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A SCANNER-BASED 3D MODELING METHOD OF IMPROVING THE TIMBRE OF CHINESE GUQIN BY TRANSPLANTING THE BASS BAR OF THE VIOLIN

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KEYWORDS: Guqin, Violin, CT/CBCT, Scanner-Based 3D modelling, 3D CNC Engraving, MATLAB

ABSTRACT:

Guqin is the Chinese oldest musical instrument and intangible cultural heritage. The Tang Dynasty was the most prosperous in Chinese history, with a flourishing culture. One of the Guqin manufactured by Master Lei Wei, a notable Guqin maker in the Tang Dynasty, was recognized as a reference standard instrument and is kept in the Palace Museum in Beijing. Stradivari, a well-known Italian violin maker, has created and improved violins that no one else can surpass. Triangulation laser and CT/CBCT Scanner-Based 3D modelling data-driven analysis of the ancient musical instrument Guqin from the Tang Dynasty has been compared with the Italy Stradivari violin in a historical review perspective in this paper. After delving into the wood, spatial structure, and other aspects of the Stradivari violin, it has been discovered that the wood, paint, and inner cavity design used by the two masters during their respective heydays are strikingly similar, revealing their shared experience in creating ancient musical instruments in their countries. The bass bar of a Stradivari violin is meant to be transplanted into a Chinese Guqin prototype and get the conclusion that the timbre of the Guqin can be improved according to MATLAB spectrum analysis. This is the first time the two masters from Eastern and Western comparison analysis after the millennium.

1. INTRODUCTION

1.1 Italy Stradivari violin

The shape and the design of the modern violin are largely influenced by two makers from Cremona, Italy: The instrument was invented by Andrea Amati and then improved by Antonio Stradivari (Tai, H.C., et al, 2018). Antonio Stradivari (1644-1737), who was a pupil of Nicolo Amati, gradually modified his models and methods through many experiments, and his late period works (1700-1720) represent the gold standard in violin making (Pollens S., 2010; Hill WH, 1963). The Stradivari violin made 300 years ago, is recognized as the world's top musical instrument. Stradivari has strong pronunciation, loud sound, beautiful timbre and excellent remote transmission effect. Its timbre is round, implicit and rich. Stradivari violin making method created a standard for later times; He designed a modern violin bridge and set the proportion of modern violins. The shallower body produced a stronger and more penetrating timbre than the early violins. Stradivari has been regarded as a master craftsman in his own time and the following decades. Today's Stradivarius is priceless. In 2011, an anonymous buyer paid a record $15.9 million for the violin called "Lady Blunt". The best one, known as "Messiah", is now in Ashmolean Museum, located in Oxford, England (Stradivarius,2020).

1.2 Guqin master Lei Wei in Tang Dynasty

The Tang Dynasty (618-907) accepted the exchange of learning from other countries. The economy, society, culture, and art showed the characteristics of pluralism and openness, and many famous poets emerged in poetry, calligraphy, painting, and music. Lei Wei, a native of Chengdu, Sichuan Province. The famous Guqin maker in Tang Dynasty is one of the best musicians in Lei's family in Sichuan Province (Encyclopaedia of Baidu, 2022). Lei Wei has greatly improved the manufacturing of Guqin. Its technology is superior, its production is meticulous and its shape is beautiful. The timbre is soft and beautiful, the sound quality is clear and elegant, the volume is vigorous and rhythmic, and it has won an unprecedented reputation.

1.3 Comparison by historical literature review

Guqin was called Qin (Musical instrument) in ancient times, and in modern times, to distinguish it from Western musical instruments, the word "Guqin" was added, which was called Guqin. Guqin is the oldest traditional plucked string instrument in China and a treasure in Chinese culture (Xu Zhenyu, et al., 2014).

The objects unearthed from the tomb of Zeng Hou Yi in Hubei Province are from more than 2,400 years ago (Tomb of Zeng Hou Yi, 2009). Since the Tang and Song Dynasties, exquisite Guqin has been handed down from generation to generation. In modern times, with the footprints of Chinese people all over the world, it has become a symbol of oriental culture in the eyes of Westerners. Studying Guqin music can have a better understanding of the profoundness of Chinese music.

