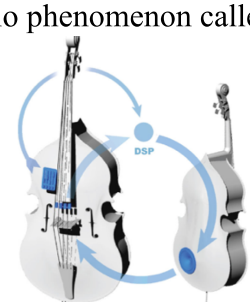



*Figure 123 Instrumental feedback loop diagram*

Audio feedback occurs when the sound picked up by the microphone or audio input is passed to the speaker and re-directed back to the microphone creating a sustained repeating signal flow. This is also referred to as a positive feedback loop.

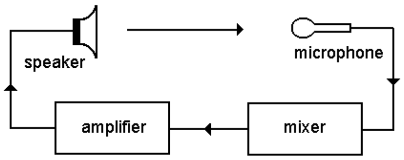


*Figure 124 Positive audio feedback loop diagram*

The speakers[114] or tactile sound transducers[115] embedded on the main body of the instrument re-project the acoustic sounds absorbed by the pickup at the same time the physically triggered sounds are projected. This allows for a "conversational interaction" with the physically actuated sounds and feedback sounds. With instruments that apply this feedback loop system, players trigger the initial sounds to start off the feedback loop and mainly experiment with the volume of the individual strings. Eventually the feedback loop spins out of control and becomes too complex to control. It is the player's job to find "the balance point between stability and extreme turbulence". [29]

#### 3.4.3.1 Ulfarsson's Halldorophone (2008~) [29]

On the 2014 version of the Halldorophone, the feedback loop system was first executed. The system takes the string vibrations from the electromagnetic pickup, goes through the slider module for volume mixing, then is sent to a 50-watt amplifier that was also embedded to the instrument. The signal flow is then finally sent to the midrange speaker cone positioned on the backside of the Halldorophone. From there the audio projected from the speaker is redirected into the soundbox and consequently back to the pickups, creating the analogue feedback loop.

#### 3.4.3.2 Overholt's Overtone Fiddle (2011) [48]

The Overtone Fiddle is the updated project of the Overtone Violin. Although the Overtone Violin is entirely electronic, the Overtone Fiddle uses both the acoustic resonant stimulation of the string and two mounted tactile sound transducers.

The two tactile sound transducers are positioned inside the external soundbox and internal soundbox. Inside each of soundboxes, a voice-coil type tactile sound transducer is installed on to its surface. These transducers create mechanical vibrations that re-excites the soundbox, bridge, and strings. They are independently powered using a 11.1-volt Li-Ion battery-powered Class-Y.


*Figure 125 Overtone Fiddle's transducer*

[114] Converts electrical energy to mechanical energy. A motor vibrates the diaphragm of speaker that in turn vibrates the air surrounding it.
[115] Converts audio signal energy to mechanical energy (vibrations).

#### 3.4.3.3 Eldridge's feedback cello (2017) [50]

Eldridge's feedback cello uses both the acoustical and mechanical feedback loop actuation system. Like the Ulfarsson and Melbye, it has an embedded 50-watt amplifier and speaker cone in the back of the instrument. However, like Overholt, it also has a tactile vibrational transducer braced to the front of the instrument. By combining the two feedback loop systems, this augmented cello can produce self-resonating behaviors along with an analogue audio feedback system.

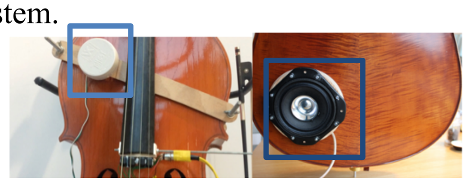


*Figure 126 Eldridge's transducer and speaker system*

The signals from the individual electromagnetic pickups are mixed then sent to a 50-watt pre-amplifier to boost the volume of the absorbed sound without increasing the noise. From the pre-amp, the signal is sent to the built-in speaker positioned on the back panel of the instrument's soundbox as well as the vibrational transducer braced to the front. The signal and vibrations re-projected back the instrument's soundbox, bridge and strings flow back and re-absorbed by the pickups.

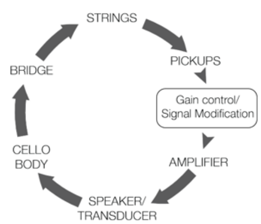



*Figure 127 Eldridge's feedback signal flow*

#### 3.4.3.4 Melbye's feedback bass (2020) [49]

Melbye's feedback bass also features an analogue feedback loop system. The individual electromagnetic pickups are first sent to the pre-amplifier that is embedded into the instrument. The signal is then sent to the Bela microprocessor and connected with the audio processing software SuperCollider. In this program, sound processing is applied digitally and controlled via the slider module. After processing the sound, it re-projected back into the instrument through an amplifier and 150-watt mid-range speaker embedded in the bass.

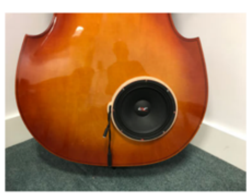


*Figure 128 Melbye's embedded speaker*

## 3.5 Bridge (*Wonsan*)

*Figure 129 Wonsan*

The bridge is commonly placed a third from the top of the soundboard. However, with the different location and placement of the bridge, the timbre and volume of the haegeum changes. Closer to the top of the soundboard, the sound becomes thinner, the resonance weaker and the volume produced becomes less prominent. The position of the bridge often depended on what piece and ensemble required of the haegeum. In accompaniment music and small ensembles, the haegeum was not required to have a loud, full resonant sound. Therefore, the bridge was suggested to be placed within the upper section of the soundboard. For solo and wind ensembles, where the haegeum held a more prominent melodic role, the bridge was often placed near the middle of the soundboard. It was not until the 1930s that the bridge position movement more frequently used. In some performances, the bridge was moved for each individual piece to adjust the timbre for that specific piece.

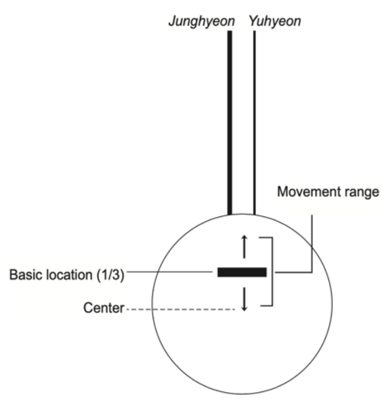



*Figure 130 Position of the bridge*

### 3.5.1 Magnetic Pickup System

A magnetic pickup system uses electromagnetism to transfer the played pitch of an instrument. By using coils, current and permanent magnets this system creates a voltage that is later sounded as a discernible pitch. The magnets created a constant magnetic field. With the vibration of the metal strings, this disrupts the field which in turn forces the coil to create an induction current at the same rate as the frequency of the string. Although a regular dynamic microphone uses a similar concept, in a magnetic pickup system, the magnetic field itself is altered rather than the coil. [52]

#### 3.5.1.1 Ulfarsson's Halldorophone (2008~) [29]

Instruments that use the magnetic pickup system require the strings to have a ferromagnetic core to alter the magnetic field fluctuation. The popular strings experimented in the Halldorophone were the Helicore strings and Prelude cello strings for the playable strings and common electric guitar strings for the sympathetic strings. With a uniform frequency response of 20Hz to 20Khz, the absorbed sound is clean and includes many overtones.

For a multichannel control of the instrument, each string is equipped with a single electromagnetic pickup module by Cycfi. The Nu Capsule Modular Active pickups[116] uses low impedance coils, permalloy ring shields to minimize the noise-to-sound ratio of acoustic sound.

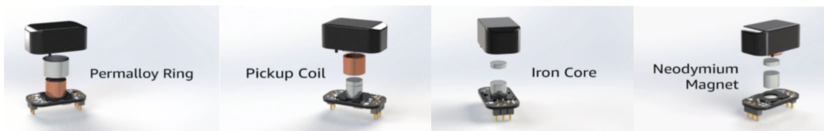



Figure 131Components of the Nu Capsule

On the Halldorophone, eight Nu Capsules are positioned near each of the individual strings of the instrument. Four of the pickups are embedded into the end of the fingerboard to absorb the vibrations of the playable strings. The pickups for the sympathetic strings are positioned closer to the soundbox.

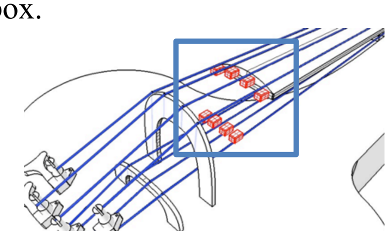


Figure 132 Halldorophone's magnetic pickups

#### 3.5.1.2 Eldridge's feedback cello (2017) [50]

Eldridge's feedback cello custom 3D-printed a clampable and removable mount for its Nu Capsule module. This clamping component is made to be adjusted under the strings and onto the end of the fingerboard. The four strings of the cello, there are four individual Nu Capsule pickup.

