

Tromba Moderna: A Digitally Augmented Medieval Instrument

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ABSTRACT

An interactive museum exhibit of a digitally augmented medieval musical instrument, the tromba marina, is presented. The tromba marina is a curious single stringed instrument with a rattling bridge, from which a trumpet-like timbre is produced. The physical instrument was constructed as a replica of one found in Musikmuseet, a musical instrument museum in Copenhagen, Denmark. The replica instrument was augmented with a pickup, speakers and digital signal processing to create a more reliable, approachable and appropriate instrument for interactive display in the museum. We report on the development and evaluation of the instrument for the Danish museum of musical instruments.

Author Keywords: Interactive Exhibit, Tromba Marina, Activated instrument, Augmented instrument, Medieval instrument, Digital Signal Processing

ACM Classification: Gestural input, Auditory feedback, Interactive systems and tools, Real-time systems

1. INTRODUCTION

Visitors to The Music Museum (Musikmuseet) can look at the 1000 or so instruments on display, but can only touch about ten of them. This preserves the museum's collection, but does not allow visitors to physically engage with, and explore the instruments. In order to cope with this problem, we selected and replicated one of the most intriguing instruments on display, a medieval monochord bowed string instrument with an unusual vibrating bridge, called the tromba marina.

With no direct access to the museum's exhibits and limited documentation regarding the dimensions and construction process of the instrument, a replica design had to be made from historical writings and iconography of the instrument.

Our research uncovered the fact that the instrument's unusual vibrating bridge is difficult to adjust effectively, in order to maintain the desired action. Combined with prior knowledge of the steep learning curve of bowed instruments, we set ourselves the goal of activating the

to play, thus providing a more engaging and rewarding museum experience.

2. RELATED WORK

Within the heritage sector, there is a strong desire to explore possibilities for improved visitor interaction with museum exhibits. Without this, visitors have questions that go unanswered, or they pass through an exhibition without being engaged [4]. But in addressing this need, one inevitably encounters what McAlpine refers to as "*the red velvet cord problem*" [5]. Museums have a responsibility to preserve and protect as well as to allow the public access to their collections. Many interactive music exhibits have been explored and implemented ranging from baton based interfaces [6] to the digitisation of the Benton Fletcher collection. McAlpine outlines this latter project at Fenton House in Hampstead, England, where keyboard instruments were digitally modelled for playback on a dedicated MIDI

keyboard within the museum. A clear and identifiable desire [5] for public interaction with the historical instruments on display was identified. Whilst the limitations of digital sampling meant that the original instruments could not have their sound perfectly replicated, this did not appear to be a major issue with the public. A more significant problem was that the mechanics of the MIDI keyboard could not mimic the feel of the real instrument. We have attempted to avoid this problem by constructing a fully functioning replica of the tromba marina. The approach presented in this paper is aimed at improving the playability and supporting the instruments natural sound by actuating (via internal driver) and augmenting the sound. Related technological developments



Fig. 1 Our reproduced tromba marina

include for example, active violin bridges [1] as well as other actuated instruments [2].



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instrument with digital signal processing. We did this in order to create an instrument that is more reliable and easier

3. ANATOMY OF THE TROMBA MARINA

In its simplest form, the tromba marina is a monochord bowed string instrument with a long, slightly flared, quasi-trapezoidal body and a uniquely fashioned bridge (often called a shoe, because of its shape – see Fig. 2). The string travels directly over one of the bridge feet, leaving the other foot free to rattle against the soundboard of the instrument in sympathy with the vibrating string. The sounding pitch of the instrument is varied by placing the side of the knuckle of the non-dominant hand, lightly, at specific nodal points on the string, in order to select various harmonics of the open string. The dominant hand controls the bow, which is drawn across the string above the non-dominant hand.



Fig. 2 Reproduced bridge with mounted pickup

There are two striking peculiarities common to almost all historical versions of the tromba marina. First is the fact that intonation is achieved entirely through the use of harmonics. Second is the vibrating bridge, in a way similar to that sometimes found on the hurdy gurdy. This kind of sympathetic vibration is very rare in a string instrument. Certain Indian classical instruments such as the sitar, do exhibit a bridge vibration, but in this case the vibration is obtained by the string vibrating against the curved surface of the bridge, rather than the vibration of the bridge against the instrument. Also worth noting is the extensive variety of names that the instrument has accrued over the centuries that it was in common use: nonneviolin, trumpet marine, trumscheit, tromba marina and mock trumpet, to name just a few. A list of colloquial names for the instrument has been compiled by Cecil Adkins [7].

