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Hyper-Hurdy-Gurdy

Skriftlig reflektion inom självständigt, konstnärligt arbete

Det självständiga, konstnärliga arbetet finns dokumenterat

på DVD: "The_integrated_consciousness"

och pdf: "The_integrated_consciousness.pdf"

Kungl. Musikhögskolan

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1 Introduction

The topic of new technologies for musical expression and artistic performance is timely and is receiving a growing attention by the sound and music computing community as demonstrated by the increasing number of scientific works and artistic performances dedicated to it. In addition, several are the international conferences that currently stimulate the development of new instruments: the New Interface for Musical Expression[1], the International Conference on Digital Audio Effects[2], the International Computer Music Conference[3], and the Sound and Music Computing Conference[4].

The application of engineering and computer technology to music creation has introduced new possibilities to invent musical instruments [1]. Meanwhile, the progress in instrument design has generated questions about the quality, expressivity, or consistency of such novel interfaces and about comparisons with the conventional acoustic instruments [2].

Consequently, during last years a large amount of new interfaces and gestural controllers have been proposed. Among the numerous examples, one can mention the augmented instruments, which are conventional acoustic instruments enhanced with sensors technology. The performer acting on the sensors can control the production of the electronically generated sounds which are based on or complement the sounds acoustically generated by the instrument. Typically, the augmentation of an acoustic instrument can be done both at hardware and software level.

On the one hand, it consists of enhancing an instrument with sensors capable of tracking different gestures of a performer. On the other hand, the augmentation

[1] http://www.nime.org

[2] http://www.dafx.de

[3] http://www.computermusic.org

[4] http://www.smc-conference.org

consists of the analysis and processing of both the sensors data and the sound of the instrument to extend the sonic capabilities offered by the instrument in its original version. Examples of these instruments are the augmented violin [3], the augmented cello [4, 5], the augmented saxophone [6, 7], the hyper flute [8, 9], or other instruments proposed by Perry Cook [10].

Some principles for the design of such new musical interfaces have been proposed in [10, 11, 12]. Research has also focused on the importance of mapping strategies (i.e., methods to transform a performer's gesture into a digital sound) [13, 14], which have an important impact on how the instrument may be played and on how the audience may perceive the performance. Evaluation methods for these new kinds of musical devices have been proposed [15]. Furthermore, research has also focused on the extraction of acoustic parameters from the sounds produced by musical instruments [6, 16, 17, 18].
Starting from all those results my two years-project for the master degree in Electro-Acoustic Music consisted of the augmentation of an instrument typical of the musical tradition of many European countries: the hurdy-gurdy (see Section 1.1). Prior to this work such a challenge was not faced yet.

1.1 Hurdy-gurdy description

The hurdy-gurdy is a stringed musical instrument that produces sound by a crank-turned rosined wheel rubbing against the strings (see Figure 1). The wheel functions much like a violin bow, and single notes played on the instrument sound similar to a violin. Melodies are played on a keyboard that presses tangents (small wedges, usually made of wood) against one or more of the strings to change their pitch. Like most other acoustic string instruments, it has a soundboard to make the vibration of the strings audible. Moreover, hurdy-gurdies have multiple “drone string”, which provide a constant pitch accompaniment to the melody, resulting in a sound similar to that of bagpipes. Each of the strings can be easily put on or removed from the contact with the wheel.

Hurdy-gurdies are able to provide percussive sounds produced by means of a buzzing bridge on one drone string. This mechanism consists of a loose bridge under a drone string. The tail of this buzzing bridge is inserted into a narrow vertical slot that holds the buzzing bridge in place.

The free end of the chien (called "hammer") rests on the soundboard of the hurdy-gurdy and is more or less free to vibrate. When the wheel is turned slowly the pressure on the string (called "trompette") holds the bridge in place, sounding a drone. When the crank is accelerated, the hammer lifts up and vibrates against the soundboard, producing a characteristic rhythmic buzz that is used as an articulation or to provide percussive effect.

The sensitivity of the buzzing bridge can be altered by turning a peg called a tirant in the tailpiece of the instrument that is connected by a wire or thread to the trompette. The tirant adjusts the lateral pressure on the trompette and thereby sets the sensitivity of the buzzing bridge to changes in wheel velocity. There are various stylistic techniques that are used as the player turns the crank, speeding up the wheel at various points in its revolution. Each sped-up "hit" produces a distinct buzzing sound. These hits are under the control of the player, and are not automatic, having to be put in with each complete turn of the wheel.

The musical repertoire has been steadily extended since approximately 1980 and the players soon encountered the technical limitations of the hurdy-gurdy. Innovative instrument makers have made many improvements and additions to the instrument in response to wishes of the musicians.

Electronics have also made inroads into hurdy-gurdies so that they can be amplified. Recently a new model of electroacoustic hurdy-gurdy has been crafted by the luthier Wolfgang Weichselbaumer[5] (see Figure 2). One of the many novelties lies in the complex system of microphones placed in different parts of the instrument in order to track the sound of each component (e.g., the buzzing bridge, the drones, the chanterelles, etc.). Each of the five present microphones is able to track with high precision the richness of the sound of each component.

[5] http://weichselbaumer.cc

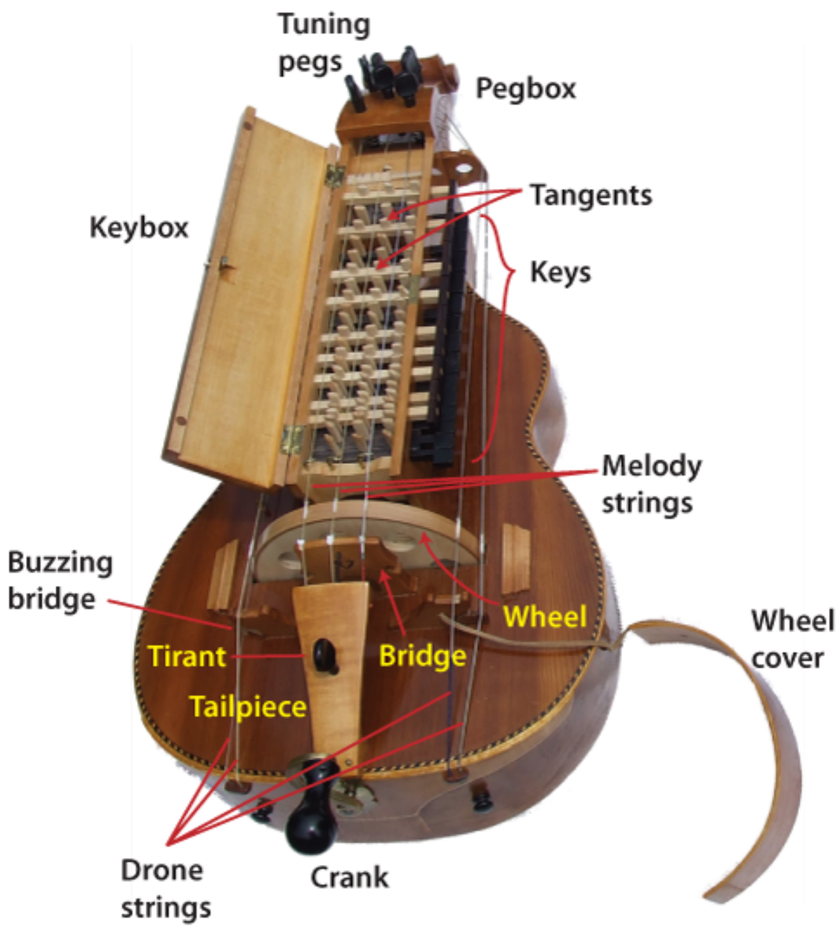

Figure 1. The hurdy-gurdy components[6].