Figure 133 Eldridge's magnetic pickups

[116] Cycfi's Nu Capsule Modular Active pickups found here: https://www.cycfi.com/product/nu-capsule-4-pack/]

#### 3.5.1.3 Melbye's feedback bass (2020) [49]

Melbye's pickups also utilized the flexibility and simplicity of the commercial Nu Capsules. The four individual pickups allowed for four audio channels but caused a bigger CPU strain for the single Bela board used for this instrument. The pickups were separately powered by a 9-volt battery from the rest of the electrical components to reduce the system noise to be absorbed. As an extra precaution, shielded cables were also used to further reduce noise.

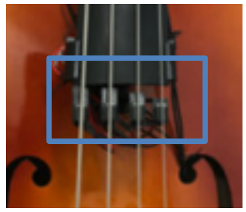


*Figure 134 Melbye's magnetic pickups*

#### 3.5.1.4 Schoner's cluster-weighted sampling (2000) [36]

Schoner's violin also used magnetic pickups to absorb the acoustical sounds produced by this augmented instrument. The pickup was placed under the string to induce the voltage of the vibrating strings. Like the other uses of the magnetic pickup, this system allowed for a reduced absorption of noise produced by metallic string vibrations and the intricate electrical components.

#### 3.5.1.5 Overholt's Overtone Fiddle (2011) [48]

The Overtone Fiddle uses the magnetic pickup system that is custom embedded to the end of the fingerboard. The magnetic pickup system was chosen due to its ability to focus and limit the absorption of sound to the vibrations of the strings rather than the acoustic whole body. With the commercially available magnetic pickups, the custom Overtone Violin's optical pickup was not necessary.

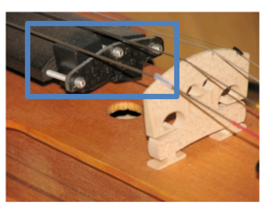


*Figure 135 Overtone Fiddle's magnetic pickup*

### 3.5.2 Optical Pickup System

#### 3.5.2.1 Overholt's Overtone Violin (2005) [30]

For the first iteration of the Overtone project series, the Overtone Violin built a custom printed PCB board pickup made of an epoxy fiberglass laminate. This PCB board consisted of six IR LEDs and six IR photodiodes that were carefully positioned to sandwich each of the six strings of this instrument. As the IR LEDs projected a directed light source to the photodiodes, the movement of the strings created a moving shadow that represented the vibration and in turn frequency of the played string. Aside from being used as the pickup system, the PCB board was also doubled as the bridge of the instrument. Small hole between the sandwiched IR LEDs and IR photodiodes allowed the strings to be vertically threaded through the PCB board directly. This component needed to be stable enough to withstand both the vibrations of the six strings and securely hold all the electrical components in place.

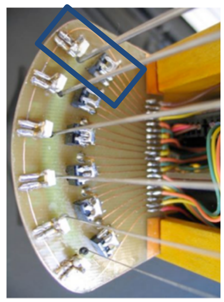


*Figure 136 Overtone Violin's optical pickup*

### 3.5.3 Piezoelectric Transducer Pickup System

Piezoelectric transducer, also referred to as a piezoelectric sensor, pickup system uses the piezoelectric effect to detect the voltage of vibrations created when playing an instrument. This pickups system works with the amount of pressure that is pressed or squeezed due to the motion of the sound vibration[117]. This motion creates an electrical current which is symmetrical to the frequency of the note played. This physical sound frequency is then converted into electrical signal and amplified to create a larger sound. Due to the extreme sensitivity of this system, the raw voltage produced is quite low and requires to be boosted with a pre-amplifier module. Since the piezoelectric pickup works within a certain constraint of minimum and maximum detectable vibrations, the raw sound tends to be either too soft or too loud. Only through the pre-amplifier, the sound can be adjusted to the adequate levels.

On stringed instruments, the piezo pickups are often sandwiched between the bridge and the top panel. As the bridge absorbs the vibration of the strings, it can transfer that energy to the pickup pressing and releasing the pressure. Some claim since the piezo pickups buffer the top of the instruments, it decreases the vibrations transferred to the top resonance. However, this may be important for fully acoustic instruments which rely on the resonance of the soundbox, the placement of the piezo does not affect the absorption and amplification of the sound.

[117] The term 'piezo' derives from the Greek word 'piezein' meaning to press or squeeze.

#### 3.5.3.1 Oriental Express's iJanggu (2005) [30]

Oriental Express's iJanggu[118] took another approach by creating an augmented Janggu attaching piezoelectric ceramic transducer disk sensors to each of the drumheads. Once the drumheads are hit, the piezoelectric sensors calculate the degree of change on the surface vibration it is placed on. This frequency is then translated into an electrical signal the computer can understand and process. With this input data, specific or ranges of values can be mapped or translated into digital sound or visual effects.

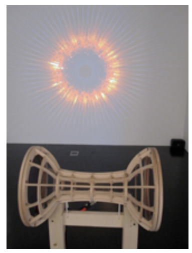


*Figure 137 iJanngu triggering visual output*

Since the iJanggu does not require any acoustical sound production to be played, this instrument opted for a transparent and barebones structure of the traditionally wooden Janngu shape. The material of the drumheads was also changed from the traditional stretched animal leather to coated plastic drumheads. As the timbre of the natural leather did not affect the sound production, it was replaced with a more structurally appropriate and less complex material.

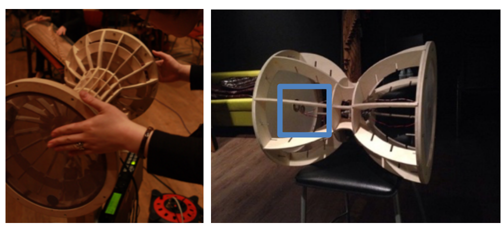


*Figure 138 iJanggu's barebone structure, coated drumhead, and Piezo sensors*

#### 3.5.3.2 Oriental Express's Haegeum (2009) [18]

Oriental Express's electronic haegeum projects[119] also introduced a barebone structured haegeum with a piezoelectric transducer used as a contact microphone input. To allow for the maximum frequency pickup, the disk is glued directly onto the bridge of the instrument. This system allows for this minimalistic instrument to be played with common haegeum techniques as well as other enhancements such as pizzicato and digital audio effects. A ¼ inch female jack is also added to the simple frame of the haegeum to connect to the audio speakers.

[118] iJanggu performance video: https://youtu.be/_F7o4LFW6xg

[119] Two electronic haegeums projects were explored, a normal haegeum and bass-haegeum. Both followed similar processes the only difference is the size of the instrument.

Electronic Haegeum: https://youtu.be/DldxHjzmZQQ    Electronic Bass-haegeum: https://youtu.be/Kxp_GG76rFU

*Figure 139 Iteration 3 of the electric haegeum and bass electric haegeum*

#### 3.5.3.3 Scrapwood City's violin [53]

In Scrapwood City's single stringed piezoelectric violin project, a circular divot is carved under placement of the bridge. This divot is just large enough to fit a single piezoelectric disk and a small hole is drilled in the center to thread the required wires to the back of the instrument.

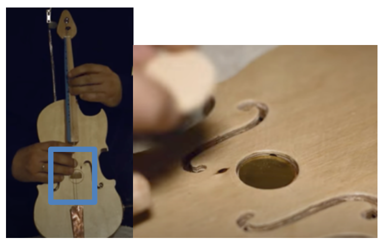


*Figure 140 Example placement of the piezo pickup*

A thin piece of wood is manufactured to cover and sandwich the piezoelectric disk. The bridge is then placed on top of this wood base for the string to be supported on. In this project, the piezoelectric disk is directly connected to a ¼ inch TRS jack to be externally connected to a pre-amplifier and speaker.

## 3.6 Bow (*Hwal*)

*Figure 141 wonsan*

The bow for the haegeum is traditionally made with bamboo and the original shape of the bow reflects how the bamboo grows. The shape of the tip of the bow with the thinning of the diameter of the bow stick (*hwaldae)* carried on to modern day bow designs. Due to the imperfect and wasteful method of selecting bamboo stalks that had the correct node spots[120],

[120] Determined how balanced the bow is. Refer to section 2.3.4

there are more wooden and carbon fiber bow being produced. However, many professional still prefer well-made bamboo bows. The adjustable leather strap connects the bow stick and the horsehair (*malchong*). The bow hair of a haegeum is around 55-65cm in length and, like all haired bows, must be rosined. Because the bow hair is threaded between the strings and requires both sides of the bow hair, both sides must be rosined.