3.1 HISTORY AND EVOLUTION

Described by Cecil Forsyth as a monstrosity [8], and by Samuel Pepys as “*better than trumpets can ever do*” [9] one can deduce that these two writers did not agree about the aesthetics of the tromba marina. One thing they did share was a fascination for how this bizarre, and now almost forgotten string instrument, could sound so very much like a trumpet, and in some cases, like a “*whole concert...*” of them. [9]

The tromba marina is widely assumed to be the “*performing descendent of the monochord*” [10] - the scientific instrument used for measuring the intervals of musical scales - although there is little or no direct evidence to support this. An entry in The Harvard Dictionary of Music - “*The tenor marked 'Trompette' in Pierre Fontaine's chanson J'ayme bien celui (c. 1400) was probably written for the tromba marina.*”[11] This is refuted by Pierre Aubrey [12] who suggests that there is no evidence to support this. Pictorial evidence of the existence of the instrument however, dates back to at least the 1480's, a shorter variant of the instrument can be seen in Hans Memling's painting *Angel Musicians*.

According to Marin Mersenne [13], earlier versions of the tromba marina had two bowed strings rather than one. By the late 17th century there are accounts of the addition of sympathetic strings, by some accounts as many as 50 - from various sources, including Samuel Pepys in 1667. This is also the century in which the first evidence of music having been written specifically for the tromba marina first occurs. At around the same time the instruments only significant virtuoso (*M. Jean-Baptiste Prin, 1650-1742*)[7] laid claim to the innovation of sympathetic strings for this instrument. There are also numerous accounts of different materials such as glass and bone being used for, or under the foot of the bridge.[13]

It's perhaps worth noting that long valved trumpets were not invented until the 1880's. [14] This is significant for two reasons: first, a trumpet player's embouchure operates differently at the higher registers of the instrument [15]. Therefore, the baroque trumpet would not be as harmonically rich for any given note as the modern day version. Perhaps then, the trumpet part of the instrument's name stems more from the style of music written for it - largely dictated by the pattern of the harmonic series - than from what we now think of as its brassy tone. Secondly, one can now imagine how limited an instrument the trumpet was in the days of the tromba marina, and perhaps understand why Samuel Pepys was so impressed. As for Forsyth - he openly admitted that he never heard the instrument anyway.

4. BUILDING THE REPLICA

Over a period of seven weeks our replica instrument was designed and built with great attention to details. Care was taken to build a historically accurate and aesthetically pleasing instrument that would not be out of place in a national museum. A picture of the replica next to its original can be seen in Figure 3.

Dimensions of the instrument were estimated from photographs, using height measurements from the museum records and descriptions from books [7][10].

The body was designed with a detachable bottom plate, for easy access to internal electronics and driver. We used a factory built french style double bass bow instead of the bow on display at the museum. At the time of building, as the



Figure 3: The original and replicated tromba marinas

instruments string had not been sourced, it was therefore not possible to calculate stresses; strength was therefore prioritised when selecting materials. The tuning peg was made from a dowel and hand-carved peg grip. A prototype of the bridge was designed in 123D Design, and printed from ABS on an Ultimaker 3D printer. This was later used as a template for a wooden version in order to accommodate a pickup. The ornamentation on the head was 3D printed from a pre-made model¹ and modified using meshmixer.

The ornamentation of the joint between neck and body was laser printed with a simple medieval inspired design. The nut was 3D printed using ABS having been designed in 123D Design. Strings used in instruments of the period were traditionally made of gut. A gut tennis racket string was used as suggested by historical reference: The thickest racquet strings, that is to say those made of a dozen or so sheep guts [13]. The string used is KLIP Legend Uncoated Natural Gut 16 String 1.30 mm.

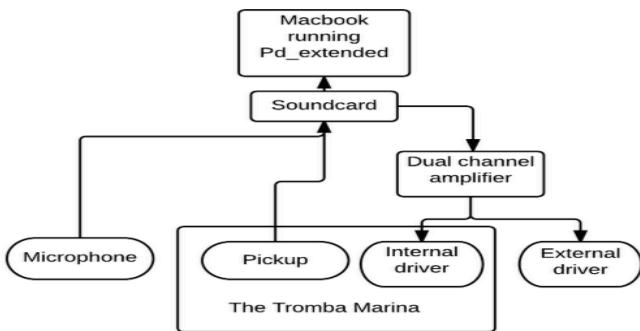


Fig. 4 Diagram of the activation of the instrument

Thin leather was used for aliquot markings of harmonics on the soundboard and neck. These were located by ear and marked from the playing position to account for player 's perspective, and subsequently checked by comparing with the theoretical positions of the nodal points to ensure consistency. A leather strip was also added for controlling the state and position of the bridge. This also reduced feedback.

