THE HYPER-ZAMPOGNA

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ABSTRACT

This paper describes a design for the Hyper-Zampogna, which is the augmentation of the traditional Italian zampogna bagpipe. The augmentation consists of the enhancement of the acoustic instrument with various microphones used to track the sound emission of the various pipes, different types of sensors used to track some of the player's gestures, as well as novel types of real-time control of digital effects. The placing of the added technology is not a hindrance to the acoustic use of the instrument and is conveniently located. Audio and sensors data processing is accomplished by an application coded in Max/MSP and running on an external computer. Such an application also allows for the use of the instrument as a controller for digital audio workstations. On the one hand, the rationale behind the development of such augmented instrument was to provide electro-acoustic zampogna performers with an interface capable of achieving novel types of musical expression without disrupting the natural interaction with the traditional instrument. On the other hand, this research aimed to provide composers with a new instrument enabling the exploration of novel pathways for musical creation.

1. INTRODUCTION

The last decades have seen an increasing interest towards the development of conventional acoustic instruments enhanced with sensor technology and digital signal processing techniques. These instruments are usually called "hyper instruments" [1] or "augmented instruments" [2], and are conceived to extend the sonic possibilities offered by the instrument in its original version. The performer's interactions with the sensors are used to control the production of the electronically generated sounds that complement, or modulate, the sounds acoustically generated by the instrument.

Some principles for the design of such new musical interfaces have been proposed [3–5]. In addition research has also focused on the importance of mapping strategies between the player's gestures and the controlled sound parameters [6–8], which have an important impact on how the instrument will be played and on how the audience will perceive the performance.

Quite a number of augmented instruments have been developed. However, looking at papers written on traditional instruments augmentation the number is quite low. Examples of augmented traditional instruments are the "electronic sitar controller" [9], the "hyperpuja" [10], or the "hyper-hurdy-gurdy" [11]). To the author's best knowledge no research has been conducted yet on the acoustic augmentation of one of the most typical exemplars of traditional instruments: the bagpipe [12].

Nevertheless, a number of people from both academy and industry have worked on the application of electronics to various types of bagpipe. Among commercially available solutions, one can cite the electronic bagpipes produced by TechnoPipes [1], DegerPipes [2], Master Gaita [3], Redpipes [4]. Typically, these fully electronic instruments consist of a chanter-like interface where single capacitive touch-switches are used in place of the tone-holes, which act as MIDI controller and/or a controller for a bagpipe sound synthesizer (usually involving wavetable synthesis).

Within the academic community there have been various efforts to improve the expressive capabilities of such controllers. Indeed usually these devices are not characterized by an accurate tracking of the partial occlusions of the tone-holes, which are typically involved in the acoustic instrument to slide between notes. The EpipE is an ad-hoc built chanter interface based on the Irish Uilleann Pipes [13, 14] and is used as a MIDI controller. It is caracterized by an array of sixteen small binary touch-switches for each tone-hole that enable the sensing of various degrees of tone-holes coverage. The instrument is also equipped with a force-sensitive resistors that allows for the measurement of the pressure exerted on the bag by the player's arm. These features allows for the mimicking the feel and responsiveness of the corresponding acoustic instrument. The FrankenPipe is a MIDI controller consisting of an acoustic chanter of a great highland bagpipe that is enhanced with photoresistors placed underneath each hole, and of an air-pressure sensor deployed in the bag [15]. These features allow a player to maintain the physical feel of playing the traditional instrument. In a different vein, more recently, an electronic bagpipe chanter interface and software system has been developed to assist in the process of learning the great highland bagpipe [16–18]. The technology involved in the chanter consists of infrared reflectance sensors, which serve the purpose to de-

[1] http://www.fagerstrom.com/technopipes
[2] http://www.deger.com
[3] http://mastergaita.com
[4] http://redpipes.eu

tect the continuous movements of the player's fingers, and an air pressure sensor, which is used in place of the chanter reed and allows the chanter to be connected to a traditional acoustic set of pipes.

This paper presents the augmentation of a bagpipe typical of the Italian musical tradition: the zampogna. This instrument (described more fully in Section 2) has a long and strong tradition in various Italian regions [19], each of which has given rise a particular model of it. This type of bagpipe has been already object of the interest of researchers in the sound and music computing community. The e-Zampognë is an interface based on the zampogna that is used as a controller for the sound synthesis of various zampogna models [20]. The uniqueness of e-Zampognë lies in the fact that is the sole interface involving double or triple-chanter, while the other systems described above are based on a single chanter. However, all the reviewed systems based on the various bagpipes models have not faced the challenge of augmenting the sonic possibilities of a bagpipe while preserving its original acoustic sound: they are just controller interfaces for sound synthesis.