The haegeum bow moves horizontally across the body and the strings. By ‘pulling’ the bow, moving left-to-right, the haegeum produces a stronger sound. ‘Pushing’ the bow moves the bow right-to-left and the sound naturally becomes weaker as it moves away from the hand grip.

| Pulling bow | Pushing bow |
|---|---|
| — | + |
| \| | — |
| ⊓ | ∨ |
| → | ← |

*Figure 142 Symbols used to represent the direction of the bow movement on scores*

Since the haegeum bow is not tightened or fastened[121], it is quite hard to maintain a smooth constant tone. By controlling the bowing speed, position, pressure, contact point and angle of the bow, the player can express breathing, emotions, and dynamics freely.

### 3.6.1 Sensor-embedded Bows

#### 3.6.1.1 Grosshauser’s bow (2008) [54]

Grosshauser’s bow features a high sensitivity, low weight, and cheap standalone system for educational bow gesture tracking. By using 1mm thick pressure sensors sticked onto the fingers, the system converts the amount of pressure for each individual finger to a visualization tool. With a PD and MaxMsp visualization tool, the ball object reacted to the amount of pressure by changing its colour and shape. Excessive pressure resulting the program to sound warning to the user.

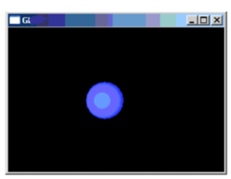


*Figure 143 Grosshauser’s pressure visualization tool*

Since this system is very flexible with removeable sensors, the user can customize the number of connections. This also means that this sensor is not for everyday use. It was designed to be used to recognize practice mistakes such as stiffness, muscle cramping, incorrect positioning and overpressure of the bow, shoulder, and chin rest.

The 16-channel programable convertor box strapped onto the players wrist held most of the electrical components required to operate the sensors. Each sensor used had its own standard stereo jack for output allowing for multichannel control data channels.

[121] Refer to section 2.3.1

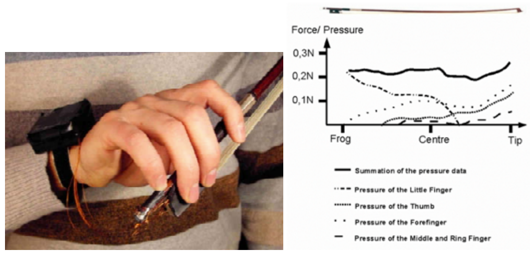



*Figure 144 Grosshauser's bow tracking*

#### 3.6.1.2 Overholt's Overtone Fiddle (2011) [48]

To accommodate for the added mass of the sensor and need to properly balance the bow, the Overtone Fiddle's bow is made from a longer carbon-fiber rod. This bow can detect the gestural movements through an absolute orientation sensor embedded onto the bow. Also, with the WiFly, a wireless radio module[122], the absolute orientation sensor data can be communicated wirelessly to the computer via UDP and OSC. These two components are being controlled by a CUI32, a battery-powered sensor circuit.

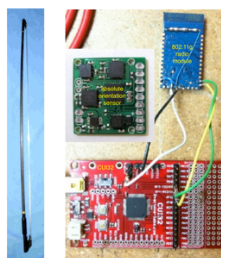


*Figure 145 Overtone Fiddle's bow and components*

#### 3.6.1.3 Overholt's Overtone Violin (2005) [30]

The Overtone Violin featured a normal traditional bow but to include right hand gestural information to the system, a fingerless nylon glove with embedded sensors was worn by the performer. With a small circuit sewn into the fabric of the glove, an accelerometer sensor[123] and sonar transducer were added. The accelerometer sensor could detect the acceleration of movement of the bow as well as the tilt of the bow on the x and y axis. With the sonar receiver placed on the violin body, the sonar transducer added to the glove could capture the absolute movement between the bow hand and the rest of the instrument. This data represented the linear bow position[124] compared to the stationary violin.

[122] Allows the data to be broadcasted on its own 'AdHoc' 802.11 base station. This receives and send data wirelessly
[123] Analog Devices ADXL-203
[124] Whether it was near the frog or tip.


*Figure 146 Overtone Violin's bow tracking glove*

#### 3.6.1.4 eHaegeum (2013) [22]

In between the leather strap of the eHaegeum bow, an accelerometer sensor was imbedded to track the bow and arm motion of the performer. This sensor tracked the X, Y, and Z axis of the bow and was used to control effects during performance. The eHaegeum bow was connected to the Arduino board inside the soundbox with a long JST connector[125].

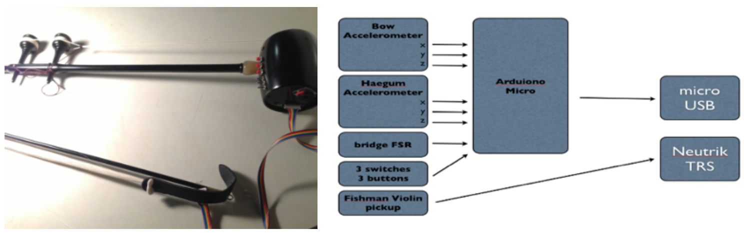



*Figure 147 eHaegeum bow*

#### 3.6.1.5 Embroidered resistive pressure sensors [51]

This paper addresses a method to implement pressure sensor patches directly on top of existing fabrics by using an embroidery technique that interlocks the upper and lower (bobbin) thread called Lockstitch. Like an FSR, this system uses the application of pressure to weaken the electrical resistance of the conductive thread.

Constructed of five layers, this sensor can detect pressure when applied to the stitches. The base material is the material of the object's surface. This should be made of a dense fabric that does not warp or twill when the stitches are placed.

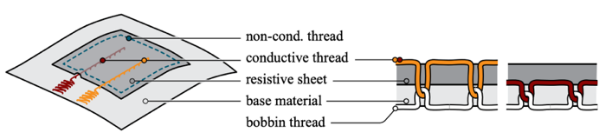



*Figure 148 Layers of embroidered FSR sensor*

On this base material, a vertical stitch pattern is embroidered into the fabric using a conductive thread. A resistive fabric is placed on top, and another stitch pattern is embroidered horizontally. These two lines of stitching is then connected to the ground and power of electrical component.

[125] The JST connector was used so it could be easily detached from the soundbox while stored.

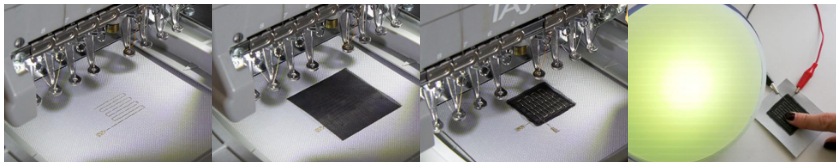


*Figure 149 Process of embroidering a FSR sensor*

The resistive fabric in this case acts as the spacer between the two conductive stitches. Since the bottom bobbin stitches are embroidered with a non-conductive thread, this component is used to securely attach the top conductive thread and does not affect the sensing aspect. When pressure is applied, the top conductive thread (orange) is pushed closer to the bottom conductive layer (red) and therefore strengthen the contact of the two connections.

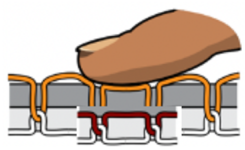


*Figure 150 Embroidered FSR pressure applied*

This paper also explores the variables such as stitch length, conductive thread placements, intersections and patterns that may alter the output of the sensors.

*Figure 151 Embroidered FSR patterns*

#### 3.6.1.6 McMillen's bow (2008) [55]

The K-bow is another example of a gestural violin bow. It consists of a Kevlar and carbon graphite material bow stick and specially designed custom frog that houses all the electrical components. To counterbalance the weight of the additional electronic components, this specific composite material bow was created.

On the bow stick, the rubber grip is substituted with a cylindrical pressure sensor. This is constructed of five layers of conductive materials. As pressure from the index finger is applied when bowing, the overall resistance of the sensor changes. The sensor data is then routed through a 12-bit ADC and transmitted to the host computer for data processing.

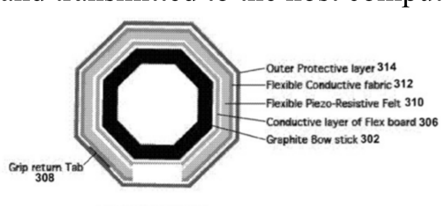



*Figure 152 McMillen's grip sensor*

Embedded inside the bow stick, is two loop antennas running down the full length of the bow. These antennas work with an emitter clipped under the fingerboard to create an RF field and an IR modulated wide field light cone is used to detect the bridge-to-fingerboard placement and bow twist angle.