4.1 CONSTRUCTION

The back of the body was made from five pieces of angled wood, cut by an angled jigsaw. The parts were glued and strengthened with fibreglass matting and cross-braces beneath. The braces did not touch the soundboard. The neck is attached to the back of the body, inside the cabinet with dowels and wood glue. The soundboard is made from a

piece of plywood and is glued to the body. The front side of the neck is covered with the same material as the soundboard, to maintain an even aesthetics. The instrument was sanded and then varnished for protection, aesthetics and acoustics.

5. ACTIVATING THE INSTRUMENT

The finished acoustic instrument was then augmented with an internal driver, external speaker and a pickup for capturing audio (see Figure 4). For the internal driver a Tectonic Elements TEAX25C10-8/SP tactile transducer was chosen. After testing different placement options, it was discovered that the volume required would not be possible by attaching the driver to the body of the instrument. An internal resonance box was created, situated under the soundhole and the driver hot-glued on to its surface.

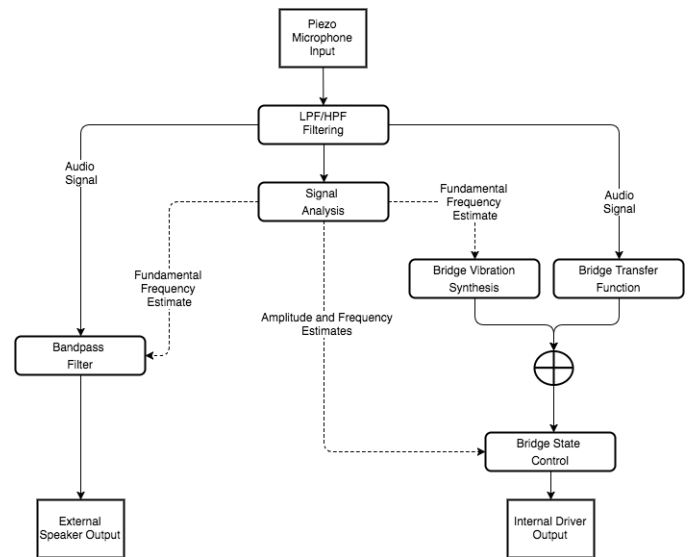


Fig. 5. Signal processing diagram for the instrument

A small Philips surround satellite speaker was attached to the backside of the instrument on the outside at the same

height as the bridge. This was added to play the direct - but filtered - signal from the pick up, as the internal driver could not supply high enough sound pressure level without causing feedback.

Feeding the driver and the speaker is a Dayton Audio DTA-2 miniature 15-watt class-T dual channel amplifier, each speaker on its own channel. Frequency response plots of the two speakers were made in an anechoic chamber.

An Ole Wilson K1 pickup was mounted in the bridge directly below the string. This pickup has good feedback reduction and supplies a very detailed sound of the instrument. For recording and testing the instrument, a M-Audio M-track plus and or a Focusrite Scarlett 8i6 audio interface was used with a Macbook Pro running Apple Logic X. A Røde NT2a in Omnidirectional mode was used to test a variety of augmentation effects, such as the arctangent body transfer function shown in Figure 5.

The augmentation software itself, written in PureData, is comprised of the combination of an arctangent synthesis function to recreate the sound transfer through the bridge to the body, and a simple impulse-based synthesis of the bridge rattle. The amplitude of these two modules is controlled by a bridge state model, which uses pitch fidelity and amplitude

¹ <http://www.thingiverse.com/thing:182265>

as an estimate of string energy, and therefore bridge vibration intensity. The input signal is also bandpass filtered, and sent to the external speaker to provide amplification of the string. The arctan function was chosen perceptually, as a digital simulation of the tapping action of the unusual tapping bridge on the tromba marina.

6. USER EVALUATION

Three user tests were designed to evaluate different aspects of the project: levels of engagement in the museum, playability and sound aesthetics.

6.1 MUSEUM ENGAGEMENT TEST

A user test was designed and conducted in order to measure levels of visitor engagement and interaction with the instrument in the music museum (Musikmuseet). Initially the test was designed to measure differences in engagement and perception of sound between the acoustic instrument and the augmented version. Due to low participant numbers, the scope of test was reduced to focus on the engagement and interest level alone, regardless of the mode the instrument.

The test was undertaken by nine participants who had not encountered the instrument before. They were given a short tutorial on playing technique as well as a little history of the instrument. The participants were not given any specific tasks and invited to explore the instrument in their own way. Video footage was taken of the participants and they were asked to fill in a short survey when they finished playing.