Figure 1. Ancestors of Guqin from the tomb of Zeng Hou Yi

In the past 80 years, musical instrument experts have recently concluded the argument about the special beautiful timbre of the famous Stradivari violin: the wood of this kind of violin was taken from the spruce trees of the European Little Ice Age 500 years ago, and because of its extremely narrow ring and high material density, it has good resonance effect and beautiful timbre. Mayer, a professor at the University of Tennessee in the United States, and Burke, an expert at Columbia University, believe that the cold climate during the Little Ice Age (1300-1850) caused the alpine spruce trees used for violin belly

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(upward surface) to grow more slowly, resulting in denser wood and better sound (LH Burckle, et al, 2003). The average altitude of the Alps is about 3,000 meters, which is rich in spruce wood for making musical instruments.

It is said from an old book of the Yuan Dynasty that whenever the snowstorm falls, Lei Wei drinks heavily in turbid wine, puts on hemp fibre and a hat, and runs to the deep forest of Mount Emei to listen to the true sound of trees. If the sound is continuous and melodious, he will choose it as the material for the cymbals. These legends illustrate the excellent material selection of the Lei family. Lei Wei Guqin doesn't need to be fortune paulownia wood, but it is better than paulownia to replace with Emei pine (Yi Shizhen, Yuan Dynasty). Here, I mentioned Mount Emei in Sichuan, where Emei pine's professional name was "Abies fabri (Mast.) Craib", and Mount Emei is about 3,000 meters above sea level (Encyclopaedia of Baidu, 2022).

The early analysis result indicates that the greatest impact on the acoustic vibration of the Guqin resonator is the Guqin's wood material (Chen Xuan, 2010). The woods most used in violin making are Maple, Spruce, ebony, Boxwood, willow, and Rosewood. Usually, the back, ribs, neck, and scroll are made of Maple while Spruce is used for the top, blocks, and linings (Ralph Tiebout, 2014; Ross, R.J. et al., 2010). Mechanically, wood is typically treated as an orthotropic material; that is, mechanical properties are unique along orthogonal axes (The Encyclopaedia of Wood, 2007).

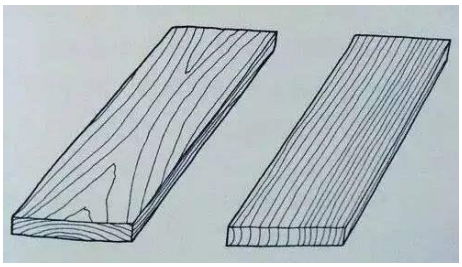


Figure 2. String cut and Radial cut (Encyclopaedia of Baidu, 2022)

Many violinists think that Stradivari's violin is musically superior to any new instrument. They claim that the sound of the Stradivari violin is different from any other violin in brilliance, depth, and personality. Recently, scientists found that Stradivari used various chemicals to treat some wood used for violin, including aluminium, calcium, and copper, which may change its acoustic characteristics (LH Burckle, 2003). Otherwise, Guqin uses Cornu Cervi Degelatinatum (Lujiaoshuang, which element is calcium) as the main paint auxiliary material (Encyclopaedia of Baidu, 2022).

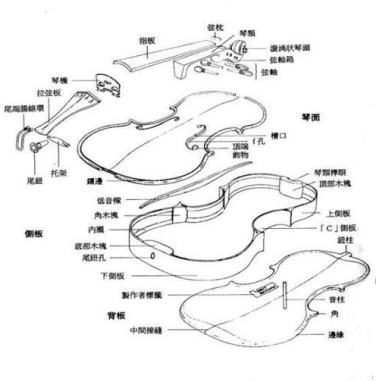


Figure 3. Structure of Violin (Encyclopaedia of Baidu, 2022)

Figure 4. Violin's Bass bar (Encyclopaedia of Baidu, 2022)

