THE HYPER-HURDY-GURDY

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ABSTRACT

This paper describes the concept, design, implementation, and evaluation of the Hyper-Hurdy-Gurdy, which is the augmentation of the conventional hurdy-gurdy musical instrument. The augmentation consists of the enhancement of the instrument with different types of sensors and microphones, as well as of novel types of real-time control of digital effects during the performer's act of playing. 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 the use of the instrument as a controller for digital audio workstations. On the one hand, the rationale behind the development of the instrument was to provide electro-acoustic hurdy-gurdy performers with an interface able to achieve radically novel types of musical expression without disrupting the natural interaction with the traditional instrument. On the other hand, this research aimed to enable composers with a new instrument capable of allowing them to explore novel pathways for musical creation.

1. INTRODUCTION

During last years numerous exemplars of the so-called "hyper instruments" or "augmented instruments" have been developed [1, 2]. These are conventional acoustic instruments enhanced with sensor and/or actuator technology, and digital signal processing techniques, which serve the purpose of extending the sonic capabilities offered by the instrument in its original version. The performer acting on the sensors can control the production of the electronically generated sounds that complement, or modulate, the sounds acoustically generated by the instrument. The attention of builders of such instruments has focused on the augmentation of various types of acoustic instruments (e.g., violin [3–5], cello [6], saxophone [7], flute [8], trumpet [9], or guitar [10–12] and piano [13]), including the traditional ones (e.g., the uilleann pipes [14], the sitar [15], the Tibetan singing bowl [16], the zampogna [17], or the great highland bagpipe [18]).

This paper presents the augmentation of an instrument typical of the musical tradition of many European countries: the hurdy-gurdy. To the author's best knowledge, prior to this work such a challenge was not faced yet. The hurdy-gurdy is one of the few instruments that can boast not only centuries of history, but also a tradition uninterrupted from Middle Age. When the hurdy-gurdy was born presumably in the Middle Age (its ancestor was called "organistrum") it was certainly one of the musical instruments most advanced of that poque from the technological standpoint. During the course of the history the instrument was subjected to several technical improvements [19]. In particular, in the last decades, innovative instrument makers have made many improvements and additions to the instrument in response to the needs of the hurdy-gurdy players wishing to overcome the technical limitations of the traditional instrument and to extend its sonic possibilities. More strings as well as systems to easily change their intonation were added, so the performer could play in a wider number of tonalities compared to that offered by the traditional version of the instrument. Furthermore, the instrument was enhanced with microphones and entered in the realm of the electro-acoustic instruments.

The author's artistic reflection on the development of an augmented hurdy-gurdy started from these considerations on the history of the instrument and aimed at continuing such a developmental path. The main objective of this research project was to provide the hurdy-gurdy with additional possibilities to allow novel musical expressions, while at the same time avoiding the disruption of the natural interaction occurring between the player and the instrument.

In Section 2 a brief description of the hurdy-gurdy is provided to render this paper more intelligible to those unfamiliar with the instrument.

2. HURDY-GURDY DESCRIPTION

The hurdy-gurdy (see Figure 1) is a stringed musical instrument whose sound is produced by turning a crank that controls a wheel rubbing against the strings. Such a wheel is covered with rosin and functions much like a continuous violin bow. The vibration of the strings is made audible thanks to a soundboard. Melodies are played on a keyboard that presses small wedges against one or more strings (called "chanterelles") to change their pitch. Moreover, hurdy-gurdies have multiple "drone string", which provide a constant pitch accompaniment to the melody. Each of the strings can be easily put on or removed from the contact with the wheel.

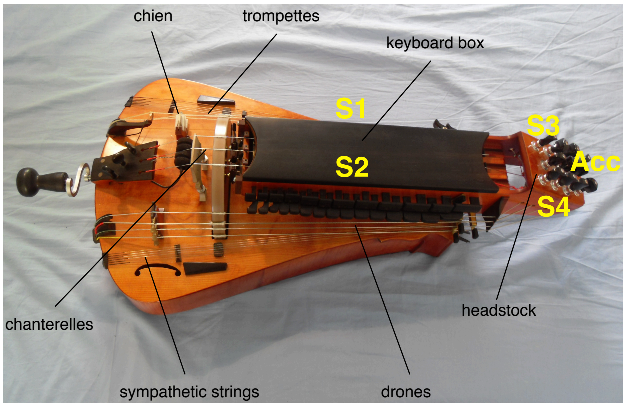

Figure 1. An exemplar of electro-acoustic hurdy-gurdy with the indications of its main components and the identified sensors positions.