The survey asked the participants whether they enjoyed playing the instrument – the results were positive with all participants answering yes, from this the assumption can be made the replica tromba marina increases interactivity. A further question asked if the instrument made their visit to the museum more interesting, which again was answered positively, with ratings no lower than 5 on a scale of 1 - 6. The majority of the participants reported skills in playing other instruments, with only 3 stating they did not. The majority of the participants had little experience with bowed instruments, only one participant stating they were very experienced. It should be noted that the test had a limited number of participants (5 being museum staff) due to low numbers of visitors, so the results are somewhat biased. Generally the participants were curious and interested about the sound of the tromba marina. The museum staff were highly positive about having an interactive instrument in their museum.

As this test was unable to verify the impact of DSP on playability, because of too few participants, another test was conducted to test the difference in playability between playing with and without DSP.

6.2 PLAYABILITY TEST

A second test was designed and conducted in order to measure the playability of the augmented instrument versus the original. The test was conducted at Aalborg University in Copenhagen, with local university students. 13 participants played the instrument over 2 rounds each lasting 2 minutes, with the mode of the instrument being changed each round and the order of modes alternated for each

participant. Each participant was given a visual demonstration on how to play the instrument, suggesting bowing and intonation techniques. They were not given specific tasks but instead invited to play the instrument in their own way. Of the 13 participants 3 stated that they had no musical experience.

The participants were asked to fill in a questionnaire, rating the ease of generating a clean tone from the instrument for both modes. They were also asked their view of the instrument in general, how natural they thought the DSP sounded and to describe the sound of the processed augmented instrument.

When testing if the DSP makes it easier to play a clean tone, the results indicate that the ordering of the modes are a more important factor than the modes themselves, with participants on average rating their second round higher than the first (Figures 6 and 7). This may be explained by the participants getting used to the behaviour of the instrument by the second round, in order to improve the validity of this test longer round times should be used.

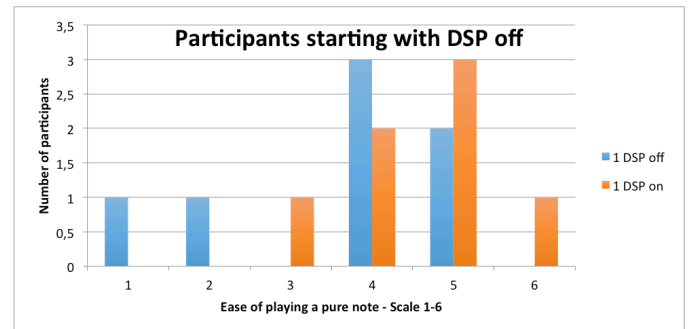


Fig. 6: Results from test at university 1st group

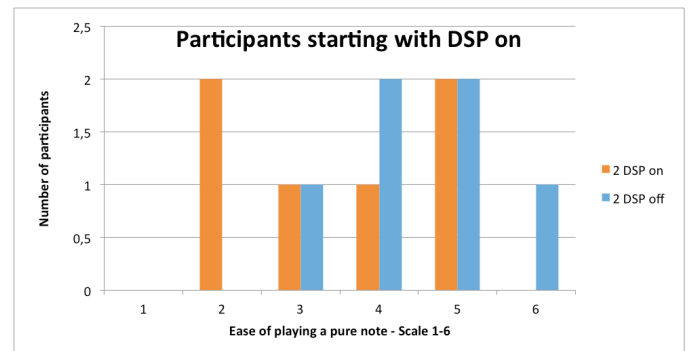


Fig. 7: Results from test at university 2nd group

It was observed during the test that users had significant difficulty activating the bridge on the acoustic instrument, but using DSP the synthetic bridge activated reliably. However, this is not reflected in the questionnaire results. When the participants were asked to describe the sound of the DSP, opposing words such as smooth and metallic were mentioned by several participants. This difference shows a very subjective experience of the instrument. The participants' experience of the instrument in general was positive, with a mean rating of 5 (on a 1-6 scale) and a median of 5. Supporting the test from the museum, the instrument was found to be interesting and was well received.

7. SOUND QUALITY EVALUATION

In an online test 14 anonymous test subjects were given pre-recorded samples for evaluation. Participants were asked to judge the similarity of the sounds, presented in six pairwise combinations, and to choose which they found most pleasing. Four sound clips were made of the instrument, including various bridge/DSP combinations. The same short melody was used for each clip. Each sound file was normalised and copies were made with assigned numbers to avoid any possibility of recognising the file by name during the test.