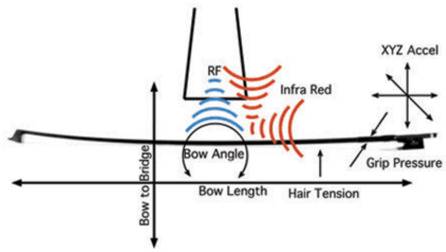



*Figure 153 McMillen's loop antennas*

The bow hair tension is measured by an angular measurement sensor attached to the hair and frog. Since the bow hair tension is manually tightened and loosened, this sensor requires some calibration. This system allows for easy setup. After tightening the bow, the player only needs to turn the power on, and the bow will auto calibrate its initial tension.

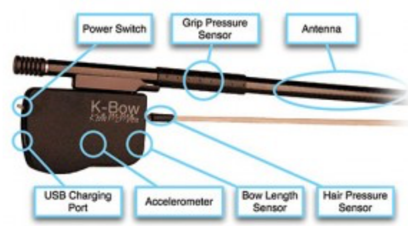



*Figure 154 McMillen's K-bow components*

Inside the custom frog, it holds most of the major sensor components of the bow. The frog itself is consisted of a circuit board with 20op amps, 2 CPU chips, a Bluetooth transceiver, a 3-axis accelerometer, a 6g lithium polymer battery and other power management systems. On the front of the frog, there is an IR photon detector that measures the bridge-to-frog distance. As the detector receives the mod signal from the array of LEDs under the fingerboard, the bow can the bow position and movement on the z-axis.


*Figure 155 McMillen's frog*

#### 3.6.1.7 Goto's Superpolm (1996) [42] [43]

Without the strings to play on and create friction against, the Superpolm bow is gesturally played in a traditional manner, it is physically different from traditional violin bows. The bow is used as a potentiometer than a string actuator. The bow itself consists of over hundred resistors positioned linearly on the length of the bow. When the bow encounters the custom metallic bridge fixed to the body, the output voltage is altered. This change in voltage occurs when the bow resistors change the resistance of the current produced by the electrified metallic bridge. Depending on the bow's contact point on the bridge, distinctive voltages represent specific points of the bow will be produced.

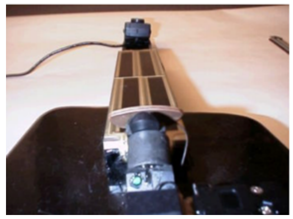


*Figure 156 Superpolm's electrified metal bridge*

Rather than the accelerometer sensor being placed on the bow, an Analog Device ADXL sensor is placed inside the soundbox of the Superpolm. As the player freely expresses their movements, the inclinations of the violin body control additional parameters of the performance.

#### 3.6.1.8 **Pardue's violin (2014) [33]**

The bow developed with Pardue's custom resistive position sensor violin used near-field optical sensors as a low-cost and accessible approach to bow tracking. This approach to bow tracking involved projecting a light source, such as an LED, at a reflective surface and measure the amount of light that bounced off the surface with a phototransistor or photodiode. [56] By placing four pairs of LEDs and phototransistors, the system was able to detect the inward pressure deflection of the bow hair. When pressure is applied on the bow hair, this forms a displacement triangle. Using the apex of the displacement triangle, the position and amount of pressure of the bow against the string can be measured.

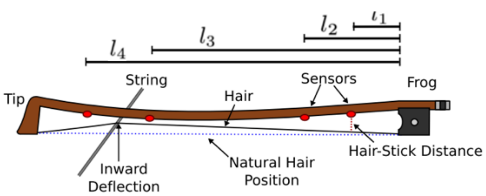



*Figure 157 Pardue's bow tracking system*

Simply put, the LEDs are projected to the bow hair (reflective surface) and the amount of reflected light the phototransistor picks up measures the distance between the bow hair and bow stick[126]. By having four sets of these sensors across the length of the bow allows for multiple points of detection. However, because the initial bow tension is not uniform every time the violin is played[127]. It is impossible to have the same or fixed measurement of the displacement triangle. As a result, Pardue wrote and utilized an equation that calculated the ratio between the initial set bow tension to the displacement triangle to accurately measure the pressure and position of the bow.

$$h_k(t) = \begin{cases} f_k(\tau(t), l(t), \rho(t)) & \text{for } l < l_k \\ g_k(\tau(t), l(t), \rho(t)) & \text{for } l \geq l_k \end{cases} \Bigg|_{k\in\{1,2,3,4\}}$$

*Figure 158 Equation to calculate ratio of setup bow tension and displacement triangle[128]*

[126] Although not approached in this paper, depending on the angle of the sensors attached to the bow, it is possible to measure bow tilt. [33]
[127] The bow is tightened by a screw near the end of the frog when playing increasing the tension of the bow hair. It is untightened after being played and packed away.
[128] [ t= tension; l= location where string touch bow; p= pressure of bow on string; t= point in time; hk= hair-stick distance; fk(below lk); gk(above lk)= continuous piecewise function with two pieces; k∈ 1…4= specific sensor on bow ]

Throughout the development of the bow, several reflective proximity sensors with photo transistor outputs were experimented. Commercial sensors such as the Fairchild QRE1113, Sharp GP2S700HCP, and the Avago HSDL9100 were tested but the final bow used the VCNL 8000 sensor.

*Figure 159 Pardue's iterations of bow sensors*

### 3.6.2 Electric Field Tracking

#### 3.6.2.1 Paradiso's bow (1996) [57]

Paradiso's project is one of the first wireless measurement system for augmented instruments. Experimentation of applying a similar system was made to fit both the cello and violin bows. Paradiso was very inspired by the Theremin. Although it is a very old instrument, he considers it the 'first truly responsive electric musical instrument that is capable of real-time control. This instrument uses simple capacitance measurement to sense the proximity of hands. Capacitance is the first non-contact interface that does not limit the musical interface. While sensors such as ultrasonic, motion sensors, photodiodes, photosensor arrays and video cameras have limited beamwidth, resolution, delay and many environmental deviations, capacitance solves many of these issues.

The RAAD cello, built for Richard Armin, included sensors that could detect its bow position and pressure. To measure the bow position, capacitive coupling was used to transfer sine-wave signals[129] from the 5cm tall antenna positioned near the bridge of the RAAD cello to the bow electrode[130]. This bow electrode was made from a 5mm resistive thermoplastic with copper tape at each end. The data from the resistive strip was transferred through a 47mm flexible coaxial cable[131] to the host computer for minimum electrical noise transfer. The bow pressure was measured through a custom thin elastic capacitor made from 35mil urethane material[132].

[129] About 100khz and 20v peak amplitude was transmitted from the antenna.
[130] An electrode is an electrical conductor that connects nonmetallic circuit parts.
[131] A coaxial cable is a cable with insulations and conductive shields for minimal electrical noise produced by the cable.
[132] Also called "poron" foam with modulus.

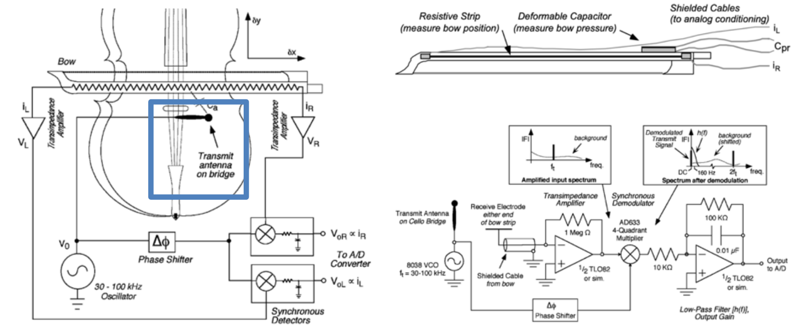


Figure 160 Paradiso's cello bow

Unlike the stationary nature of the cello, the violin needs to have more flexibility in movement and playing space. Therefore, the wired cello bow system cannot be directly replicated for the violin bow. For Paradiso's violin bow, it used similar components of the cello bow but in different placements. Instead of the antenna transmitting a signal and receiving it in the bow, the system was reversed for the violin bow. Two CMOS555 Timer, a low-power oscillator, sat on each end of the violin bow producing two different frequencies[133]. These two oscillators were connected by a resistive strip that acted as a voltage divider. The lateral movements of the bow were measured by the strength ratio of the two frequencies that was being received by the antenna. [134]

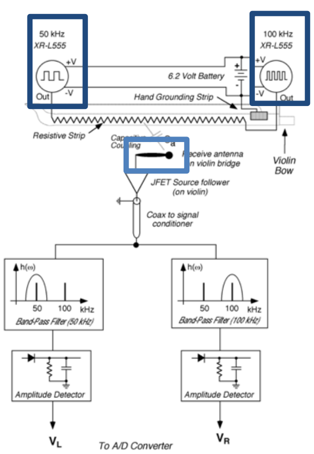


Figure 161 Paradiso's violin bow

For measuring the bow pressure of the violin bow, a third CMOS555 oscillating at 25Khz was used. A piezoresistive strip attached to the bow under the index finger of the bow (right) hand controlled the oscillator's frequency with the amount of pressure applied. This sensor acted like a resistive divider for the CMOS. All three CMOS555 oscillators were powered with a 6-volt battery positioned on the frog. Due to the lack of technology, all batteries available during the time of the project were quite large and heavy. And unfortunately, the weight of the battery did modify playing technique.