Hurdy-gurdies are able to provide percussive sounds produced by means of one or more buzzing bridges. These are called “chiens”, act like a sort of hammer having a tail and a free end, and are placed under one or more drone strings called “trompettes”. The tail of such chiens is inserted into a narrow vertical slot that holds them in place, while their free end rest on the soundboard and is more or less free to vibrate. It is precisely the vibration of the free ends of the chiens that produce the unmistakable percussive sound of the instrument: when the wheel is turned slowly the pressure on the trompettes strings holds the chien in place, sounding a drone, while when the crank is accelerated, the hammer lifts up and vibrates against the soundboard producing the characteristic buzzing noise. Such a buzz is used as an articulation or to provide rhythmic percussive effects.

Recently a new model of electro-acoustic hurdy-gurdy has been crafted by the luthier Wolfgang Weichselbaumer [1] (see Figure 1). One of the many novelties lies in the complex system of six embedded microphones placed in as many parts of the instrument in order to track the sound of each component: one piezo-electric microphone is placed under the buzzing noise bridge capable of detecting mainly the contribution to the instrument sound given by the trompettes strings; one piezo-electric microphone is placed under the wooden part where the drones were positioned, capable of tracking mainly their contribution; one piezo-electric microphone is placed under the bridge of the chanterelles positioned capable of tracking mainly their contribution; two one piezo-electric microphones are placed in correspondence of the two sets of sympathetic strings, capable of tracking mainly their contribution; one omnidirectional small microphone placed near the chanterelles bridge, capable of tracking the overall acoustic sound of the instrument. Each of the five present microphones is able to track with high precision the richness of the sound of each component. Such a microphone system is at the basis of the augmentation presented in this paper.

[1] http://www.weichselbaumer.cc/

3. MAIN CONCEPTS

The first step to satisfy the goal of augmenting the hurdy-gurdy to achieve a novel interface for musical expression, capable to open radically new paths for composition and performance, consisted in determining the needs and conditions to meet for the new instrument. This research started by the author’s questioning about his personal needs, as a performer, of extending the sonic possibilities of the instrument and overcoming its limitations when used in conjunction with the most widespread current technologies for sound processing. Such need resulted in the following requirements.

The first requirement consisted of enhancing the instrument without physically modifying it with holes, carvings or attaching new pieces of wood for instance: the technology should have been easy to put on and remove, and the instrument could have been still played in the normal acoustic way, if wanted.

The second requirement was to augment the instrument in such a way that the conventional set of gestures to play the instrument would remain unaltered: the instrument should have kept working in the conventional way after the augmentation. For this purpose, the way of playing the instrument was analyzed in order to identify the possible set of new gestures that a performer would act on the instrument without interfering with the natural act of playing. The right hand appeared immediately the most difficult to act on. This was due to the complexity of tracking the quick and subtle movements (especially small variations in acceleration) of the wheel, wrist and fingers while turning the crank. A solution was attempted by placing some accelerometers attached to the wrist, but the tracking resulted not to be optimal due to accuracy and latency issues. A possible solution to track the wheel would have been that of using magnets inserted into it and leveraging the so-called “hall effect”. However, these solutions would have required the performer to wear some sensors (e.g., wireless bracelets, or wireless boards with embedded accelerometers), which would have been perceived as obtrusive, or to groove some carvings into the wheel to put magnets and cope with the problem of having some cumbersome cables placed on the instrument: this not only would have limited the ease of playing and even of moving the instrument, but also would have affected the robustness of the added technology. For these reasons, the research was focused on the tracking of the left hand gestures and of the orientation of the instrument.

The third requirement consisted of limiting as much as possible the unwanted interactions of the performer with the technology added to the instrument different from the sensors. This resulted in reducing at the minimum the amount and the length of the involved wires, and to hide as much as possible the technology inside the instrument as well as by adopting wireless solutions.