[6] *The image has been taken from http://www.wikipedia.org.*

Figure 2. *The electro-acoustic hurdy-gurdy crafted by the luthier Wolfgang Weichselbaumer, "Viola" model.*

Common terms used for describing the various components of the instrument are the following:

- *trompette*: the highest-pitched drone string that features the buzzing bridge
- *mouche*: the drone string pitched a fourth or fifth below the trompette
- *petit bourdon*: the drone string pitched an octave below the trompette
- *gros bourdon*: the drone string pitched an octave below the mouche
- *chanterelles*: melody strings, also called chanters in English
- *chien*: (literally "dog" in French), the buzzing bridge
- *tirant*: a small peg set in the instrument's tailpiece that is used to control the sensitivity of the buzzing bridge

1.2 Objectives and motivations

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[7] (its ancestor was called "organistrum") it was certainly one of the musical instruments most advanced of that époque from the technological standpoint. During the course of the history the instrument was subjected to several technical improvements (e.g., the addition of the buzzing bridge for the trompette not present before the XVI century[8]), and the concept of a producing sounds by the friction of a string on a wheel was even source of inspiration for the development of the "viola organista" musical instrument invented by Leonardo da Vinci. In the last decades instrument makers tried to extend the sonic possibilities of the hurdy-gurdy by adding more strings as well as systems to easily change the intonation of the trompettes and of the drones, 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. To date the point of arrival of this evolution is certainly represented by the "Viola" model crafted by the luthier Wolfgang Weichselbaumer in collaboration with the worldwide famous hurdy-gurdy virtuoso Valentin Clastrier (see Figure 2).

My artistic reflection on the development of a new hurdy-gurdy started from these considerations on the history the instrument and aimed at continuing such an evolution 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. Being a hurdy-gurdy player, this project was motivated by my personal expressive need of extending the sonic possibilities

[7] As testified by its representation sculpted in the "Portico de la Gloria" of the Santiago de Compostela Cathedral.

[8] As testified in the painting *"The Garden Of Earthly Delights"*, by Hieronymus Bosch, 1490 – 1510.

of the instrument: this not only in terms of a novel sound production, but also in terms of new types of sound control. However, such an instrument was conceived not exclusively for a personal usage, but to allow the next generation of hurdy-gurdy performers to avail themselves of novel types instrument-performer interactions and to explore new ways for musical expression. More importantly, the expected outcome of this study was an instrument that could be suitable for the use in both live improvisation and composition contexts.

2 Methodology

This chapter describes the development process followed to augment the hurdy-gurdy crafted by the luthier Wolfgang Weichselbaumer (see Chapter 1). The augmentation consisted on the enhancement of the instrument with different types of sensors and microphones, as well as on the real-time control of digital effects during the performer's act of playing. The development of the instrument followed the following work packages (WPs):

WP 1: Analysis of requirements. During WP 1 the needs and conditions to meet for the new instrument were determined. Specifically, on the one hand, the performers' needs and possible interaction strategies were investigated. On the other hand, the research focused on the analysis of the requirements that the technologies had to support in order to meet these needs of the performers. The types of sensors technology that were needed were also pinpointed.

WP 2: Design. During WP 2 the research focused on investigating the positions where placing the sensors individuated in WP 1. In addition, mapping strategies between the performer gestures and the sound production were defined.

WP 3: Implementation. During WP 3 the hurdy-gurdy was augmented according to the outcomes of the previous WPs. The needed hardware and software applications were implemented.

WP 4: Evaluation. During WP 4 each hardware and software component of the prototype was extensively tested. Moreover, a usability experiment was conducted with a professional hurdy-gurdy performer. The evaluation allowed to improve the implementation of WP3 as well.

WP 5: Composition and performance. During WP 5 the prototype was utilized for musical creations and performances purposes.

In more detail, the instrument development process followed an iterative life cycle model[9] where the WPs listed above where not completed totally one after the other but incrementally with iterations intended to review and improve each step.

2.2 WP 1: Analysis of requirements

The first step to satisfy the goal of augmenting the hurdy-gurdy in order to achieve a novel interface for musical expression, capable to open new paths for composition and performance, consisted in determining the needs and conditions to meet for the new instrument. This research started by questioning myself what I needed as a performer to extend the sonic possibilities of the instrument and overcome its limitations when used in connection with the most widespread current technologies for sound processing.

The first requirement I set was to enhance the instrument without physically modifying it with holes, carvings or attaching new pieces of wood for instance: the technology should have been easily put on and removed, and the instrument could have been 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. 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

[9] http://en.wikipedia.org/wiki/Iterative_and_incremental_development

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 placed on it and leveraging the so-called "hall effect"[10]. 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 on 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, I chose to focus my research on the tracking of the left hand gestures and of the orientation of the instrument. This required to answer to the following questions: i) which types of gestures could be exploited; ii) which types of sensors could be used to track such gestures; iii) where the sensors should be placed on the instrument; iv) how they could be activated independently or simultaneously. During the development process, various sensors and their placements were investigated. In the following I only summarize the choices adopted in the final version of the instrument.

While playing the melodic strings by means of the keys on the keyboard the thumb can be exploited to press a sensor. These gestures produced by the thumb can be tracked by sensors capable of detecting simultaneously the pressure force and the position along a specific area. To a certain extent this would not interfere with the normal way of playing. In addition, it could be in principle possible to use the pinkie to press a key, the index to press a sensor placed on the keyboard and the thumb to press a sensor placed at a even larger distances from the keyboard. Moreover, when the melodic strings do not need to be played, the left hand is totally free and could act on sensors placed very far from the keyboard, and more than one sensor could be in principle activated by different fingers.

[10] http://en.wikipedia.org/wiki/Hall_effect

Furthermore, all these gestures can be performed simultaneously with tilting up and down or forth and back the whole instrument. Such movements can be tracked by three-axis accelerometers or gyroscopes.

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 as much as possible 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 that of using sensors and an acquisition board for the sensors data that could lead to an accurate and low latency tracking. Specifically, particular attention was given to reducing the message loss probability, data distortion, and latency in the data transmission. This was a fundamental aspect in order to build a reliable and real-time system for analysis of the performer gestures and for the processing of the sounds produced. Furthermore, in the choice of the technology to be used, particular attention was given to cost-effective solutions.