[133] The tip produced a oscillation/frequency of 50Khz while the frog produced 100Khz.
[134] To prevent any accidental electrical shock from the oscillators, both the performers right hand and chin rest were grounded with insulated electrodes. This uses the process called Intra-body signaling.

#### 3.6.2.2 Schoner's cluster-weighted sampling (2000) [36]

On Schoner's augmented violin, to measure the bow position compared to the stationary strings, two oscillators were used at the tip and frog of the bow. The tip of the bow sent a 35Khz frequency down the resistive strip attached to the bow stick while the frog sent a 25Khz frequency. By calculating a ratio of these two frequencies, the antenna positioned on the bridge was able to determine the bow's contact point on the string. Another oscillating signal at the frequency of 49Khz was sent down a single wire placed amongst the bow hair. This signal ratio was also received by the same bridge antenna and represented the bow's distance from the bridge. A pressure sensor was placed where the index finder is often positioned. This data was transmitted through a FM-carrier at 68Khz.

#### 3.6.2.3 Young's Hyperbow Controller (2002)

The Hyperbow gestural controller has many iterations and experimented prototypes. Although each of these versions of the project used alternate designs and materials, they all had similar electronical components. With the use of 3D acceleration, 2D bow force, 3D angular velocity, the six degrees of freedom were able to be measured by the bow. By utilizing electrical field position sensing techniques, the bow was wireless and free from movement limitations. [58]

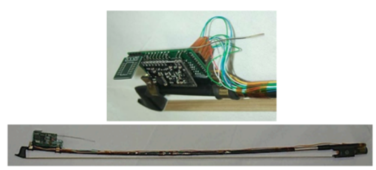


*Figure 162 Hyperbow's second protoype*

*Figure 163 Hyperbbow's thrid and final prototype*

The Hyperbow developed by Young follows a similar system as Paradiso. The position data of the bow is collected by sending two square wave signals from the tip and frog of the bow. These oscillators are connected by a resistive strip the length of the bow and the ratio of the two frequencies are gathered wirelessly by the antenna mounted on the tailpiece and extended closed to the bridge. The frog of the bow houses the microcontroller, two 2-axis accelerometer and RF transmitter to measure additional bow movements. [59]

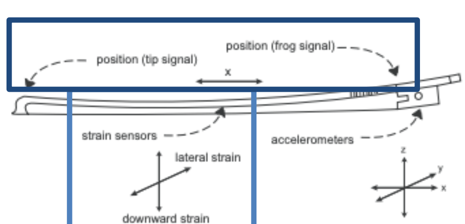



*Figure 164 Hyperbow bow tracking system*

The pressure applied to the bow is measured by two foil strain gauges mounted on the middle of the bow stick. The downward strain, positioned under the bow stick and parallel to the bow hair, is intended to measure the downward bending of the flexible bow stick. The lateral strain measures the pressure applied to the sides of bow stick. A Wheatstone circuit is used to measure the displacement of the fluctuating resistor. [59]

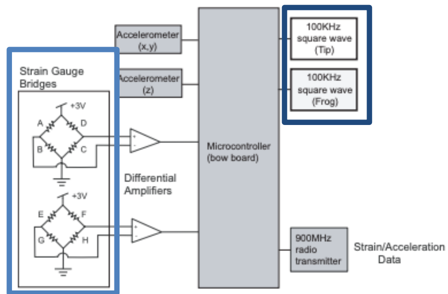


*Figure 165 Hyperbow's circuit*

As a part of the Hyperbow interface featured a web-accessible archive of violin bow stroke data. This database was created to take the sensor data from the physical Hyperbow and record its data to be accessible for everyone to compare and add their own datasets. A web-based database[135] was approached to allow for easy comparison of datasets when working on collaborations and other research projects. It would also benefit other researchers who wish to study bowed string synthesis acoustics, and technical study of performance practice.

Through a PureData patch, the sensor data from the Hyperbow and an audio recording was visualized and analyzed. [60]

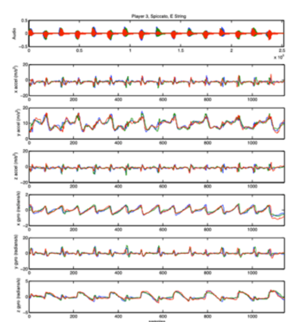


*Figure 166 Hyperbow's gestural database visualization*

#### 3.6.2.4 Bevilacqua's violin (2006) [61]

Bevilacqua's violin has both a physical and software element to its bow position and pressure tracking. On this wireless bow module, it holds a Ethersense daughter board, a PCB, a microcontroller, two ADXL202 accelerometer sensors, a digital radio transmitter, and a cell battery. The first prototype was quite cumbersome due the thickness of the radio transmitter and placement of the cell battery. However, with the updated design and parts, the second prototype was less uncomfortable for the player.

[135] Notable past databases are the Rutgers MCL Interaction Capture Repository and the CMU Graphics Lab Motion Capture Database.

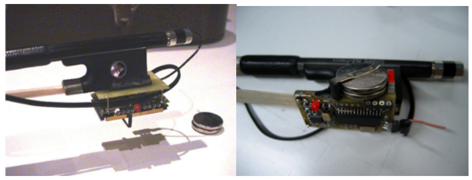


Figure 167 Bevilacqua's bow module (version 1) (version 2)

The bow position system is very similar to Paradiso. With two different frequency signals being emitted from the tip and frog of the bow, the capacitive coupling place positioned near the bridge collects the ratio of the two signals. In this project, the resistive strip is made from two layers[136] of S-VHS tape glued together. Although used in the final version of this project, Bevilacqua details some limitations of this system. The two signals do not cover enough of the bow to pick up smaller and delicate motions. The bow's extremities are neglected due to the reach of these two sensors and the right hand of the player often impedes the signals by defecting or absorbing the transmitting signals. The limitation to bow angles and performance techniques allow need to be addressed.

Figure 168 Bevilacqua's bow position antenna

Along with the physical alteration to the violin, a software-based recognition system was developed to detect bowing styles received from the sensors. This recognition system records the maximum ($a_{max}$) and minimum ($a_{min}$) absolute value of the acceleration data. With the peak and trough levels, the different strokes[137] are categorized using a K-nearest-neighbor (Knn) algorithm. Later, these cluster of different strokes and categories are used to control additional sound processing.

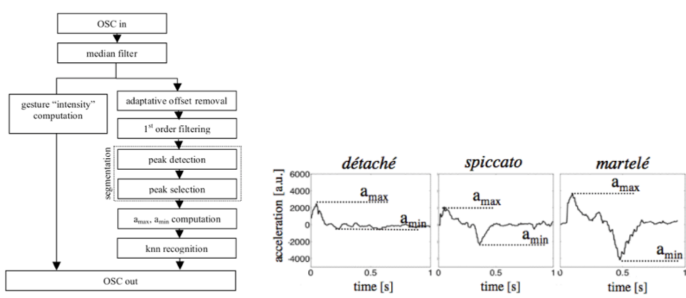



Figure 169 Bevilacqua's stroke classification system

#### 3.6.2.5 Askenfelt's bow (1988) [62]

Askenfelt's bow measures bow motion and force with custom thin resistor wire placed among the rest of the bow hairs. This wire is placed closer to the fingerboard facing edge of

[136] Two layers of the tape is used to protect the resistive side of the tape and increase the overall resistance of the tape to a more adequate range.

[137] For faster strokes, when peak labeling is deemed unreliable, the system compares the classification with audio data.

the bow hair. Since most players tilt the bow inwards, the placement of the wire was determined for the best constant contact with the electrified strings. Aside from bow force, which is measured by four strain gauges[138] glued to metal strips at both ends of the bow hair, the rest of the measured parameters are measured by the resistor wire.