The fourth requirement was to allow hurdy-gurdy performers to achieve unprecedented sound modulations. In first place, this consisted of enabling the possibility of exerting a strict control of a sound effect at note level. Indeed, by means of current technologies a hurdy-gurdy performer can use an effect (e.g., a delay) to control the sound modulation of a whole musical sentence, but can not apply that particular effect on a single note of the musical sentence and keep the other notes unaffected by that effect. In second place, the augmentation had to provide the possibility to modulate separately the sound produced by the various components of the instrument (see Section 2). This could be only possible by involving a set of microphones and a palette of signal processing algorithms capable of detecting and isolating such components. In third place, performers had to be able to avail themselves of sound effects specifically built for the various components of the instrument that could allow to transcend the physical limitations of the instrument itself. For instance, smooth and long glissando and bending are not possible on the traditional instrument. Analogously, the frequency of a drone could be modulated to add some vibrato (thing not possible on the conventional instrument since the drones are not pressed by the fingers) or the sound of a single chanterelle could be transformed into a bi-chord.

4. DESIGN

4.1 New gestures identification

The design process started with the identification of a new possible set of gestures that could be reasonably added to the normal playing technique without disrupting it. The most important of these are the following:

- while playing the chanterelles by means of the fingers acting on the keys of the keyboard, the thumb is normally free and can be exploited to press an area of the keyboard or slide upon it;
- the pinkie can be used to press a key, the index to press an area of the keyboard, and the thumb to press another another area of the instrument placed at a even larger distances from the keyboard;
- when the fingers are not involved in acting on the keys (e.g., when chanterelles are used to produce their sound as open strings, or when sympathetic strings are plucked) the left hand is totally free and different fingers could press/slide on various areas of the instrument even very far from the keyboard;
- all these new added gestures, as well as the ones of the conventional playing technique, can be performed simultaneously with tilting up and down or forth and back the whole instrument.

4.2 Hardware technology identification an placement

The technology involved in the augmentation (additional to the set of embedded microphones already present) was designed to consist of sensors used to track the set of new gestures and a microcontroller board for the digital conversion of the sensors analog values. Three types of sensors could be involved:

- pressure sensors, to track pressure of the fingers on an area of the instrument;
- ribbon sensors, to track the position of the fingers on an area of the instrument;
- accelerometers to track the tilting of the instrument.

A first design choice was that pressure and ribbon sensors had to cover relatively wide areas in order to achieve an optimal accessibility. The use of strip-shaped sensors of various lengths was considered the optimal choice for this purpose. A second design choice was to place a ribbon sensor on top of a pressure sensor in order to detect simultaneously the information about the pressure force exerted by the finger as well as its position on a certain part of the instrument. The microcontroller board was designed to be as small as possible in order to be placed easily on the instrument, and to have wireless connectivity in order to avoid the use of a cable connecting it to an external computation unit responsible for processing both the microphones and the sensors signals.

The number and placement of the identified sensors and microcontroller board represented a challenging problem due to the complexity of the shape of the hurdy-gurdy, the hardware limitations of the sensors themselves, and the set requirement of keeping unaltered the natural interaction of the player with the instrument. Four pairs of pressure-ribbon sensors and one 3-axis accelerometer were chosen. The four pairs of sensors were placed on top of the keyboard box (see “S1” in Fig. 1); at the side of the keyboard box (see “S2” in Fig. 1); on the top of the headstock (see “S3” in Fig. 1); on the bottom of the headstock (see “S4” in Fig. 1). These positions were chosen for their easiness in reachability with the fingers and because they did not interfere neither with the normal way of playing nor with the functioning of the various components of the instrument. The best position to place the accelerometers was identified to be on the interior part of the headstock (see “Acc” in Fig. 1), since it did not interfere with the placement of the other sensors and could easily be attached to the instrument. The best position for the microcontroller board was also identified as the space behind the headstock. This choice was motivated by the fact that the wires coming out from the sensors could reach the board easily, with the shortest distance, and without interfering with the functioning of the various components of the instrument. In addition, in that position the board was hidden from the sight and above all it could be naturally protected from unwanted collisions.

4.3 Mapping strategies

The design for the interactive control of the developed instrument was based both on the extraction of features from the data captured by sensors and from the acoustic waveforms captured by microphones. A set of mapping strategies between the performers 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.

The hurdy-gurdy is an instrument with an intrinsic high level of affordances as far as the features suitable for the control of the digital sound production are concerned. It can be used as a percussive, melodic and accompanying instrument, and from all of these characteristics it is possible to find a variety of potential controls by extracting acoustic features from the sound captured by the microphones. These controls can be used in conjunction with those resulting from the interaction with sensors.