Results from the similarity part of this test show that all the sound samples were considered to be quite similar. Given that this instrument is not well known, it is likely that most participants had not heard a tromba marina before, and so it is no surprise that the variations of bridge model and bridge state presented to them was not noticed. Very few people considered any of the sounds to be exactly the same however. The most noticeable difference appeared to be between the sound of the vibrating bridge and the static bridge.

The aesthetic comparison part of the test also showed that there was very little preference for one sound state over another. Giving sound clips values 1 and 2 in each comparison pair, then calculating the average gives results very close to 1.5, suggesting there is no overall preference. The one exception being a score of 1.8 in favour of DSP and vibrating bridge combined over the static bridge with no

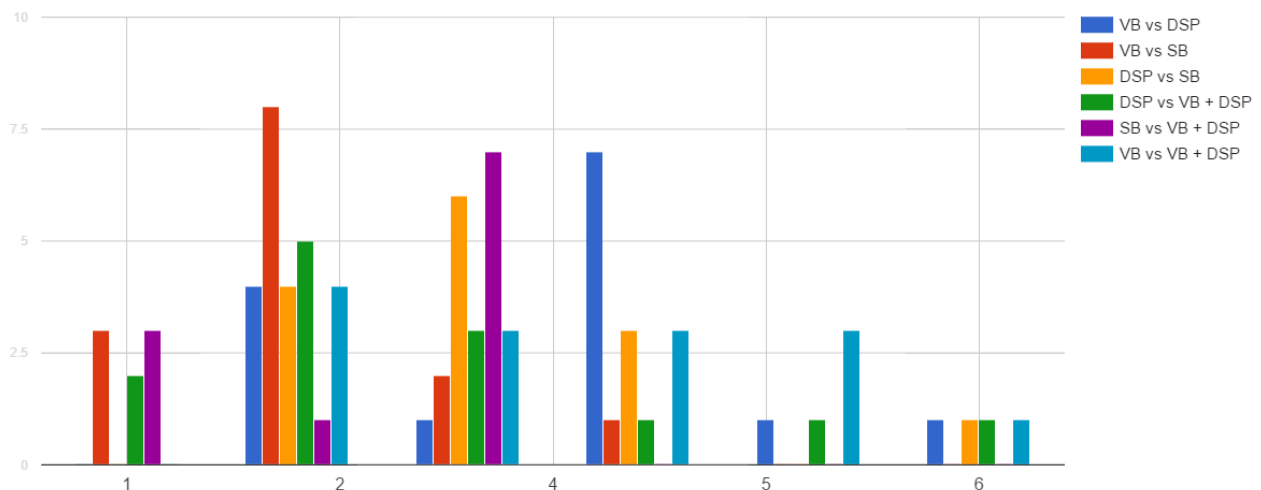
8.1 FUTURE WORK

There are several lines of research and development that could be followed in order to improve and continue this work. It would be of benefit to develop a more accurate method of detecting bowing interactions in order to more closely model the original instruments sound and behaviour. There has already been extensive work on this topic, with many approaches available. Further analysis of the physical action of the bridge could be carried out, in particular, studying the three dimensional movement of the bridge and mapping this to the waveform of the instrument. This analysis could be used to further develop the Pure Data simulation model. The Pure Data patch could be transferred to a mobile or embedded device. A thinner soundboard could well make the instrument more acoustically resonant, and improve the effectiveness of the internal driver. The use of a second internal driver to increase haptic feedback could also prove effective.

There is the possibility of departing from acoustically faithful recreations of the instrument and exploring different sound models. Trials in the lab with digital effects and unnatural acoustic behaviors proved engaging and gave interesting results. For example, a version of the software could be set-up so that each time the player bowed, the frequency of the bridge was set to a random harmonic ratio of the fundamental.

Various other physical modifications have been discussed, such as having servos or motors to physically recreate taps

Subjective Comparison of Bridge States



DSP (Fig. 8).

8. CONCLUSION

This project attempts to address the low level of visitor interactivity at the Music Museum in Copenhagen, Denmark by creating and augmenting a replica of a tromba marina. During user testing the overall reception was positive. Most participants who tried the instrument enjoyed playing it, and the staff at the museum considered our instrument to be exactly the kind of exhibit that they wanted to see more of at the museum.

or a motorised fan over the soundhole to create a vibraphone like vibrato effect. The addition of an external pedal to control the vibrato, servo-bridge effect or any of the parameters already available in the Pure Data patch would also expand the expressive capabilities of the instrument.

The vibrating foot of the bridge could be effectively switched on or off by the use of an internally mounted electromagnet and a small magnet inserted in the foot of the bridge. Finally, the development of apps or games with the aim of improving playing technique or teaching the history and variations of the instrument would be interesting.

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