This project uses the Wheatstone Bridge circuit to calculate the output voltage of the resistor wire. To calculate output voltage of the circuit $(V_G)$, the resistance of the unknown resistor $(R_x)$ must be calculated from the three known resistors. The voltage of the left and right pairs of resistors are calculated separately and subtracted from each other to solve for the final output voltage.

$$R_x = \frac{R_2 \times R_3}{R_1}$$

$$V_{left} = \frac{R_1}{(R_1 + R_2)}$$

$$V_{right} = \frac{R_x}{(R_x + R_3)}$$

$$V_G = V_{left} - V_{right}$$

*Figure 170 Equations for solving the output voltage*

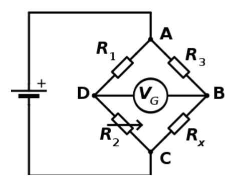



*Figure 171 The Wheatstone Bridge circuit*

For Askenfelt's violin, the lateral bow position and bridge-to-bow distance (BBD) uses two connected Wheatstone Bridge circuits. To measure the bow position, the resistive wire in the bow hair is used to calculate the Wheatstone circuit. The resistive wire already has two resistive values at each end of the wire omitting a voltage and completing one half of the circuit.

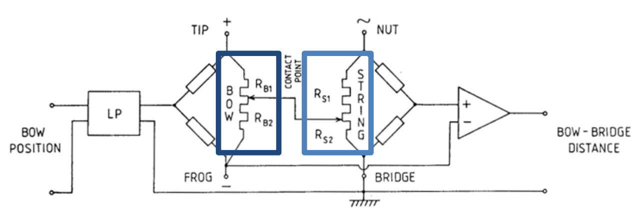



*Figure 172 Askenfelt's resistive bow position and pressure circuit*

The missing half of the circuit is determined by the resistances of the two wire sections. When the bow hair and resistive wire contacts the electricized string at a certain point of the bow, this divides the length of the wire into two sections. The distance between tip and the contact point $(R_{B1})$ and the distance between the contact point and the frog $(R_{B2})$.

[138] The amount of bending of the metal strips is detected by the strain gauges. The amount of bending is caused by increased pressure of the bow and bow hair.

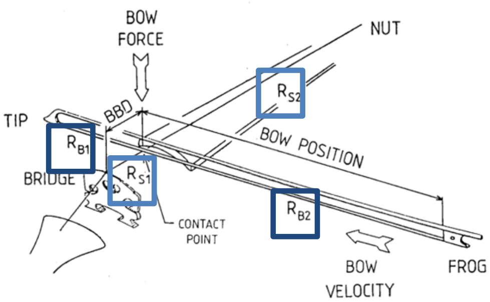



*Figure 173 Askenfelt's resistive bow position and pressure system*

The bridge-to-bow distance is calculated in the similar way as the bow position. However, instead of the dividing the resistive bow wire into two sections, it uses the string itself as an alternative resistive wire. The distance from the nut to the bow contact point ($R_{S2}$) fills one resistor leg of the missing half while the distance between contact point and bridge ($R_{S1}$) fills the other leg.

The bow velocity is calculated by the speed of the change of the bow position signal. The bow force also uses a separate Wheatstone Bridge circuit from the bow position and pressure to calculate the displacement of the strain gauges.

#### 3.6.2.6 Maestre's EMF bow tracking (2007) [63]

Maestre's violin bow gestural tracking system uses the Polhemus Liberty System, a 6-DOF sensor using electro-magnetic fields (EMF), positioned on the neck of the violin and bow. The Polhemus sensor module attached the bow is positioned at the bow's gravity center to minimize rearrangement of balance in the bow. The additional wires and electronics required for the sensor modules are strapped onto the forearm to allow undisturbed performance movements and habits.

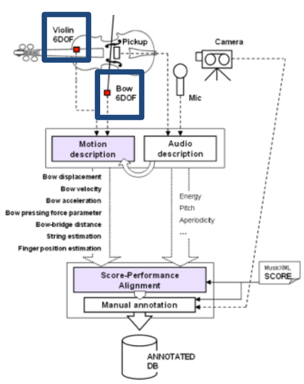



*Figure 174 Maestre's bow tracking system*

Along with the two Polhemus sensors, two audio sources from a microphone and pickup are used to assist in verify the sensor data. An additional video input is also used in Maestre's system. As optical tracking system on its own are not reliable for performances, the video component is being used as a secondary authentication and control parameter.

#### 3.6.2.7 Kim's AirHaegeum (2020) [37]

Taking a creative approach to the traditionally horse-haired wooden bow of the haegeum, the AirHaegeum created their own bowing apparatus. This flat, stone-like controller functions as a bow when playing[139]. Like a physical bow on a string, it actuates sounds and plays pitches received from the virtual laser string when moved horizontally. Since the AirHaegeum has only one virtual laser string, it is up to the bow to decide which of the two strings of the haegeum it triggers. Through sensors capable of detecting the tilt angle of the bow, the host computer can switch between triggering the inner or outer string pitches of a traditional haegeum. [64]

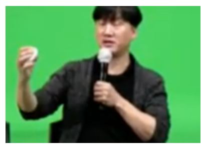
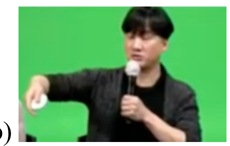
a)  b) 

*Figure 175 Airhaegeum bow tilt. a) inner string b) outer string*

The AirHaegeum bow also uses a pressure sensor and acceleration sensor to map the bow movement and force applied to the string[140]. When the performer moves their right hand holding onto the bow controller, the instrument's system can detect the motion in six degrees of freedom. The amount of pressure applied to the thumb controls the instruments volume. For flexible access to the 30mm diameter pressure sensor it is installed under a silicone top of the bow's external case.

*Figure 176 AirHaegeum bow's pressure sensor*

[139] With its 1000 mA lithium polymer battery and single chip radio transceiver, this bow is a completely wireless controller that connects and operates with the help of the host computer.
[140] The acceleration sensor used in this project is the 6DOF inertial: MPU6050 and the pressure sensor is the RA30p.

# Chapter 4

# Conclusion

This thesis comprehensively gathered and summarized the existing materials of Korean history, culture and *gugak* that are currently available. It narrated the journey the haegeum experienced through centuries of evolutions and developments. Looking back into the history, the concept of shamanistic beliefs from the Gojoseon period is still present in certain concepts such as *paleum* in the haegeum material make up. The belief that with the inclusion of all eight materials, the haegeum can produce all the sounds of the universe and bring the listeners closer to a flawlessly balanced nature is still considered while building the instrument. The intermixing and high influence of Chinese high and folk cultures held an important role in shaping *gugak* and its instruments from the earliest documented start. Through all the major wars and ruling power transfers, the adaptation of the music scene and practice created both new welcoming and unfortunate changes to the continuation of the music genre. As separate kingdom during The Three Kingdom, each section of the Korean peninsula held their own distinct musical practice and favored instruments but also participated in cultural transfers and absorbed musical practices and culture from neighboring states and countries. The merging of the kingdoms created many hybrid instruments unfortunately weaking the existing musical characteristics of the separate kingdoms but widening the reach of various techniques and practice throughout the peninsula.

As the country started relying less on foreign influences and creating their own cultural elements, such as the development of the Korean alphabet and governing systems, standardization of many elements of society were made. A more comprehensive notation system that could finally notate the characteristic unregular pitch, ornamentation and time values required in gugak was created with the new alphabet system. Specifically, in *gugak* during the Joseon period, the first standard tuning system for *a-ak* (Chinese-origin) instruments were implemented. Since all the instruments in the *a-ak* ensemble arrived in Korea over the time, they had contrasting systems tuning and performance. For these instruments to be played together concurrently, it was crucial to recalibrate to a standard tuning. With the rising economy of the country, more demand for instruments for both commoners and high-ranking aristocrats began the need for alternative material explorations. Materials readily available in the Korea were favored to create these new native instruments.

During the couple decades of the Late Joseon and Japanese Occupation period, many of Korea's cultural heritages and documentation were unfortunately lost. This gap in history resulted in many aspects of *gugak* to adapt with the remaining knowledge and artifacts. New ensembles, performance practices, music and iterations of instruments were created to continue traditions. As the lines between *dang-ak, a-ak,* and *hyang-ak* blurred exponentially during this time, more folk and aristocratic music were favored over ceremonial, ritual, or court music.