The first step in the mappings design process consisted of defining associations of each pair of sensors to a component of the instrument. Sensors placed in positions S1, S2, S3, and S4 indicated in Fig. 1 were mainly used to control the sound captured by the microphones of the chanterelles, trompettes, sympathetic strings, and drones respectively. Nevertheless, such associations could change in such a way that the same pair of sensors could control more than one instrument component, or, vice versa, more than one pair of sensors could control a single instruments component. The second step consisted of the definition of the mappings between the performers gestures acted on the sensors and the parameters of the selected algorithms for the various sound effects. 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 hurdy-gurdy tradition.

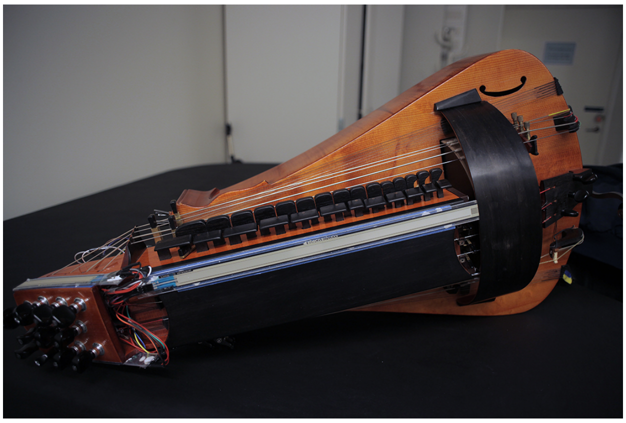

Figure 2. The developed Hyper-Hurdy-Gurdy.

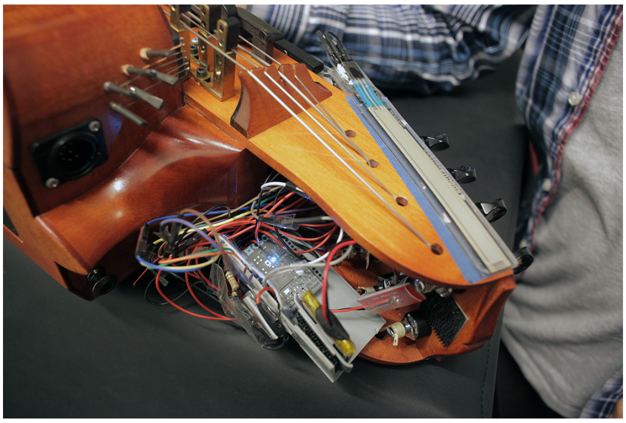

Figure 3. The placement of the wireless microcontroller board on the instrument.

5. IMPLEMENTATION

5.1 Hardware

The designed augmentation was achieved at hardware level by involving the pressure sensors FSR 408 Strip Force Sensing Resistor [2] manufactured by Interlink Electronics, the ribbon sensors Soft Pot [3] manufactured by Spectra Symbol, and the microcontroller board x-OSC [4] manufactured by x-io Technologies Limited.

In each of the four ribbon-pressure sensor pairs, the ribbon sensor was attached, thanks to its adhesive film, on top of the pressure sensor in order to create a unique device capable of providing simultaneous information about position and pressure of the finger interacting with it. The pressure sensor was in turn attached, thanks to its adhesive film, to a plastic rigid support, which was appropriately cut in order to meet the size of the sensors. This support was involved for two reasons. The first one was that placing the sensors directly on the instrument did not allow an optimal tracking of the forces and positions exerted by the fingers on the sensors due to the fact that in some cases (e.g., the keyboard box) the wood could slightly move up and down, and a more rigid, homogenous, and stable base was needed. The second one was that thanks to the support the created device could be easily attached or removed to the instrument. In order to avoid ruining the wooden parts of the acoustic instrument, a specific low-impact scotch tape strip was placed on the part of the instrument where the plastic support was attached.

The x-OSC board was selected for its features: small size, on-board sensors (including a 3-axis accelerometers), and wireless transmission of sensors data over WiFi, with a low latency (i.e., 3ms [20]) and via Open Sound Control messages [5]. Figures 2 and 3 illustrate the position of the sensors and microcontroller board in the developed instrument.

5.2 Software

As far as the software is concerned, the Max/MSP [6] sound synthesis and multimedia platform was utilized. An application was coded to implement the designed sound effects and mappings, by analyzing and processing both the sounds detected from the microphones embedded in the instrument and the data gathered from the sensors.