The fifth requirement I set concerned the control of the sound production. In order to accomplish an instrument that could allow a hurdy-gurdy performer to achieve unprecedented sound modulations, I focused on 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 cannot decide to apply that particular effect on a single note of the musical sentence and keep the other notes unaffected by that effect. In addition to this, I aimed at having an instrument in which I could modulate separately the sound produced by the various components of the instrument (i.e., the melodic strings, the sympathetic strings, the buzzing bridge, the drones, and the trompettes). This is only possible by involving a set of microphones and a palette of signal processing algorithms capable of detecting separately such components.

The sixth requirement consisted in the definition of sound effects specifically built for the various component of the instrument that could allow to transcend the physical limitations of the instrument. 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 melodic string can be transformed into a bi-chord.

Finally, the seventh requirement was to involve computationally efficient algorithms for the analysis and processing of the sensors' data and of the acoustic waveforms captured by the microphones. This aspect was fundamental for a practical usage of the instrument in real-time contexts such as live performances.

2.2 WP 2: Design

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 on the acoustic waveforms captured by microphones. The placement of sensors represented a challenging problem due to the complexity of the shape of the hurdy-gurdy and the hardware limitations of the sensors themselves. In the design phase, particular care was devoted to maintain the natural interaction of the player with the instrument, limiting the amount of new gestures required to act on the new interface and avoiding cumbersome technological solutions.

The hurdy-gurdy is an instrument with an intrinsic high level of affordance 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. Accordingly, a set of mapping strategies between the performer's gestures and the sound production needed to be investigated. It was important to determine mappings that were intuitive to the performer and that took into account electronic, acoustic, ergonomic and cognitive limitations. As a consequence, a requirement for the proposed augmentations was to allow intuitive mapping possibilities for a playable and consistent instrument without reducing the richness of the original instrument.

The first design choice consisted on the selection of the type of sensors to be used. Among the various possibilities I opted for strip sensors that could detect position and pressure exerted by a finger. This choice was motivated not only by the requirements set illustrated in previous section, but also by the shape of the sensors themselves: strip sensors of various lengths could occupy a rather large area of the instrument and, therefore, they could be reachable easily by the fingers.

As far as the second design choice is concerned, the number of sensors, the features of the microcontroller board for the digital conversion of the sensors' analog data, and the sensors' placement on the instrument were defined. In the final prototype I used 4 pairs of pressure-ribbon sensors (in each pair a sensor was placed on top of the other, see Section 2.3.1), and a three-axis accelerometer, for a total of 9 sensors. The choice of placing a ribbon sensor on top of a pressure sensor was fundamental. This was motivated by the need of detecting 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 required on the one hand to be as small as possible, in order to be placed easily on the instrument, and on the other hand to have wireless connectivity, in order to avoid the use of a cable connecting it to the computer processing both the sound and the sensors' data. Figures 8 and 9 illustrate the positions identified for both sensors and microcontroller board. The 4 pairs of sensors were placed i) on top of the keyboard box (S3); ii) at the side of the keyboard box (S1); iii) on the top of the headstock (S2); iv) on the bottom of the headstock (S4). 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 on the headstock, since there the vertical displacement from the position in which the instrument is usually played could be maximum. The best position for the microcontroller board was 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.

The third design choice consisted of the association of each pair of sensors, placed in the position mentioned above, to a component of the instrument. S1, S2, S3, and S4 were mainly used to control the sound captured by the microphones of the trompettes, sympathetic strings, melodic strings, and drones respectively. Nevertheless, such associations were not strict. For composition purposes, they could change in such a way that the same pair of sensors could control more than one instrument's component, or, vice versa, more than one pair of sensors could control a single instrument's component.

The fourth design choice consisted of the types of sound effects to be used. Such a choice was mainly due to the needs I felt for writing my first compositions for the instrument. Among others, I used various types of reverb, delay, pitch shifting, vibrato, tremolo, and the combination of thereof.

The fifth design choice concerned the definition of the mapping strategies between the performer's gestures acted on the sensors and the parameters of the algorithms for the various sound effects. The mappings were carefully designed to allow a good integration of both acoustic and electronic components of the performance, resulting in one single instrument: an electronically-augmented acoustic instrument that is respectful of the tradition. Therefore, the electronics was used to extend the timbre palette of the acoustic instrument by transcending its physical limitations. In order to decide on a particular setup, many questions needed to be answered, such as for instance which sensors represented the best solution for the performer's needs, 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. Various mappings were defined, but only a subset was used in the final version of the prototype. Examples of these mappings are the following. 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 is not pressed the effect is not activated, and when is pressed the presence of the effect can 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 two mentioned effects 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. As far as the accelerometers are concerned, they were used to track the tilting of the instrument up and down or back and forth. The amount of such tilting movements was mapped to the activation of an effect such that when the amount of tilting overcome 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. The DVD attached to the thesis contains audio-visual examples of some of the utilized mapping strategies. They are summarized in the Appendix.

2.3 WP 3: Implementation

This section describes the hardware and software solutions adopted according to the requirements and design choices defined in the previous WPs. In particular, it motivates the selection of such solutions identified among those available in commerce.

2.3.1 Hardware Technology

The involved hardware technology consisted of a set of microphones embedded in the instrument, sensors and a wireless micro controlled board for the digital conversion of the analog values of the sensors. They are illustrated in the following sections.

Microphones

The hurdy-gurdy crafted by the luthier Wolfgang Weichselbaumer was conceived and developed according to my needs, so to have 6 embedded microphones. These consisted of:

- one piezo-electric microphone placed under the buzzing noise bridge capable of detecting mainly the contribution to the instrument's sound given by the trompettes strings.
- one piezo-electric microphone placed under the wooden part where the drones were positioned, capable of tracking mainly their contribution.
- one piezo-electric microphone placed under the bridge of the melodic strings positioned capable of tracking mainly their contribution
- two one piezo-electric microphones placed in correspondence of the two sets of sympathetic strings, capable of tracking mainly their contribution
- one omni-directional small microphone placed near the melodic strings bridge, capable of tracking the overall acoustic sound of the instrument

The instrument was also enhanced with a set of five knobs for the adjustment of the input volumes of the various microphones.

Sensors

During the two years in which the project lasted, I had tried out a large variety of sensors in order to understand their potentialities to answer to my needs as performer and composer. In the final version of the instrument two types of sensors were chosen among those tested: ribbon sensors and pressure sensors. These sensors were chosen because of their capability of tracking two types of gestures, respectively linear position and pressure force.

Among the ribbon sensors available on the market, I chose to use the Soft Pot[11] manufactured by Spectra Symbol[12] (see Figure 3) due to its features. This is a little ribbon controller (also known as "soft potentiometer") with an adhesive backing. It is available in different dimensions: length: from 10mm to 2000mm, width: 20.50mm, thickness: 0.58mm (such a thickness makes it the thinnest linear sensor available today). There is a nominal 10K ohm resistance across the two outer leads. The middle pin resistance with respect to either of the outer pins changes depending on where on the strip one presses.