Of all the characteristics of a violin, those that concern its shape are probably the most important ones, as the violin maker has complete control over them (Sebastian Gonzalez, et al., 2021). When the violin has been observed inside as Figure 4 shows, the bass bar is visible, this is quite different from Guqin as Figure 5 shows,

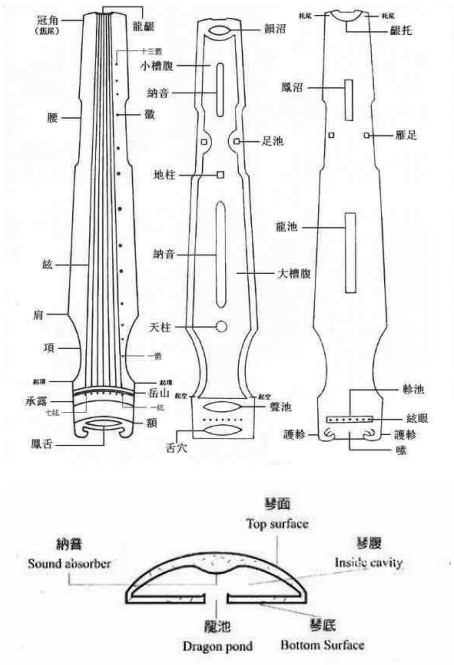


Figure 5. Structure of Guqin (Encyclopaedia of Baidu, 2022)

In a summary, when two Masters from China and Italy, and their musical instruments have been compared, it can get the conclusion from a literate review perspective as Table 1 shows.

Classification (in descending order of importance of affecting sound quality)	**Sub-Classification**	**Italy Stradivari violin**	**Guqin master Lei Wei in Tang Dynasty**	**Conclusion**
1: Wood	Wood	Spruce for the top, Maple for the back (Ross, R.J. et al., 2010)	Abies Fabri (Mast.) Craib for the top, Catalpa for the back (Yi Shizhen, Yuan Dynasty)	Similar for the top, different for back
	Origin altitude	Long winter at high altitude Avg. altitude 3000	Long winter at high altitude Avg. altitude 3000	Same

	Cutting	Radial cut	String cut	Different
2: Paint	The special composition of the paint	Aluminium, Calcium and copper (LH Burckle et al., 2003)	Calcium (Encyclopaedia of Baidu, 2022)	Similar
	Paint	Alcohol paint or oil paint (LH Burckle et al., 2003)	Raw lacquer (Encyclopaedia of Baidu, 2022)	Different
3: Internal	The proportion of the sound pool	1：1	1：0.5 (Zhao Deda et al, 2015)	Although they are different, they have found a mathematically perfect ratio
	Internal contrast	Bass bar	Have sound absorber, without bass bar	Different
	Soundhole	Front	Back	Opposite
4: Year	Master years	1644 — 1737	785 - 804 A.D.	Both are the pinnacle of musical production

Table 1. Summary Comparison between Italy Stradivari violin and Guqin made by master Lei Wei in Tang Dynasty

After delving into the wood, spatial structure, and other aspects of the Stradivari violin, it has been discovered that the wood, paint, and inner cavity design used by the two masters during their respective heydays are strikingly similar, revealing their shared experience in creating ancient musical instruments in their countries. But one significant difference internally is that the violin has a bass bar. Another difference is that the violin uses a radial cut. It needs to be tested whether the bass bar is a way to improve timbre.

2. METHOD

To test this hypothesis, the following problems need to be solved: How to select the reference standard instrument; As an expensive antique, the reference standard instrument cannot be touched, how to reconstruct it without touching it; The biggest difficulty was how to reconstruct the internal structure of the instrument without break opening it because the human eye can't observe the enclosed construction.