The first issue encountered was that the microphones were not effective in detecting separately each of the components of the instrument. For instance, the sound produced by the drones was in part detected by the microphones of

[2] http://www.interlinkelectronics.com/FSR408.php
[3] http://www.spectrasymbol.com/potentiometer/softpot
[4] http://www.x-io.co.uk/products/x-osc/
[5] http://www.opensoundcontrol.org/
[6] http://www.cycling74.com/

the chanterelles; similarly, the microphone of the trompettes detected also the sound of the chanterelles. A complete isolation of such components is not possible in an acoustic instrument such as the hurdy-gurdy since the vibrations produced by one component propagate everywhere in the instrument and are detected by contact microphones or external microphones placed in a whatever part of the instrument. Therefore, some signal processing techniques were needed to achieve the goal of isolating as much as possible the sound of each component in order to process it separately. For instance, a low pass filter was applied to the input signal coming from the microphone of the drones in order to limit the amount of signal resulting from playing the chanterelles. Vice versa, a high pass filter was applied to the signal coming from the contact microphone placed on the chanterelles bridge to limit both the low frequencies produced by the drones and of the noise of resulting from pressing the keys. Ad hoc signal processing algorithms were also implemented for analyzing the captured acoustic waveforms in order to achieve particular sound effects. For example, to extract only the buzzing noise component from the sound produced by the trompettes, a signal gate was involved which was activated according to a threshold set on the sound amplitude. The specific research challenge in using all the algorithms for processing the captured acoustic waveforms was that of finding the best combination of the algorithms parameters in order to achieve the best result.

Furthermore, in presence of the hits on the crank made in order to produce the buzzing noises, the resulting impulsive variation in the acceleration tracked by the accelerometers needed to be excluded. To solve such issues, various mean filters, median filters, and low pass filters, were applied. These processing techniques were effective in smoothing the rapid variations happening in the signal. However, their application had the side effect of introducing latency. Therefore, a large amount of research consisted in finding the right values for the parameters of such filters in order to achieve the best tradeoff between the accuracy in tracking and the latency of the response produced by the filters.

Once a good tracking of both performer's gestures and instrument components sounds was achieved, several mappings were implemented. Examples of these are the following [7] :

- The amount of volume of a sound effect was mapped to the amount of pressure exerted by a finger on a pressure sensor, such that when the sensor was not pressed the effect was not activated, and when it was pressed the presence of the effect could be modulated individually for each note.

- The sliding of the finger on a ribbon sensor was mapped on the amount of frequency transposition in a pitch shifting algorithm such as the glissando effect could be produced.

- The combination of the use of both the pressure and ribbon sensors for the previous two mappings resulted on a glissando effect whose activation depended on the presence of the finger on the sensor, the frequency transposition depended on the finger position, and the volume depended on the amount exerted pressure force.

- The amount of up-down or back-forth tilting movements tracked by accelerometers was mapped to the activation of an effect: when the amount of tilting overcame a certain threshold the effect was activated. This way of using the tilting as a switch for an effect rather than a continuous control was due to the fact that great displacements from the normal position of the instrument could be tracked in a easier way and were subjected to less variations. Indeed the rapid and strong movements produced while playing the hurdy-gurdy with the buzzing noise of the trompettes could lead to impulsive variations in the signal acquired by the accelerometers, and this could not adapt well for a continuous control usage.

Moreover, a variety of mappings were defined on the basis of 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" [21] were used.

Finally, additional mappings were implemented to control various sound effects, synthesizers, loops, and virtual instruments available on the Logic Pro X [8] and Ableton Live [9] 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.

6. EVALUATION

The developed instrument was subjected to extensive tests aimed to validate the implemented augmentation from the technological and expressive standpoints. In addition to the author's own evaluation, the Hyper-Hurdy-Gurdy was tested by Johannes Geworkian Hellman [10] , a well known hurdy-gurdy performer and virtuoso. The testing session was conducted in a acoustically isolated room of the KMH Royal College of Music of Stockholm and lasted about one hour. The setup consisted of the developed Hyper-Hurdy-Gurdy configured to have all sensors mapped to at least one parameter of a sound effect, a soundcard (Fireface UFX), two loudspeakers (Genelec 8050B Studio Monitor), and a laptop (Macbook Pro) running the software applications described in Section 5.2.

The session consisted of three parts, which took about 10, 35, and 15 minutes respectively. In the first part the performer was asked to interact with the instrument without receiving any information about the added technology. This procedure was adopted in order to assess the very first

[7] A comprehensive list of audio-visual examples of the implemented mappings is available at:
https://www.youtube.com/watch?v=9c1QFg2bG9w

[8] http://www.apple.com/logic-pro/
[9] http://www.ableton.com/
[10] http://www.johannesgeworkianhellman.com/

approach with the instrument. During this part, only the four pair of sensors were explored. The mappings related to the accelerometers were not detected. This was due to the fact that the position of the instrument was not tilted and the accelerometers, differently from the other sensors, were not visible. The associations between the sensors and the corresponding controlled components of the instrument were all identified and understood.