Among the available pressure sensors, I chose the FSR 408 Strip Force Sensing Resistor[13] (see Figure 4) manufactured by Interlink Electronics[14] due to its features. It consists of a robust polymer thick film sensor that exhibits a decrease in resistance with increase in force applied to the surface of the sensor. It is available in any active length up to a 609.6mm X 10.2mm width active area. The sensor can be ad hoc cut to suit a particular length.

[11] http://www.spectrasymbol.com/potentiometer/softpot

[12] http://www.spectrasymbol.com

[13] http://www.interlinkelectronics.com/FSR408.php

[14] http://www.interlinkelectronics.com

Figure 3. The Soft Pot ribbon sensor from SpectralSymbol utilized in the final prototype.

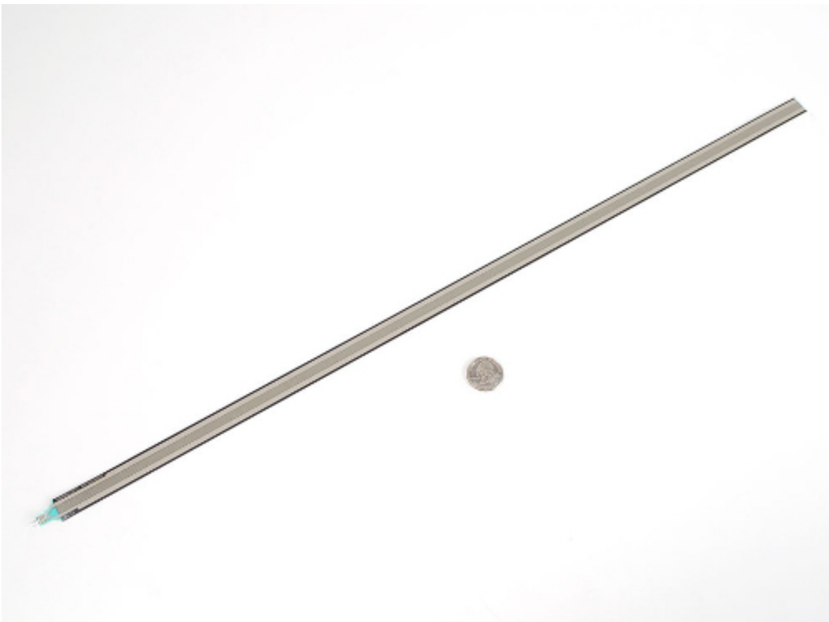

Figure 4. The FSR 408 Strip Force Sensing Resistor pressure sensor from Interlink utilized in the final prototype.

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.

Microcontroller board

To achieve a natural performer-instrument interaction, the quantities measured by the sensors needed to be estimated with high accuracy without introducing delays. After trying out different micro controller boards (e.g., Arduino Mega[15], Brain Junior[16]), I opted for the x-OSC board[17] developed by x-io Technologies Limited[18] (see Figure 5). The x-OSC is a wireless I/O board that provides just about any software with access to 32 high-performance analogue/digital channels and on-board sensors (gyroscope, accelerometer, magnetometer) via Open Sound

[15] http://arduino.cc/en/Main/arduinoBoardMega

[16] http://lividinstruments.com/products/builder/

[17] http://www.x-io.co.uk/products/x-osc/

[18] http://www.x-io.co.uk/

Control (OSC) messages over WiFi [19]. There is no user programmable firmware and no software or drivers to install making x-OSC immediately compatible with any WiFi-enabled platform. All internal settings can be adjusted using any web browser. This board was chosen for the following reasons:

- it is small (45 × 32 × 10 mm) so it could be easily inserted in the instrument
- it has wireless connectivity (so no extra wires between the instrument and the computer performing calculations are involved)
- it has a latency of 3ms (more details on the wireless transmission protocol can be found in [19])
- data are streamed according to the Open Sound Control protocol.
- both the board and the battery could be easily attached to a plastic support

Figure 5. The x-OSC wireless microcontroller board.

As reported in the Open Sound Control website[19], *"OSC is a protocol for communication among computers, sound synthesizers, and other multimedia devices that is optimized for modern networking technology. Bringing the benefits of modern networking technology to the world of electronic musical instruments, OSC's advantages include interoperability, accuracy, flexibility, and enhanced organization and documentation. This simple yet powerful protocol provides everything needed for real-time control of sound and other media processing while remaining flexible and easy to implement. There are dozens of implementations of OSC, including real-time sound and media processing environments, web interactivity tools, software synthesizers, a large variety of programming languages, and hardware devices for sensor measurement. OSC has achieved wide use in fields including computer-based new interfaces for musical expression, wide-area and local-area networked distributed music systems, inter-process communication, and even within a single application."*

2.3.2 Software Technology

The software consisted of an application that served the purpose of analyzing and processing both the sounds detected from the microphones embedded in the instrument and the data gathered from the sensors in order to implement the designed sound effects and mapping strategies.

The Max/MSP sound synthesis and multimedia platform was utilized[20]. The choice of this platform was due to different reasons. First of all, it was OSC- and MIDI-compatible, so it was the appropriate platform to communicate with the involved hardware technology through the OSC and MIDI protocols. Secondly, it allowed the real-time analysis and processing of the data coming from the sensors

[19] http://opensoundcontrol.org/

[20] http://cycling74.com

as well as of the acoustic waveforms coming from the microphones. Thirdly, it allowed to implement in an easy way the mapping strategies between the performer gestures and the parameters of the involved sound effects. Fourthly, it was the programming language for real-time audio processing that I knew better and which I had more experience with.

The first issue encountered in the implementation of the sound effects 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 the melodic strings; similarly, the microphone of the trompettes detected also the sound of the melodic strings. 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 melodic strings. Vice versa, a high pass filter was applied to the signal coming from the contact microphone placed on the melodic strings' 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.

A second issue that I encountered consisted on unwanted behaviors of the signals coming from sensors and accelerometers. These signals had in some cases problems of noise disturbance that might be due to several reasons, e.g., distortion in the wireless transmission for a small amount of time. Moreover, the accelerometers had a too much high sensitivity to small variations in acceleration that needed to be reduced for an effective use. Furthermore, in presence of the hits on the crank made in order to produce the buzzing noises, the resulting impulsive variation in the acceleration needed to be excluded. To solve such issues, various mean filters, median filters, and low pass filters, were applied. These processing techniques are 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.

Another aspect of the research on the optimization of the sensors' behavior was that of finding the range of values in which each sensor worked better for the variations in dynamics that I needed for expressive purposes.

As far as the algorithms for the sound effects are concerned, I used different types of reverb, delay, pitch shifting, vibrato, tremolo, and the combination of thereof. The majority of them was coded by myself from scratch by combining the standard routines of Max/MSP. I only used an external library for the reverb effect. I addition, I defined a variety of algorithms for sounds spatialization using a surround sound system composed by various loudspeakers and I leveraged the facilities offered by the "Ambisonic Tools for Max/MSP"[21] [20] to spatialize virtual sound sources along bi-dimensional and tri-dimensional trajectories.