2.1 Scanner-Based 3D Modelling

2.1.1 The reference standard instrument: It is worth mentioning that this experiment did not choose Jiu Xiao Huan Pei from the Forbidden City. The Jiu Xiao Huan Pei is Leiwei's representative work and the number one Guqin in the Forbidden City (Zheng Minzhong, 2006), but because the inner cavity part was damaged based on a deep neural network object detection (Yingxi Tang, 2022), it was not selected as a reference standard instrument in this experiment. A Cai Feng Ming Qi (1248 mm length) made by Lei Wei collected by the Zhejiang Museum (Zhejiang Museum, 2019) has been selected as a reference instrument as Figure 6 shows.

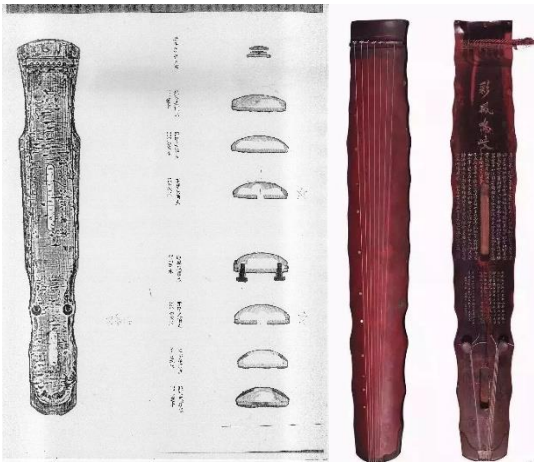


Figure 6. Jiu Xiao Huan Pei (Zheng Minzhong, 2006) & Cai Feng Ming Qi Guqin (Zhejiang Museum, 2019)

2.1.2 3D scan: Laser scanners collect data that allow the extraction of information about the position of discrete points in space, producing a dense point cloud, which consists of the 3D coordinates of points on the surface of an object of interest (Verykokou, S. and Ioannidis, C., 2023). A triangulation laser scanner as a non-contact scanner has been selected to reconstruct the external surface geometry, and point clouds derived from laser scanners as Figure 7 have been generated. Thus, the outer surface has been reconstructed.

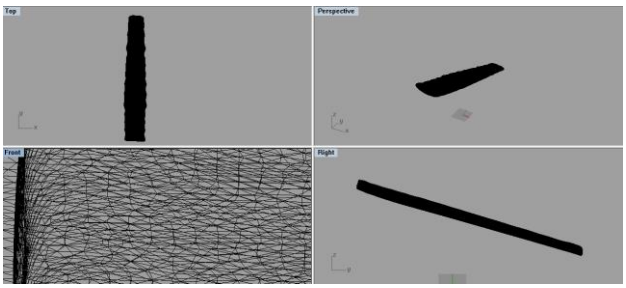


Figure 7. Point clouds derived from laser scanners

2.1.3 CT/CBCT scan: One of the difficulties in modelling a musical instrument is that it is not an easily definable engineering structure with the inner part that is not visible to the naked eye. The Computed Tomography (CT) scanner presents itself as a useful tool for reverse engineering a musical instrument (Michael Pyrkosz, et al.2010).

Computed tomography is a digital imaging method, which allows the creation of sections of varying thicknesses of the structures under examination using an X-ray beam. Two basic types of computed tomography scanners are in use nowadays: fan-beam computed tomography scanners, which are also referred to as computed tomography (CT) scanners, and cone-beam computed tomography (CBCT) scanners (Verykokou, S. and Ioannidis, C., 2023).

GE medical computed tomography scanner has been used during this digitalization, and 1270 CT photos per 1 mm cut (1248 mm length was considered) have been generated as Figure 8 demonstrates. The reference standard instrument preparation has cost a 2-year-long time because the raw lacquer used in Guqin can only dry under certain conditions of temperature and humidity, and it takes a lot of time to repeatedly polish the surface.

Figure 8. CT of Guqin (samples from the 1270 photos)

2.1.4 Point Clouds to 3D Models: The point clouds obtained by the scanner can be transformed from the local reference system of the scanner to the ground reference system, and then the point clouds can be merged as Figure 9 shows.