This research was motivated by the author's artistic need to make the zampogna an interface capable of enabling musical expressions neither achievable with the traditional instrument nor with the application to it of current commercially available technologies for sound processing, nor with the interfaces of current electronic bagpipes. In Section 2 a brief description of the zampogna is provided to make this paper more intelligible to those unfamiliar with the instrument.

2. ZAMPOGNA DESCRIPTION

The zampogna is a bagpipe typical of the central and southern part of Italy [19]. It has a bright and powerful sound very rich in overtones. There are many types of zampogna bagpipes, with the main differences being timbre, tuning, size, number of pipes, and types of materials used. The type of zampogna object of this research is the so-called "zampogna a chiave" (literally zampogna with key), which belongs to the most pure tradition of the Molise region of Italy. Figure 1 illustrates an exemplar of zampogna a chiave crafted by master Luigi Ricci from Scapoli. This particular model of zampogna is identified by four unequal pipes, two chanters and two drones, all with double reeds and all ending with a conical bell to emphasize the sound. The first chanter is a soprano chanter called "ritta" and is played by the fingers of the right hand. It has nine tone-holes but only five are actually used by the hand. The second chanter is a long bass chanter called "manca" and is played by the fingers of the left hand with the exception of the thumb. It has four tone-holes and the last one is covered with a metallic key (from which the epithet "a chiave"). The first drone is called "bordone" and its tuning is changed by the thumb of the left hand. The second drone (not always present in the various zampogna models), is the smallest pipe and is called "fischietto" (literally little whistle). Its tuning is not changeable and can be activated or deactivated thanks to a detachable cap.

Like most of bagpipes, the air supply is achieved by means of a bag (traditionally made of animal skin, e.g., got, but currently mostly with synthetic material, e.g., Gore-Tex) that is held under the player's right arm. The player ensures a steady flow of air through reeds of all pipes by maintaining a constant pressure on the bag with the elbow. As with all bagpipes, it is worth noting that the instrument does not afford a real control on the dynamics. The main difference between zampogna and other bagpipes lies in its polyphonic capabilities due to the number of pipes for melody greater than the usual one. In addition, unlike the vast majority of bagpipes, all the pipes in the zampogna are planted in the same wood block connected to the bag. Regarding tone-holes effects, zampogna allows for partial occlusions: the tone-holes of ritta, manca, and bordone can be gradually covered and uncovered to slide between notes.

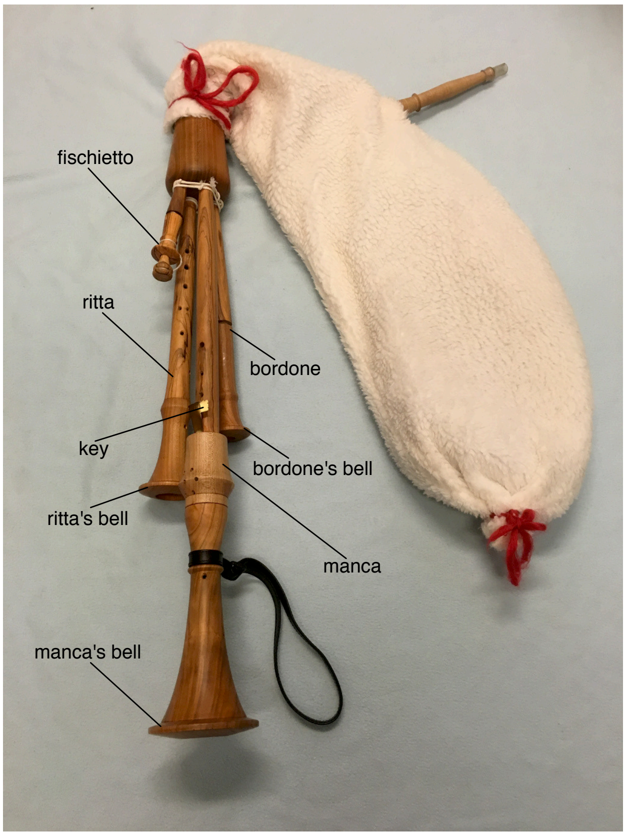

Figure 1. An exemplar of zampogna bagpipe with the indication of its main components.