At the core of the software application there is the implementation of the mapping strategies between the performer's gestures and the parameters of the sound effects. An example of the implementation of these strategies is illustrated in the

[21] https://www.zhdk.ch/index.php?id=icst_ambisonicsexternals

screenshot of the Max/MSP patch reported in Figure 6. As it is possible to notice, the sound captured by the microphone corresponding to the melodic strings (already high-pass filtered), is processed in different ways. In the first, the sound is kept unaltered and, depending to the tilting of the instrument along the vertical axis above a certain threshold, a version of the sound transposed to the superior octave is summed. The resulting sound is then spatialized along the output channels 1, 3, 5 and 7. The second mapping strategy consists in applying a delay line with feedback to the sound resulting from the transposition to the superior octave activated by the tilting of the instrument. The amplitude of such a delay effect is modulated by the pressure force exerted on the sensor pressure sensor in the pair S3. Therefore, to get the processing resulting from the combination of the pitch shifting and delay effects the performer must tilt the instrument on a certain degree and simultaneously press the pair of sensors S3. Finally the sound is delivered on the output channels 2, 4, 6, and 8. In the third mapping strategy the sound is fed to an algorithm of pitch shifting where the amount of transposition is modulated by the position of the finger on the ribbon sensor in the pair S1. In this way a glissando effect can be produced by sliding the finger up and down on the sensor. The amplitude of this effect is modulated by the pressure force detected by the pressure sensor of the same pair S1. Finally the sound is fed to a delay line with feedback and delivered on the output channels 2, 4, 6, and 8.

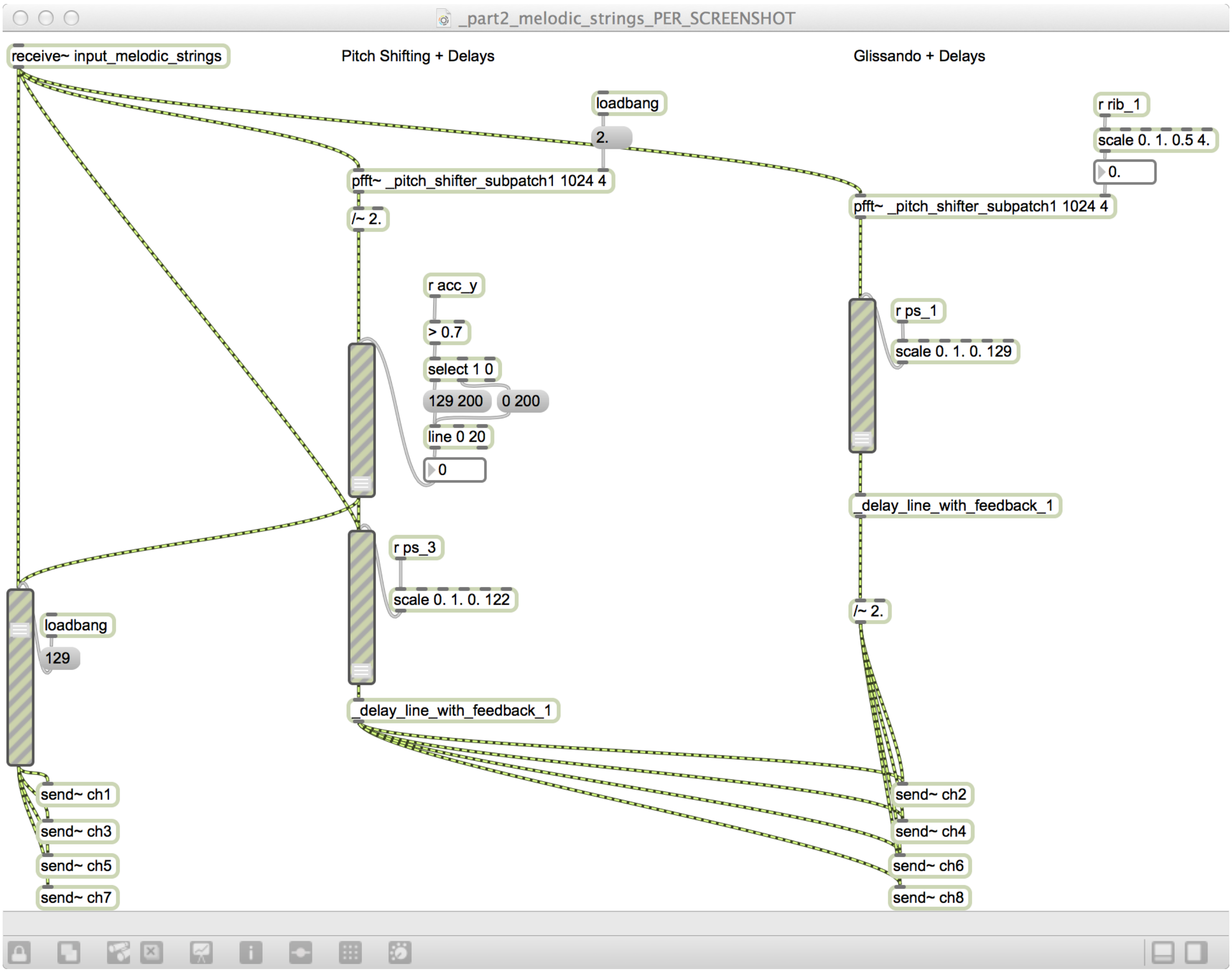

Figure 6. *A screenshot of one of the coded Max/MSP patches implementing some mapping strategies.*

2.4 WP 4: Evaluation

A key aspect of the project consisted of the validation of the proposed instrument during each phase of its development. Extensive tests were conducted with particular regard to the functioning of the sensors, the involved algorithms for sound processing and their computational efficiency during the real-time usage, as well as the utilized gesture-to-sound mappings. Such validation phases were fundamental to direct my research towards efficient and effective solutions for my needs. In particular, it allowed me to improve the implementation choices done during WP3. As a result of the overall evaluation process the final version of the prototype as described in previous sections was accomplished (see Figures 7 and 8)