The haegeum before was consistently considered as a pauper's instrument due to its diverse timbre production and large range of emotions not suitable in court music. However now, like the *janggu* and its *jangdan*, the haegeum is rarely omitted from any ensemble and is considered crucial to the ensemble orchestration. The development in technology, available materials, tools, and experimentation also affected how today's traditional Korean instruments are constructed.

## 4.1 Previous Works Application to the Haegeum

The research referenced in chapter three of this thesis details the existing applications of technology available in today's context. Since many of the projects are directed towards western stringed instruments, not all previous augmentation designs will fit or apply to the haegeum's history, culture, tradition, practice, and performance techniques. There are several limitations and challenges these previous works can bring if directly applied to the haegeum. Through individually exploring and theoretically applying each augmentation concepts to the haegeum, it will be hugely advantageous to building a conscious augmented instrument.

#### 4.1.1.1 Tunning Pegs

Many of the referenced projects and works, mechanical pegs are often favored over friction-held wooden pegs. The ease and stability of mechanical gear tuners makes sense to implement onto the instrument. The traditional haegeum previously limited beginners and younger players due to the difficulty of constantly tuning the strings. This system also maintains the tuning while deep ornamentations much better compared to their wooden counterpart. Most all electronic and augmented haegeums referenced in this thesis utilize this system on their instruments. On a side note, many recently made traditional haegeums give the option of replacing the original wooden pegs to mechanical pegs.

In Ulfarsson's work, a whammy bar is designed and implemented on an augmented cello-like instrument. Due to the nature of the haegeum and its characteristic playing technique of ornamentation, applying a whammy bar would be interesting. Ornamentation on the haegeum is achieved by gripping the two strings and applying pressure in and out. However, for new players, the tension of the strings may make it hard to perform deep ornamentations. By having a component such as this that could easily bend the strings and pitches would benefit the instrument's audience. If applying the whammy bar, it would be imperative to carefully position it where it would be always accessible to control while playing. Unlike the cello, the ornamentation in *gugak* happens constantly and at various degrees. In the most traditional setting, the haegeum is played cross-legged on the ground, this limits the use of a pedal control. Also, given that both hands are already engaged with controlling notes and bowing, a natural implementation of this bar would be necessary if included on the augmented haegeum.

While ideating this thesis, the idea of creating a peg mechanism that would automatically tune the strings was examined. This would be a system of gears and step motors that could pitch detect the notes actuated in that moment and automatically re-tune the strings if the pitches fluctuated from the set tuning. It would compare the sounded pitches with the left thumb position on the neck via potentiometer. Since on the haegeum a single hand position can play up to two octaves, it would limit the range notes needed to be pitch detected and tuned. However, this system on its own would not be a conscious addition to this instrument. The first problem being that equal temperament tuning is a western music concept and has no importance in *gugak.* The need to westernize elements of a traditionally existing instrument does not align to the haegeum's unique characteristics. The question of what respecting the original instruments and making sure removing elements that causes it to lose its distinctive purpose is important here. With re-tuning every note that is not completely in tune also creates problems when playing ornamentations, quick bends, and general texture of the haegeum.

#### 4.1.1.2 Strings

The strings on the haegeum have the unique characteristic of bending notes when pulled inwards. With the abundant space between the silk-wounded strings and neck, the player has the option of adding various pitch elements and ornamentation to pieces. Effects such as playing high notes without moving the hand position or performing various depths and speeds of ornamentation are some of the possibilities. This characteristic of the haegeum initiated the idea of making the string itself a sensor. This way it could detects if further pressure has been applied. Pardue and Ko's approach of electrified strings and conductive traces on the fingerboard does not work on this instrument. Since the distance between neck and strings on the haegeum would never allow for these components to touch naturally.

A commercial rubber conductive sensor could be an easy option to implement. However, it does not comply with the haegeum concept of *paleum*[141]. According to this *gugak* concept, each material holds special importance to the whole instrument. therefore, replacing the silk strings with a rubber alternative would not have the same intention. To overcome this, conductive silk thread sensors were researched. While Ehrhardt's work allows the string to detect vibrations, it is not suitable for the needs of the haegeum. Composed of two layered braided metal, this approach is not flexible nor robust enough to withstand the tension of the haegeum's ornamentation practices. Honnet and Hwang's approach to chemically adding conductivity to the silk string material is much more in line with the instrument's characteristics and values. Specifically, Honnet's simple process of developing conductive sensing strings and fabrics through in-situ polymerization is the most accessible route to implementing this idea.

Kim's virtual laser string, although a very interesting and aesthetic approach, removes the tactile feeling of the physical string. Since this thesis's purpose is to build an augmented instrument that specifically enhance and evolve the original haegeum's qualities, it would be difficult to convince collaborators and trained haegeum players with the knowledge, background, and experience to use this instrument on a regular basis. By completely removing the strings, it leaves the instrument with a large open space. This may be appealing when attempting to creating new performance but seems too far from the original design and purpose of the haegeum.

[141] Although many aspects of the *paleum* is not as relevant today, this thesis strives to create the most authentic and culturally correct augmented haegeum. Crushed stone is no longer used when adjusting the sound and timbre of the soundbox. Due to the advancement of woodworking tool, makers can control the sound through carefully shaping the resonator itself. See section 2.3.4

#### 4.1.1.3 Neck

In the case of a linear potentiometer replacing the strings on a western instrument, the fingerboard is still present to support the tactile feel and initiate muscle memory. Goto and my previous work on completely string-less instruments explores the violin and cello as a MIDI controller than a sounding instrument. Although the strings are no longer present, the instrument shaped controller can still detect what note to actuate through the sensing of finger placements on the fingerboard. Grosshauser and Schoner takes a similar approach with linear potentiometer but places it between the strings and fingerboard. Linear potentiometers are a foolproof way of tracking hand or finger position on an instrument. In the case of the haegeum, because the large gap between the neck and strings, adding the potentiometer between the strings and neck had no value. Yet, since the left-thumb is situated to rest on the back of the neck, a potentiometer installed there could track the hand position and force pressure data accurately.

Although implementing Strohmeier's self-made kinesiology tape sensors could be valuable as a thin and detachable hand position tracker, the three or four layered tape potentiometers would be more favorable in terms of durableness and accountability. This approach to linear potentiometers and force-sensing resistors could be a noteworthy method of tracking the bodily gestures of the haegeum performer. While it is common practice for performers to sit cross-legged on the floor, this does not mean they are limited to performing completely stationarily. The haegeum being originally a *Minsok-ak* instrument, interprets many emotions while playing. In many cases, the performer follows the very important internal rhythm of the *jangdan* physically. This is seen through head, elbow, and waist movements by the performer. If Strohmeier's kinesiology tape sensors were to be applied to the major movement areas, the performer could be able to use natural emotive movements to control various programable effects.

#### 4.1.1.4 Soundbox

The soundbox forms a large portion of any acoustical instrument's shape, design, and appearance. It also heavily dictates what timbre of sound is being produced by the instrument. The choice in materials and physical dimensions heavily weigh the timbre of the overall instrument. Prototyping augmented instruments with 3D-printing is an understandable approach. For example, Yoo's Arang-e used the 3D-printing technology to create a carbon-fiber resonator. This material allowed the electric haegeum to become increasingly durable to humidity changes and in turn helped keep the string's tuning more constant. This material of resonator also absorbs the unwanted electrical sounds produced by the built-in electronics, amplifiers, and battery. As portrayed, there are many benefits to this approach. However, the Arang-e is an electric instrument and relies on amplification and filters to shape its timbre. To build an augmented instrument with both competent acoustic and electronic capabilities, this instrument requires the presence of a resonant cavity built with reliable materials. As seen in Ulfarsson's hyperinstrument, this work undoubtedly holds its own identity in terms of the shape and material of the soundbox. Noguera's laser cut electronic violin applies an interesting and accessible approach to creating a wooden violin frame.

The assorted options of physical programmable switches, buttons, sliders, and other controls elevate the augmented instrument's effects control. From the researched references, there were diverse approaches to successfully position these physical triggers that minimally limited the motion of the performer. Ulfarsson, Melbye and Eldridge achieved this by adding extending panels of controls while Overholt and Goto utilized the space available to them on the instrument. Considering the small structure of the haegeum, the original design of the instrument would not be able to support the space for multiple triggers. Nevertheless, modeling Overholt, the space between the two pegs could support a wireless control panel. This panel may be explored to be detachable and therefore also applicable for traditional acoustic haegeums. The eHaegeum and Arang-e are examples of electric instruments that does not depend on to acoustic resonator. Because of this, they can embed controls directly on the surface of the resonator shell while also storing all required electronics and boards inside the resonant cavity. However, striving for an all-inclusive augmented haegeum, filling this cavity does not benefit the sound production of the instrument. Be as that may, an augmented instrument requires a place to hold the electronics on or in the instrument frame. Exploring a location where it effective but also aesthetically pleasing for the design of the instrument is crucial. In the case of the eJanggu, a double ended drum with a short connecting middle, a plug was fitted to separate the two cavities. If the electronics were be placed in the middle connector of this instrument, it would cause less of an effect on the sound production.