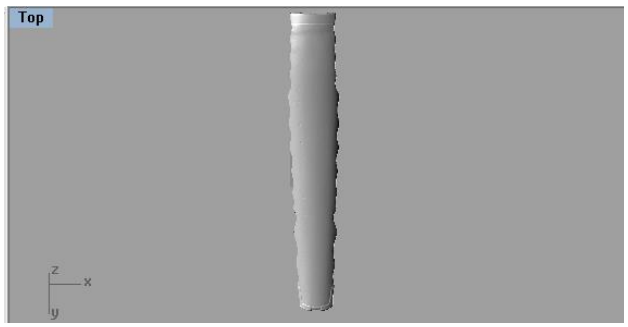


Figure 9. 3D modelling of surface

2.1.5 Tomographic Images to 3D Models: The 3D reconstruction of the region of interest depicted in tomographic images captured by a scanner (e.g., CT/CBCT/ MRI/ultrasound scanner) is based on image segmentation, i.e., on dividing each tomographic image into individual non-overlapping distinct regions (segments) homogeneous concerning some feature of the image, e.g., brightness or texture (Lo Giudice, et. al, 2020). Segmentation may be performed both manually and automatically. Segmentation methods can be distinguished into two main categories Intensity-based methods and Geometry-based methods. Internal 3D modelling has been generated with UG (UnifiedGraphics) software, which is a powerful 3D design software that helps users create and edit 3D graphics. Open with Rhino software as Figure 10 shows.

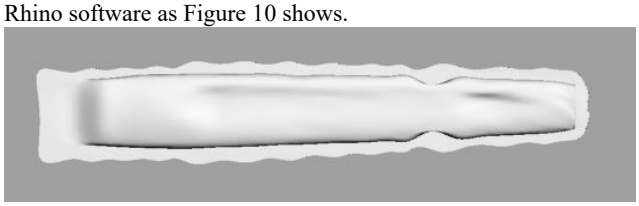


Figure 10. Internal 3D modelling with UG

2.1.6 Correction: The correction of the inner 3D model with the edges of the outer 3D model has been made to reduce errors. The prototyped model is geometrically congruent to the original one, the error is controlled within 0.1 mm.

2.1.7 3D Models to CNC Engraving: Use CNC (Computer Numerical Control) JD Paint 5.19 to generate the engraving path, 3D engraving and printing to make the wooden part of the Guqin prototype 001, it took another two years to get it ready with raw lacquer.

Figure 11. Picture of Guqin prototype 001 (a) wooden part (b) After painting with raw lacquer

In another one, the bass bar was added, adjusted position, and tested it and was found that it was best to put it in the corresponding position of the seven strings. The No. 002 Guqin prototype was made from radial-cut spruce and saved as a comparison. After the production, the perspective CT image is as follows, it can be seen the position of the bass bar.