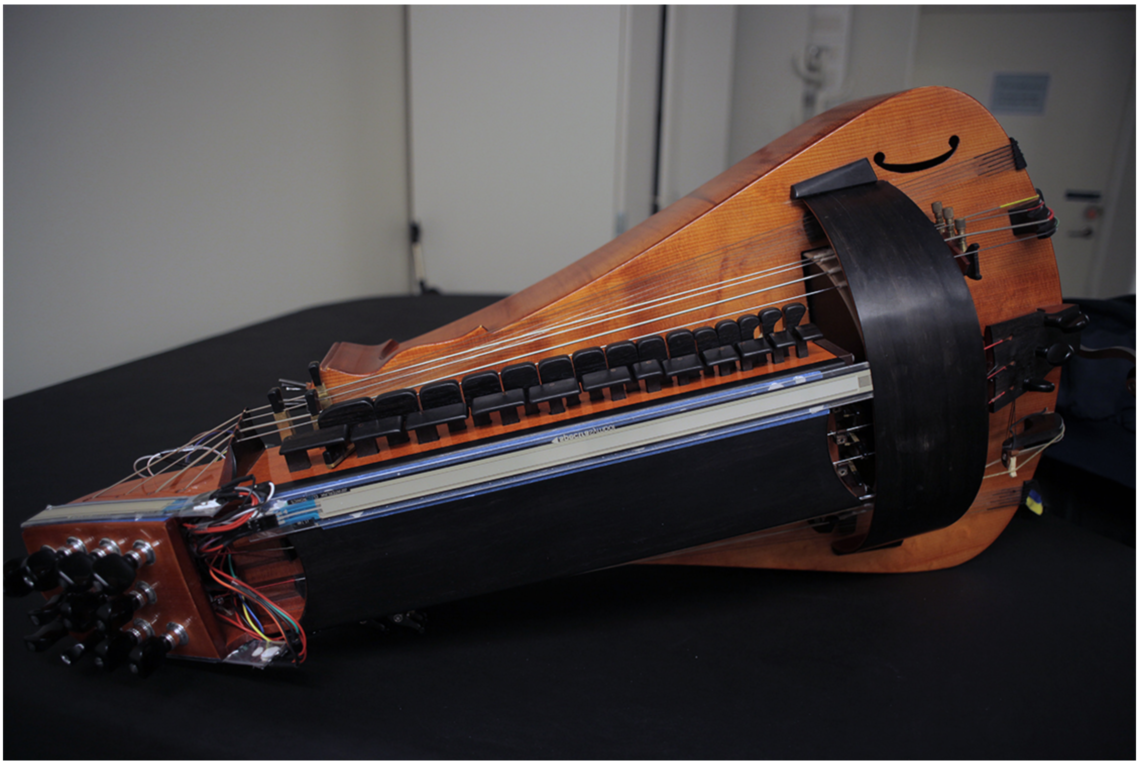

Figure 7. The final prototype of the hyper-hurdy-gurdy.

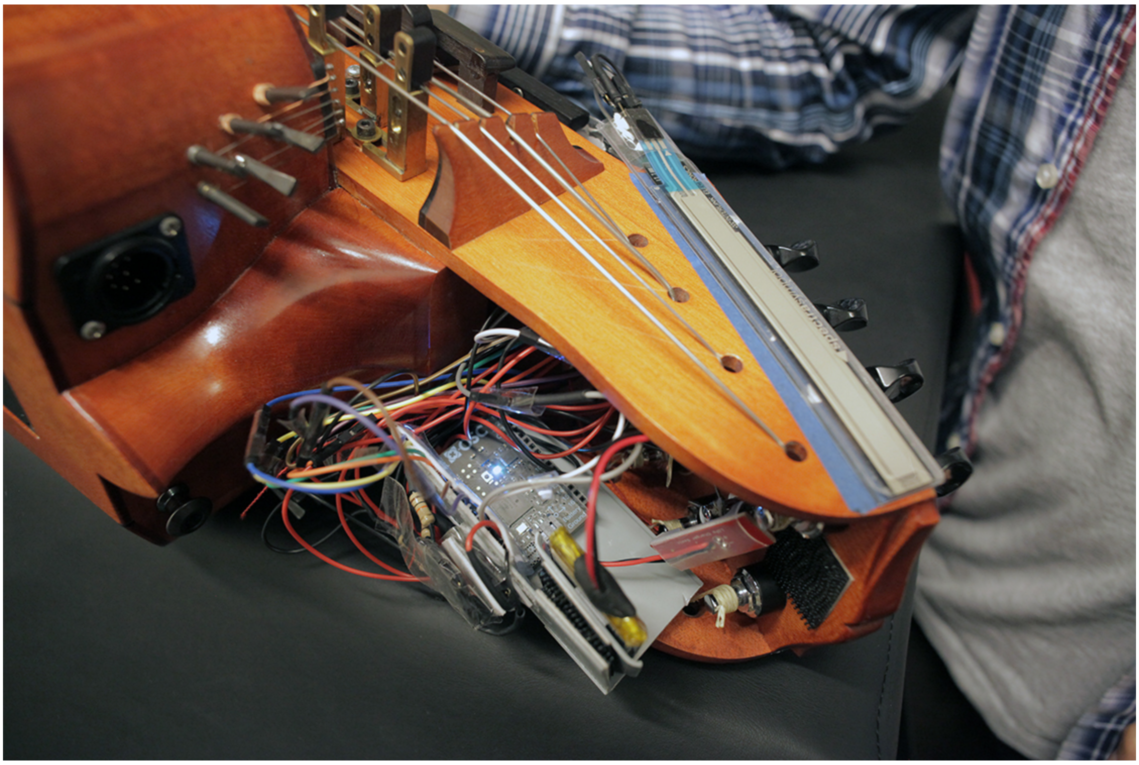

Figure 8. *The placement of the microcontroller board on the instrument*

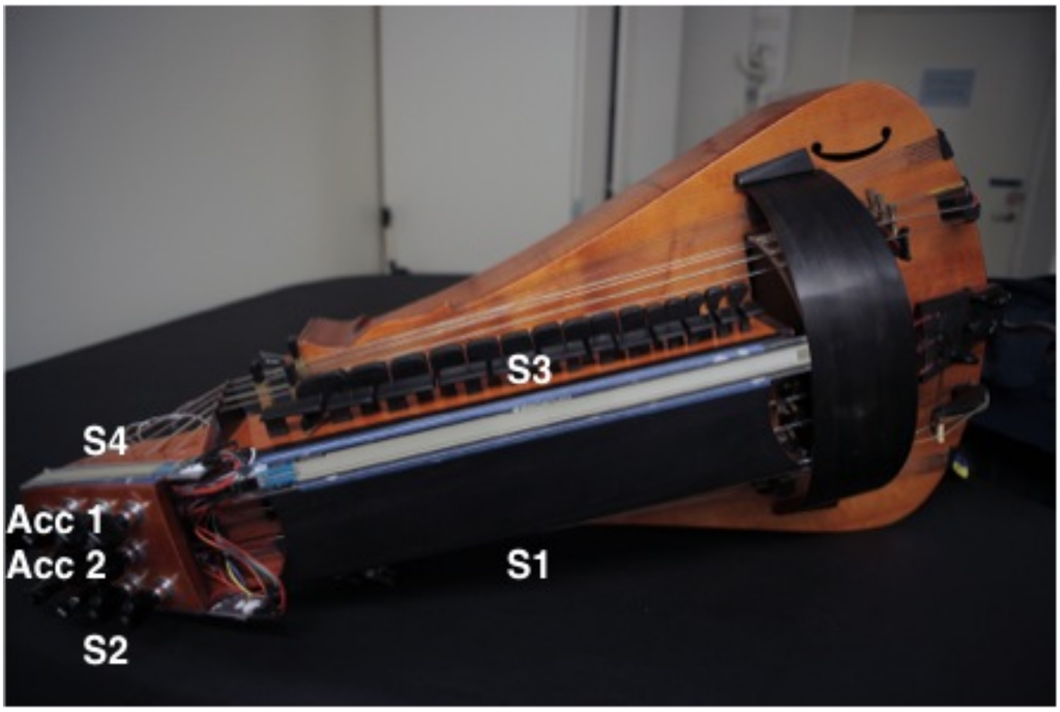

Figure 9. Name and position for the utilized sensors.