Ulfarsson, Overholt, Eldridge and Melbye's use of analogue audio feedback loop could be a compelling component to include on the augmented haegeum. Considering that most traditional Korean instruments identify as being a part of ensembles, implementing a way to include these other instruments could shape the connections to its roots. *Jangdan* in *gugak* is often resonated throughout the ensemble by driving and molding the rhythm of the entire cohort. As the analogue audio feedback loop re-excites pitches on the acoustic haegeum strings, without manual actuation, it could be interesting how it could represent the internal feeling and incorporation of this crucial gugak concept. The janggu's *jangdan* physically affecting the haegeum's physical body while the haegeum working off the pattern of the *jangdan*.

#### 4.1.1.5 Bridge

Unlike the evenly spaced-out strings of a western stringed instrument, the haegeum's two strings are positioned rather close to each other. The performance practice of ordinarily gripping the strings at once and the added technique of minimizing the already short gap between the strings positions the haegeum to implement individual string magnetic pickups. Ulfarsson, Overholt, Eldridge or Melbye's approach of utilizing this modular pickup system prioritizes the string vibrations rather than the whole soundbox vibrations. They are capable of accurately focus on the intended sounds being produced by each string individually and filter out the surrounding noise. If the objective of the augmented instrument was to separate and only amplify the sounds of the strings, the two strings of the haegeum could be considered as a single element and implement a single module.

Also considering this thesis's priority of capturing the authentic sound of the haegeum. The implementation of the magnetic pickups does limit the unwanted effects such as wolf tones and electrical white noise. With this limiting, this system also removes all the natural resonance of the instrument. To create a sound that reflects the traditional resonant timbre of the haegeum, a thin piezoelectric contact microphone input glued to the front plate of the soundbox, as seen on Oriental Express and Scrapwood City's works, could be added to the magnetic pickup system. The performer could combine the sounds of both inputs from string and soundbox, creating the perfect mix of clarity and resonance.

#### 4.1.1.6 Bow

The common practice of incorporating of acceleration, velocity, pressure, absolute orientation and 6DOF inertial sensors could be easily applied the same to the haegeum bow. Unlike McMillen's work on creating a custom frog that holds all the circuitry, sensors, battery, and Bluetooth component needed in sensing movement data, the haegeum bow is noticeably minimalistic and limited. The custom pressure sensors near the frog of the bow, explored in Grosshauser and McMillen's work, could be beneficial as an index finger sensor on the stick of the bow. The more sophisticated approach of applying embroidered resistive pressure sensors to the haegeum's leather strap could also be an effective method of measuring the pressure balance between the inner and outer string. For many beginners, gripping the haegeum's untightened bow is a steep learning curve. Learning how to apply enough pressure to the leather strap or stick to create enough bow hair tension takes weeks of practice and training. It is only after mastering this balancing technique, they can produce a truly clear haegeum sound. The implementation of pressure sensors on the haegeum bow could simply be used as switch trigger for effect control. It could also be used to calculate the bow position, or a mechanical system of spring could be attached to assist with the directions of pressure needed for actuate each string. Depending on the pressure detected on the leather strap, a mechanical spring could expand and contract to reinforce the pressure needed manually by the performer.

Pardue, Goto, Paradisio, Schoner, Young, and Bevilacqua had similar approaches to bow position tracking through resistive or capacitive coupling transfers. All their approaches could be applicable to the haegeum bow, but Askenfelt's work allows the same sensing capabilities while also being aesthetically pleasing. By installing a thin resistor wire in the bow hair, the general look and weight of the bow is not altered.

Out of all the research references, many augmented bow systems choose to utilize a wireless system to send and receive information. It is understandably less limiting for the performer's range of motions, but the required additional electronics often weighs and unbalances the bow down. For western instruments, the obligation to keep the bow as light and balanced is crucial for the instrument's nature. However, in the case of the haegeum, since the bow is already securely threaded through the two strings, this need for unlimited movement is not as relevent. Wired sensors, compared to wireless systems, are exponential faster and favorable when transferring data to the host computer. The use of easily detachable JST connectors on the eHaegeum and Ko's work would be a more sensible method for the augmented haegeum bow.

### 4.2 Future Works

During the period of this thesis, early prototyping has been explored to understand the physical nature of the instrument and its limitations. This instrument is currently being called the Jeongeum 全琴. Continuing with the letter "*geum*" to respect its Chinese lute origin but replacing the peasant "*hae*" to "*jeon*" meaning maintain, keep whole or intact.

Figure 177 Ongoing development of the first conscious augmented haegeum prototype

Going forward, further exploration of materials, concepts and approaches addressed in this thesis would be necessary. Many of the theoretical application of previous works and new approaches require physical prototyping, user research and development in the case of the haegeum instrument to deem it a suitable evolution. It is only after this period of proper experimentation, that this author can propose a complete design of a conscious augmented haegeum.

# Terminology

| Revised Romanization | Hangul | Hanja |
|---|---|---|
| *haegeum* | 혜금 | 奚琴 |
| *gugak* | 국악 | 國樂 |
| *jeongganbo* | 정간보 | 井間譜 |
| *jangdan* | 장단 | 長短 |
| *Jeong-ak* | 정악 | 正樂 |
| *Minsok-ak* | 민속악 | 民俗樂 |
| *hyang-ak* | 향악 | 鄕樂 |
| *dang-ak* | 당악 | 唐樂 |
| *a-ak* | 아악 | 雅樂 |
| *pungmul* | 풍물 | 風物 |
| *gut* | 굿 | - |
| *pansori* | 판소리 | - |
| *sanjo* | 산조 | 散調 |
| *paleum* | 팔음 | 八音 |
| *chuimsae* | 추임새 | - |
| *nonghyeon* | 농현 | 弄絃 |
| *chuseong ; toeseong* | 추성 ; 퇴성 | 推聲 ; 退聲 |
| *kkumimeum* | 꾸밈음 | - |
| *daruchigi* | 다루치기 | - |
| *yoseong* | 요성 | 搖聲 |
| *jeonseong* | 전성 | 顫聲 |
| *ingeojil* | 잉어질 | - |
| *jo (Pyeong-jo ; gyemyeong-jo)* | 조 (평조 ; 계면조 ) | 調 (平調 ; 界面調) |
| *tori (Gyeong tori; Susimga tori; Yukjabaegi tori; Menari tori)* | 토리 (경토리; 수심가토리; 육자배기토리; 메나리토리) | - |
| *gyeonganbeop* | 경안법 | 輕按法 |
| *yeokanbeop* | 역안법 | 力按法 |
| *ungungbeop* | 운궁법 | 運弓法 |
| *seokanju* | 석간주 | 石間硃 |
| *dangbu akki* | 당부 악기 | 唐部 樂器 |
| *Samhyeon Samjuk* | 삼현삼죽 | 三絃三竹 |
| *Hyangdang Gyoju* | 향당교주 | 鄕唐交奏 |
| *Gojoseon* | 고조선 | 古朝鮮 |

| | | |
|---|---|---|
| *Goguryeo* | 고구려 | 高句麗 |
| *Baekje* | 백제 | 百濟 |
| *Silla* | 신라 | 新羅 |
| *Dangun Wanggeom* | 단군왕검 | 檀君王儉 |
| *Hwanin* | 환인 | 桓仁 |
| *Il-yeon* | 보각국사 | 普覺國師 |
| *Wang Geon* | 태조 왕건 | 太祖 王建 |
| *General Yi Song-gye* | 이성계 | 李成桂 |
| *Pak Yeon* | 박연 | 朴然 |
| *Samguk Yusa* | 삼국유사 | 三國遺事 |
| *Samguk Sagi* | 삼국사기 | 三國史記 |
| *Munmyo Jeryeak* | 문묘제례 | 文廟祭禮 |
| *Goryeosa* | 고려사 | 高麗史 |
| *Hallim Byeolgok* | 한림별곡 | 翰林別曲 |
| *Akhak Gwebeom* | 악학궤범 | 樂學軌範 |
| *Akseo* | 악서 | 樂書 |
| *Wenxian Tongkao* | 문헌통고 | 文獻通考 |

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