3. DESIGN

The design of the augmentation of the zampogna bagpipe originated from the results of a long-lasting research on how to extend the sonic possibilities of the instrument and overcoming its limitations when used in conjunction with the most widespread current technologies for sound processing. Such a research was entirely based on the author's personal needs as a performer to avail himself of a novel interface for musical expression, capable of opening unexplored paths for composition, improvisation, and performance. These needs led to the following requirements that guided the design:

- The added hardware technology should have been easy to put on and remove, and the instrument could have been still played in the normal acoustic way. This resulted in the design choice of enhancing the instrument without physically modifying it with holes or carvings;

- The augmentation should have kept unaltered all the conventional set of gestures to play the instrument. This resulted in the minimization of the amount of technology, in its hiding as much as possible from the player's fingers, and by adopting wireless solutions. This also led to the identification of the possible set of new gestures that a performer would act on the instrument without interfering with the natural act of playing;

- The hardware and software technology should have supported the separate tracking and consequent independent modulation of the various pipes;

- The hardware and software technology should have allowed zampogna players to achieve unprecedented musical expressions such as sound modulations, sound spatialization, and generation of additional synthesized sounds.

Considering the set of requirements listed above, the research conducted during the design phase focused on the identification of new possible and reasonable set of gestures that could be added to the normal playing technique, the selection of the types of sensors to track such gestures, the identification of the positions where placing the selected sensors, and on the definition of mapping strategies between the player's gestures and the sound production.

3.1 Interaction design

The design of novel performer-instrument interactions started with the accurate analysis of the zampogna playing technique. This requires to have basically always both hands on the instruments not only to keep the fingering position, but also to sustain the instrument. Therefore, fingers are not really free to move too much from the playing position. Among all possible fingers movements that could be exploited, the author opted for a minimal design which focused only on two new gestures of the thumbs of both hands. These consisted in pressing a rather small area adjacent to the finger-holes played by the thumb on ritta and bordone pipes (see Figure 3) that could be exploited without compromising the natural act of playing. This area of each pipe was the easiest to reach by the thumb at any moment of playing. The player could still use the thumb to play the associated notes as usual and was given the possibility to exert and additional pressure when wanted in order to act on a sensor placed therein. Even in presence of open holes during a musical sentence, such an area could still be easily accessed.

In a different vein, the zampogna is an instrument that affords to be moved in various directions without compromising the natural act of playing. Therefore, a set of gestures associated to the orientation of the instrument was defined. Specifically, front-back and left-right movements of the pipes, as well as their combination, were selected because they were the most natural and easiest to perform. The range of each of these movements was defined as not too wide to avoid to hinder the normal playing technique.

3.2 Hardware identification and placement

The hardware technology involved in the augmentation was designed to consist of microphones to capture the contribution of each pipe, sensors used to track the set of new gestures, and a microcontroller board for the digital conversion of the sensors analog values. The overall setup consisted of a soundcard for the digitalization of the microphones signals, a laptop for the processing of such signals and those of the sensors, and a system of loudspeakers for the sound diffusion.

A fundamental design choice was that of tracking separately the sound of each pipe. This was found to be achievable by placing a small microphone in each of the pipes bells. In particular, only the ritta, manca, and bordone pipes were chosen to be enhanced with such microphones. The reason to exclude the fischietto pipe from such an augmentation was due to its cap mechanism, which made not possible the placement of a microphone inside it.

On the one hand, the microcontroller board was designed to be as small as possible in order to be placed easily on the instrument. On the other hand, it was designed to have wireless connectivity in order to avoid the use of a cable connecting it to the external computation unit. Its best placement was identified on the wooden block where the pipes are planted, being this a part of the instrument not touched by the fingers during the act of playing, and where all cables from sensors could most easily merge.

Regarding the technology to sense the identified new gestures, two types of sensors could be involved: pressure sensors, to track the pressure exerted by the thumbs on the areas specified in Section 3.1, and an inertial measurement unit (IMU) to track the position of the instrument. The placement of the latter was identified on the wooden block as that position did not constitute any hinderance to the fingers movements (see Figure 4).