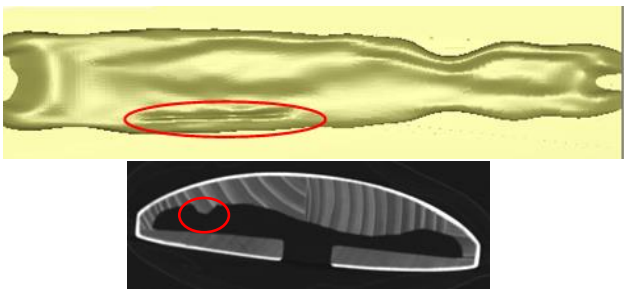


Figure 12. 3D/CT picture of Guqin prototype 002 with bass bar

2.2 Discussion

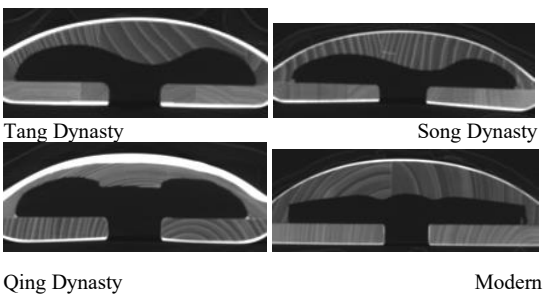


Figure 13. CT picture of Guqin from different years

From the perspective view, it can be seen what is meant by "The Qin of the Tang Dynasty is round, the Qin of the Song Dynasty is flat" in ancient Chinese literature. The height of the Tang Qin is higher and the cavity is larger than the Song Qin. This scientific asymmetrical design may have been lost since the Qing Dynasty and turned into a symmetrical design, which has been used in modern times. There should be some errors caused using qualitative inheritance because the inheritance of ancient knowledge cannot be quantified by 3D data. This also proves from the side that it is difficult to surpass the Lei Wei Guqin of the Tang Dynasty in the later period.

2.3 MATLAB Spectrum Comparison Model Building

It is a difficult problem how to describe and record sound graphically.

MATLAB is widely used in the fields of engineering and science, from data acquisition and analysis to application development. The MATLAB environment integrates mathematical calculations, graphical output, and powerful computer programming languages, The MATLAB Engine API for Python allows you to call MATLAB as a computational engine from Python (Call Python from MATLAB, 2022). The built-in interface allows users to read data from instruments, files, and external databases and programs.

The microphone model this experiment use is: Logitech G733 Gaming Headset, the sound card model is: Realtek Digital Output (Realtek High-Definition Audio), and the computer and operating system are: AMD Ryzen 7 5800X 8-Core Processor 3.80 GHz, Windows 10. And the overall composition of the audio test system is as follows: Guqin -> radio microphone -> sound card ->computer MATLAB system

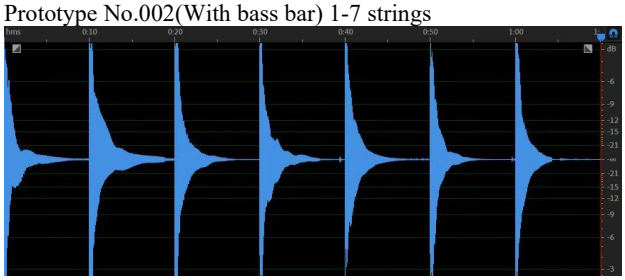
The data acquisition toolbox includes three modules: M-File function set, Data Acquisition Engine, and Hardware Driver Adaptors. As shown in the figure below, these modules allow the user to exchange data between MATLAB and the user's data acquisition hardware.

MATLAB (R2021a edition) spectrum analyser has been used to compare the Guqin prototype with bass bar (002) and without bass bar (001).

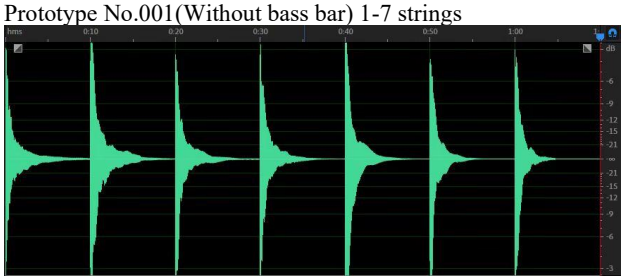
3. EXPERIMENTAL RESULTS

The performance comparison between prototype No.002 “With bass bar” and prototype No.001 “Without bass bar”.

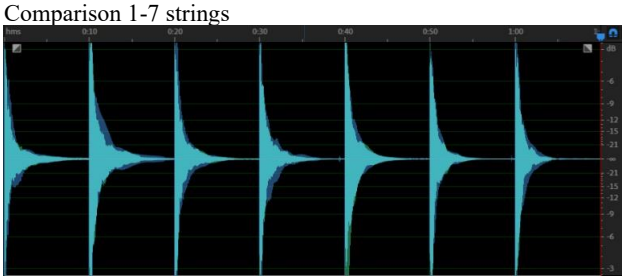
Prototype No.002(With bass bar) 1-7 strings