The first version of the prototype was available at the end of the first year of my master studies. At hardware level it consisted of the same 8 sensors involved in the final version but with a wired connection to the computer (an Arduino microcontroller board was involved in place of the x-OSC board). At software level, it consisted of a palette of sounds smaller than that used in the final prototype. That initial version served as a proof of concept and allowed not only to validate the developed technology but, more importantly, to explore its expression capabilities and the possibilities for artistic creation.

In addition, the first version of the prototype was also tested by Johannes Hellman, an excellent professional hurdy-gurdy performer, student at the Folk Music Department of the KMH Royal College of Music. The testing session lasted about one hour. During that time he could try the various sound effects I developed. 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. Overall his feedback was very positive and confirmed the goodness of my design choices.

2.5 WP 5: Composition and performance

As a result of the first explorations about the expression possibilities of the first version of the prototype, I composed my first piece for hyper-hurdy-gurdy (which is also the first in the history), and I performed it at the Audiorama concert venue in Stockholm on the 11th of April 2014. The piece was called “Incantesimo”, which means “enchantment” in Italian. It was inspired by my readings about shamans’ rituals. It is conceived to have a magical and ritual character. It was 20 minutes long and involved 21 loudspeakers placed around the audience. The performance was positively welcomed by the audience and the instrument met the interest and curiosity of several people that at the end of the concert asked for details about it.

During the second year of my master studies I could explore extensively the possibilities for musical creation offered by the technology I developed. This research led me to compose a second piece called “The integrated consciousness” for hyper-hurdy-gurdy and chamber orchestra. It was 30 minutes long and involved 8 loudspeakers placed around the audience. I performed it together with KammarensembleN at the Stora Salen of the KMH Royal College of Music in Stockholm on the 19th of April 2015. The composition is shortly described in the next chapter.

3 Work presentation

This chapter gives of an overview of the composition I wrote for my master degree exam concert, taking into account the conceptual, compositional, and technological standpoints.

The title of the composition is “The Integrated Consciousness” and it is for hyper-hurdy-gurdy and a chamber orchestra composed of 13 musicians, and a surround sound system composed by 8 loudspeakers placed around the audience and orchestra (see Figure 10 for the musicians’ stage positioning and for the loudspeakers’ placement). The chamber orchestra involved the following instruments:

- Flute, Bass Flute
- Oboe
- Clarinet
- Soprano Saxophone, Tenor Saxophone
- Bassoon
- French Horn
- Trombone
- Percussions: Bass Drum, Triangle, Tam Tam (small), 2 Tom-toms, Snare Drum (always con corde), Glockenspiel, Crotales, and Tubular Bells
- Piano
- Violin
- Viola
- Violoncello
- Double Bass (5 strings, with a low C string)

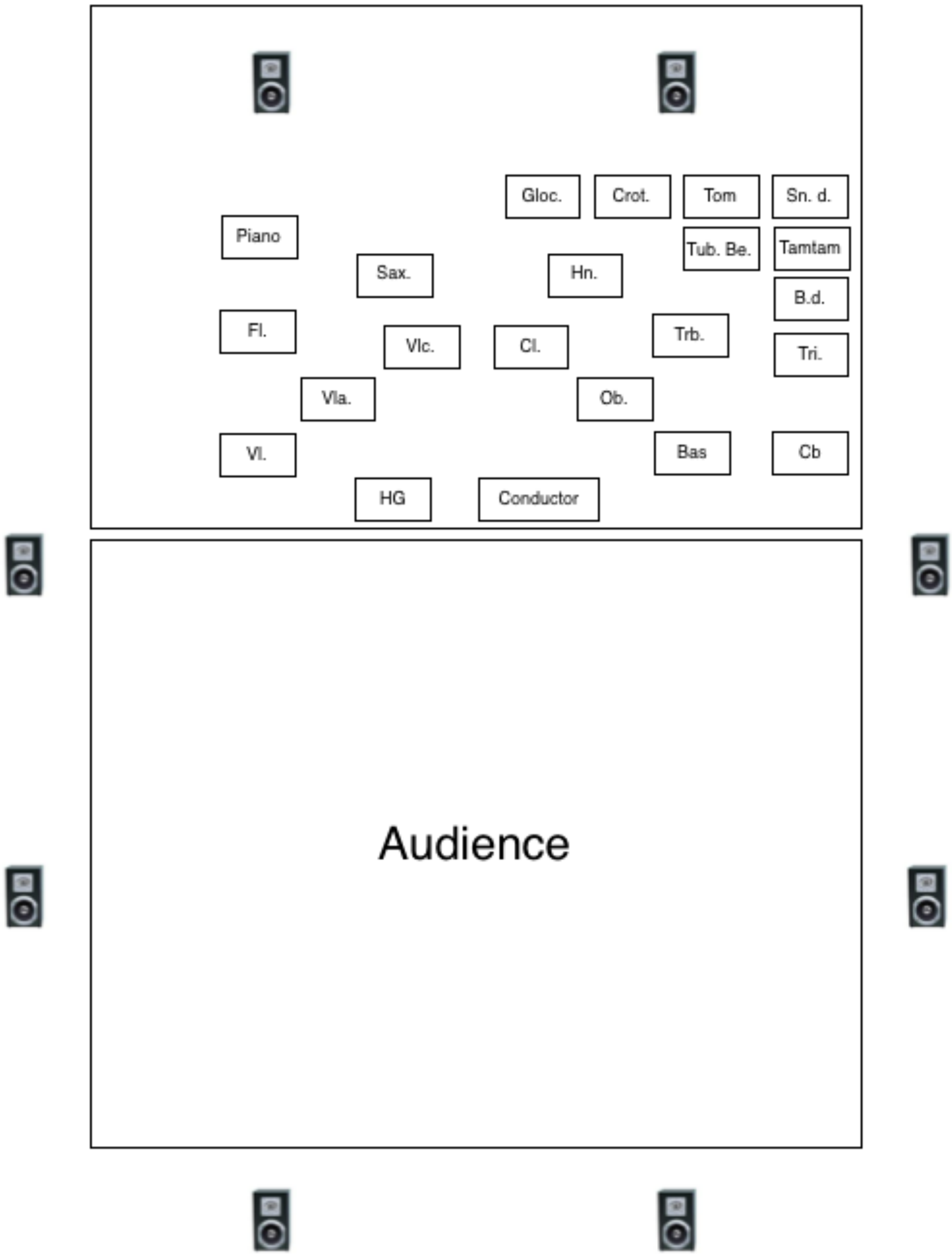

Figure 10. Stage positioning for the musicians and placement of the surround sound system.