In the second part the various sensors and mappings were explained, and questions were made regarding the appropriateness of the sensors position, intuitiveness of the mappings involved, and the effectiveness of the types of sound effects utilized. The performer reported to have appreciated the fact that the sensors were placed in ergonomic ways, they were easy to reach while normally playing, and they did not require too much force to be activated. Moreover, very positive comments were reported about the effectiveness of all the implemented mappings, in particular about the appropriateness and accuracy of all the involved ranges of the parameters. One of the most relevant comments was *"With this instrument I can easily apply and control an effect to each note I produce, so now I can do things that I could not achieve with the controls for the effects I normally use."* Interestingly, from some comments it emerged the need of having available some discrete controls in addition to the continuous ones present.

In the third part, the performer was asked to play the instrument, taking advantage of the new affordances offered by the instrument and exploring the novel possibilities for improvisation. As one would expect a final comment was *"I think one would need a lot of exploration and experience to learn how to really use these new possibilities"*. Nevertheless, overall, his feedback was very positive and confirmed the goodness of the author's design choices.

7. HYPER-HURDY-GURDY IN LIVE PERFORMANCE

The Hyper-Hurdy-Gurdy has been used for musical creations and performances purposes. It was premiered at the Audiorama concert venue in Stockholm in April 2015. A 21-channels composition, named "Incantesimo", for solo Hyper-Hurdy-Gurdy was performed. Subsequently, various pieces were composed and performed by the author both as a soloist and in chamber orchestra. Videos documenting a technical demonstration of the Hyper-Hurdy-Gurdy and its usage in live performances are available on the author's personal website [11] . Those live performances constitute the final validation of the developed instrument.

8. CONCLUSIONS AND FUTURE WORK

On the one hand, the rationale behind the development of the instrument was to provide hurdy-gurdy performers with an interface able to achieve novel types for musical expression without disrupting the natural interaction with the traditional instrument. On the other hand, this research aimed to enable composers with a new instrument capable of allowing them to explore novel pathways for musical creation. The proposed research resulted in an augmented instrument suitable for the use in both live performance, improvisation, and composition contexts. Novel timbres and forms of performer-instrument interactions were achieved, which resulted in an enhancement of the conventional electro-acoustic performances as well as in a variety of new compositional possibilities.

This augmentation of the traditional hurdy-gurdy originated from the author's two passions and interests: traditional instruments and music technology. The development of the Hyper-Hurdy-Gurdy and the compositions for it represent the author's challenge of combining these two far worlds. This research was motivated by the author's need to investigate new paths for individual musical expressions as well as to research how to progress the possibilities for music creation with the hurdy-gurdy and electronics normally associated to it. At the conclusion of the project, it is the author's opinion that the developed instrument is effectively capable of responding to such needs. Undoubtedly, these needs are also shared by many musicians and composers who constantly search for novel tools and ideas for their artistic works. However, in the author's vision, completely novel paths are not practically possible with the current conventional acoustic and electro-acoustic hurdy-gurdies, since basically all the expression possibilities available with them have been already investigated. With the introduction of a novel generation of Hyper-Hurdy-Gurdies, the possibilities for absolutely novel musical research paths are countless, and revolutionary approaches to composition and improvisation can be explored. The pieces that the author composed and performed might be considered as a proof of these statements.

As far as future works are concerned, the author envisions various possibilities for extending the results of this project. First of all the collaboration with an instrument maker would be beneficial in order to craft from scratch a hurdy-gurdy with the sensors embedded in it. Secondly, different types as well as a larger number of sensors could be added. In particular a set of small and fully configurable buttons and knobs placed onto the instrument would be useful to change presets of sounds effects and/or mappings: this would allow to avoid the use of external tools dedicated for this purposes such as footpedals. Furthermore, an actuated system could be added in a way similar to that proposed for the actuated violin presented in [22] or the smart guitar developed by Mind Music Labs [23].

Finally, it is the author's hope that the results presented in this paper could inspire other digital luthiers, performers, and composers to continue this research on augmenting the hurdy-gurdy as well as on composing for it.

Acknowledgments

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