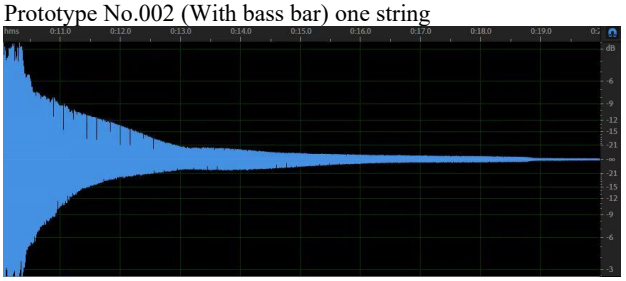
Prototype No.001(Without bass bar) 1-7 strings



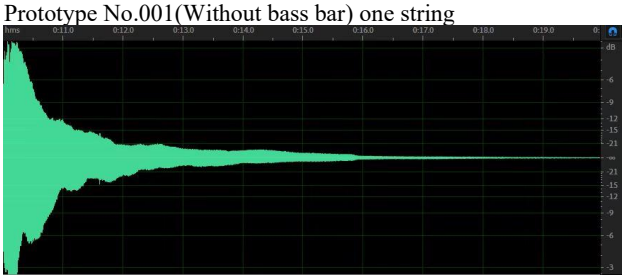
Comparison 1-7 strings



Prototype No.002 (With bass bar) one string



Prototype No.001(Without bass bar) one string



Comparison one string

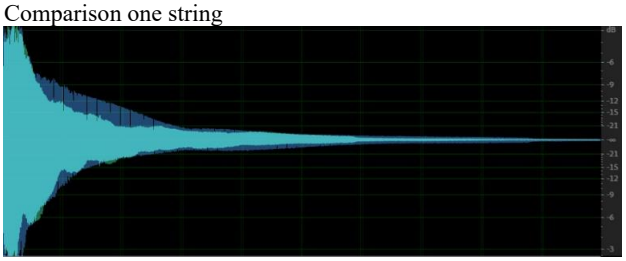


Figure 14. Pictures portfolio of performance comparison

Using MATLAB spectrum analyser to compare Guqin prototype with bass bar and without bass bar will find that the improved Guqin with added bass bar has a significant increase in resonance time, longer aftershocks, better resonance, and a more harmonious sound from the intuitive experience. This is the figurative description of the ancient Chinese idiom "The remnant sound goes around the beam for three days."

4. CONCLUSION

The documentation of intangible cultural heritage is a particularly sensitive topic. Documentation of sound is also part of the registration of intangible heritage.

There was a lot of resistance to digitally modelling the instrument because the interior wasn't visible. Triangulation laser and CT/CBCT Scanner-Based 3D modelling data-driven analysis of the ancient musical instrument Guqin has been compared with the Italy Stradivari violin from a historical perspective in this research.

It has never been discovered that the two top musical instrument masters have explored the same direction in the structural

improvement of musical instruments. The experiment has been carried on transferring the bass bar of the violin to Guqin and using radial-cut Spruce instead. Through spectrum analysis, the tone is greatly improved. This is an improvement of the Guqin in one thousand and two hundred years of history.

Through 3D analysis, it is also found that the inheritance of the Chinese Guqin flourished in the Tang Dynasty because of the inability to quantitatively analyse it, gradually declined and its descendants could hardly reach the state of its heyday. This research aims to arouse scholars' attention to the digital preservation of intangible cultural heritage.

In the next step, the raw lacquer used in the Guqin will be applied to the violin to see how the tone changes, and the effect of changing the position of the sound hole on the sound.

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This project has reached the National Finalist of "Exploring Original Plan" 2022 - Exploring the New Era of Cultural Heritage Digital Activation Award Selection, which is hosted by the China Cultural Relics Protection Technology Association, Tencent Digital Culture Laboratory, Tencent Research Institute, Tencent Sustainable Social Value Organization, and the Creative Industry Technology Research Institute of the Renmin University of China.

This improved Guqin was invited to participate in the International Horticultural Exhibition Floriade Expo 2022, "China Intangible Cultural Heritage Master Piece" of "A Growing Chinese Bamboo Garden" in China’s Pavilion.

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