3.3 Mapping strategies

A set of mapping strategies between the player's gestures and the sound production was investigated. It was important to define mappings that were intuitive to the performer and that took into account electronic, acoustic, ergonomic and cognitive limitations. In order to decide on a particular setup, many questions needed to be answered, such as for instance how many parameters of a sound effect the performer could be able to simultaneously control, or how long a performer would need to practice to become comfortable with a particular setup. These mappings were carefully designed to allow a good integration of both acoustic and electronic components of the performance, resulting in an electronically-augmented acoustic instrument that is respectful of the zampogna tradition.

The design of the interactions described in Section 3.1 allowed for the independent modulation of the sound of each pipe tracked separately. Therefore, one of the mappings that received most attention consisted in the association of a tracked gesture to the sound modulation of a pipe. These associations were defined as:

- the pressure sensor placed on the ritta was associated to the control of the ritta sound, as well as the right-back movement;
- the left-back and left-front movement was associated to the control of the manca sound;
- the pressure sensor placed on the bordone was associated to the control of the bordone sound, as well as the right-front movement.

Another most used mapping focused on the control of both manca and bordone with the same gestures:

- the pressure sensor placed on the ritta was associated to the control of the ritta sound, as well as the right-back movement;
- the pressure sensor placed on the bordone was associated to the control of both manca and bordone sound, as well as the left-back movement.

Figure 2. The developed Hyper-Zampogna.

4. IMPLEMENTATION

4.1 Hardware

The designed augmentation was achieved at hardware level by involving three high quality small microphones, model Sennheiser MKE 1 miniature clip microphone [5], two pressure sensors FSR 400 Force Sensing Resistor [6] manufactured by Interlink Electronics, and the microcontroller board x-OSC [7] manufactured by x-io Technologies Limited.

The x-OSC board was selected for its features: small size, on-board sensors (including an IMU), and wireless transmission of sensors data over Wi-Fi, with a low latency (i.e., 3ms [21]) and via Open Sound Control messages [8]. It was inserted in a plastic box attached with a velcro strip on the wooden block. A velcro strip was also attached to the front part of such plastic box, which allowed the rapid and easy change of attachable batteries.

In order to avoid ruining the wooden parts of the acoustic instrument, a specific low-impact scotch tape strip was placed on all the parts of the instrument where the added hardware was attached. Figure 2 illustrates the Hyper-Zampogna resulting from the augmentation of the zampogna a chiave shown in Figure 1. Figures 3 and 4 illustrate the position of the sensors and microcontroller board in the developed instrument.

[5] http://en-us.sennheiser.com/miniature-clip-on-lavalier-microphone-musicals-live-shows-broadcast-mke-1
[6] http://www.interlinkelectronics.com/FSR400.php
[7] http://www.x-io.co.uk/products/x-osc/
[8] http://www.opensoundcontrol.org/

4.2 Software

A software application was coded in Max/MSP [9] sound synthesis and multimedia platform to implement various sound effects as well as gestures-to-sound parameters mappings. This was achieved by analyzing and processing both the sounds detected from the microphones embedded in the instrument and the data gathered from the sensors.

The placement of the microphones inside the pipes bells allowed for an accurate and separate tracking of ritta, manca and bordone without the need of the application of any further digital signal processing technique to achieve such purpose: the sound of the other pipes was not detected.

The captured acoustic waveforms of each pipe were then processed separately and modulated by the player's interaction with the sensors. This processing consisted in the application of various effects and spatialization techniques. In more detail, various custom effects were implemented mainly involving pitch shifters, vibrato, tremolo, phaser, chorus, wah-wah, parametric equalizers, and dynamics control. Sound spatialization was achieved by defining algorithms used to spatialize virtual sound sources along bi-dimensional and tri-dimensional trajectories in presence of multichannel surround sound systems. For this purpose, the facilities offered by the "Ambisonic Tools for Max/MSP" [22] were exploited.

Moreover, synthesized sound were generated. This was achieved by means of a real-time low latency pitch tracker, whose produced tracked frequencies were utilized to con-

[9] http://www.cycling74.com/

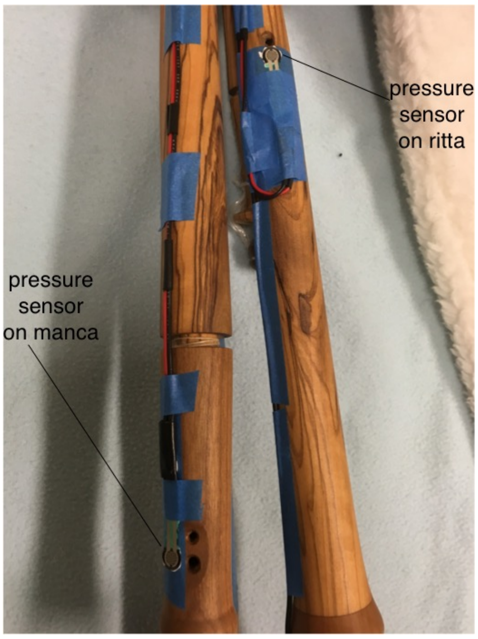

Figure 3. A detail of the involved pressure sensors and their position.

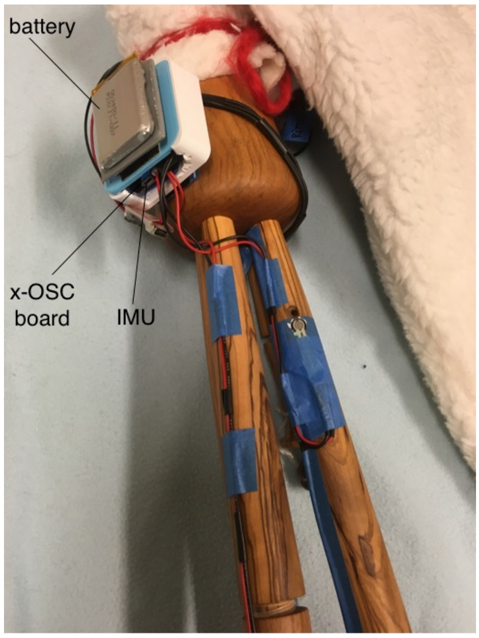

Figure 4. The placement of the wireless microcontroller board with embedded IMU onto the instrument.

trol a custom synthesis module that well merged with the zampogna acoustic sound. The captured sounds before being fed into the pitch tracker underwent a highpass filtering that allowed to achieve an optimal tracking.

Finally, additional mappings were implemented to control various sound effects, synthesizers, loops, and virtual instruments available on the Logic Pro X [10] and Ableton Live [11] digital audio workstations. For this purpose, Max/MSP applications as well as Max for Live devices were implemented, in which the sensors data where processed and converted into MIDI messages.

5. CONCLUSION AND FUTURE WORK

While previous applications of sensors technologies to bagpipes in both academic and industry communities focused on the creation of bagpipe-like controllers for wave-table synthesis or MIDI instruments, this research aimed to an augmentation of the zampogna bagpipe that could fully preserve its original acoustic beheaviour and playing technique. This was achieved by tracking separately the acoustic waveforms of the different pipes as well as modulating both the captured and additional synthesized sounds by means of sensors conveniently located and mapped to digital effects parameters.

The development of the Hyper-Zampogna offered both technical and artistic challenges that the author enjoyed embracing. Analogously to the augmentation of the hurdy-gurdy that he proposed in [11], the augmentation of the zampogna originated from his passion and interest in music technology and traditional instruments, and represents his challenge of combining these two far worlds.

On the one hand, the rationale behind the development of such augmented instrument was to provide electro-acoustic zampogna performers with an interface capable of achieving novel types of musical expression without disrupting the natural interaction with the traditional instrument. On the other hand, this research aimed to provide composers with a new instrument enabling the exploration of novel pathways for musical creation.

The Hyper-Zampogna is currently in a prototype stage and has not been evaluated yet by a zampogna player different from the author. Such an evaluation is planned as well as the use of the Hyper-Zampogna on stage with compositions written by the author.

In future works, the author envisions the extension of the results of this project by means of the creation of a larger palette of sound effects and mapping strategies to control them with the available sensors. In addition, the author plans to augment other types of zampogna different from the zampogna a chiave here involved, such as the "surdulina" and "zampogna gigante" models [19]. A collaboration with a zampogna maker would be beneficial in order to craft from scratch zampogna bagpipes with the sensors and microphones embedded in it.

Finally, it is the author's hope that the results of this research could inspire other builders of augmented instruments to focus on the augmentation of the zampogna bagpipes as well as that composers start writing pieces for it. More information about the Hyper-Zampogna can be found at the author's personal website [12] .

Acknowledgments

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[10] http://www.apple.com/logic-pro/
[11] http://www.ableton.com/
[12] http://www.lucaturchet.it

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