The composition makes use of the following equipment:

- Computer running the Max/MSP software
- MIDI footpedal controller, connected to the computer
- Soundcard with at least 5 input channels and 8 output channels
- 16 microphones to amplify each instrument of the chamber ensemble (2 microphones for the piano, 1 microphone for the pair Glockenspiel-Crotales, and 2 microphones for all the other percussion)
- 8 identical loudspeakers
- Mixer with at least 24 input channels

3.1 Aims and concepts at the basis of the composition

The composition was inspired by my readings of the books written by Prof. Corrado Malanga about the human being as well as the genesis and structure of the universe. Hereinafter, I briefly summarize some of his findings and theories just for the sake of illustrating some of the concepts I relied on in order to compose my piece. A more detailed explanation can be found in [21, 22, 23].

In his research, highly based on quantum physics theories (such as the Theory of the Holographic Universe of David Bohm), as well as neuroscience, psychology, mythology, and philosophy, Malanga arrived to formulate a general scheme of the structure of the universe as well as of the human being. According to his theories, the various parts of the universe can be described by coordinates on four axes: Time, Space, Potential Energy, and Consciousness. The latter is the "real" part of the universe, that is something not mutable, what gives the life. It is something outside the Time, the Space and the Energy. These three axes are the "virtual" part of the universe, i.e. the physical world, all what can be modified. In this environment, any piece of matter is a set of points of the virtual part of the universe, which can be described by a mathematical operator called "spin", in the form of magnetic, electric and gravitational field.

On the other hand, living beings have, in addition to this set of points, also a component related to Consciousness. In particular, the human being is composed by four components: Body, Mind, Spirit, and Soul. Such components are related to the general scheme of the Universe in the following way: the Body can be described by the three virtual axes (Space, Time, Energy) but not by the Consciousness axis. In this view, the body is simply a piece of matter without life. What gives the life to a human being is present in the other three components (Mind, Spirit, and Soul), which have got the axis of Consciousness. Specifically, the Mind can be described by a point that has coordinates on the axes of Space, Time, and Consciousness, but not on the Energy; the Spirit can be described by a point that has coordinates on the axes of Energy, Time, and Consciousness, but not on the Space; the Soul can be described by a point that has coordinates on the axes of Space, Energy, and Consciousness, but not on the Time. Table 1 schematically summarizes these concepts.

	Space	Time	Energy	Consciousness
Body	Yes	Yes	Yes	No
Mind	Yes	Yes	No	Yes
Spirit	No	Yes	Yes	Yes
Soul	Yes	No	Yes	Yes
Integrated Consciousness	Yes	Yes	Yes	Yes

Table 1: General scheme of the human being's components according to Corrado Malanga.

The three components also represent different aspects in a human being: the Spirit is the male part of the self, as well as the rational part, the one that relies on rules; the Soul is the female part of the self, as well as the irrational/anarchic/creative part; the Mind is the conscious part of the self, and the one that acts as a link between Spirit and Soul.

In addition to this, the three virtual axes are composed by two opposite parts separated by a center of inversion. Therefore, another important concept at the basis of Malanga's theory is that of dualism. Such a concept is also intrinsically present in the distinction between the virtual and real parts of the universe. Notably, in Malanga's view, this is also linked to the concept of free will.

Furthermore, according to Malanga's theories, which seem to find confirm in the traditional mythology of various ancient cultures, at the beginning of times, Mind, Spirit, and Soul were a unique thing, which was subsequently divided into three parts. The human being in his life should aim, through a process of increasing awareness, at integrating such components together and to become an Integrated Consciousness.

The aim I set out to achieve with this work has been the representation of such concepts by means of a composition that makes use of modern technologies for music creation. My composition tried to represent through music, a content that by its own nature is very complex and difficult to communicate, but that is simultaneously wonderful and fascinating to me. Therefore, one could consider my piece as a sort of program music, since I attempted to musically render an extra-musical narrative.

All the concepts mentioned above were rendered in music through composition's form, structure and compositional strategies. These are briefly illustrated in the following sections.

3.2 Composition's form

The closest form to that of this piece is that of the concerto from the Classical period onwards, since it is a musical composition in which a solo instrument is set off against a chamber ensemble. Similarly to concerti, in my piece the soloist has the main role (e.g., he/she often plays the melody) while the orchestra has a background role (e.g., it often plays the accompaniment), as well as the soloist and chamber ensemble alternate episodes of opposition, cooperation, and independence in the creation of the music flow. This particular form was chosen because, in my aims, it could adapt well to transfer in music the concept of dualism.

Concerti were principally designed as works to demonstrate the virtuosity of the soloist, and they were often written for the composer's own use as a soloist. In addition to this, my composition aimed to emphasize the features of the developed instrument, its use, and above all the novelties in the expression possibilities.

However, it differs from the conventional concerto because it has not some of its typical features. First of all the piece is structured in five movements, while typically the concerto has three movements, and the tempi of the movements are not disposed according to the fast-slow-fast pattern of the concerto. In addition, usually the first movements of concerti follow the structure of sonata form and the final movements are often in rondo form.

3.3 Composition’s structure

The piece is composed of five movements:

1. “Body”
2. “Mind”
3. “Spirit”
4. “Soul”’
5. “Integrated Consciousness”

Each movement aimed at representing through music the concepts of the four components of the human being according to Malanga’s theories, as well as the result of their integration. Since in Malanga’s view the four components were described by coordinates along the four axes Time, Space, Energy, and Consciousness, I set at the basis of the composition of the five movements some associations between those axes and some musical parameters. Specifically, I associated Time with rhythm, Space with harmony, Energy with melody, and Consciousness with pitched sounds.

In addition to this, I took into account the characteristics of the four components and I associated them with some musical parameters. Maleness was associated with frequency, rationality with a rigid definition of rhythmical patterns and tempi.

As a consequence of all these considerations I could characterize the five movements in the following ways:

1- Since according to Malanga's theory the body was described by Space, Time and Energy but not Consciousness, the Body movement was characterized by a predominance of un-pitched sounds.

2- Since the mind was described by Space, Time, and Consciousness but not Energy, the Mind movement was characterized by the presence of pitched sounds, rhythm, harmony, and by the absence of a melody. This movement was also characterized by a predominance of medium frequencies.

3- Since the spirit was described by Energy, Time, and Consciousness but not Space, the Spirit movement was characterized by the presence of pitched sounds, rhythm, melody, and by the absence of a harmony. This movement was also characterized by a predominance of low frequencies. Moreover, other characteristics of this movement were fast tempos and defined rhythms.

4- Since the soul was described by Energy, Space, and Consciousness but not Time, the Soul movement was characterized by the presence of pitched sounds, harmony, melody, and by the absence of a defined rhythm. This movement was also characterized by a predominance of high frequencies. Moreover, another characteristic of this movement was the use of randomness: I decided to base this part on aleatory components to render the idea of anarchy, absence of rules, as opposed to rationality that was rendered in the Spirit movement.

5- Since a human being with an integrated consciousness has all the components together, then the Integrated Consciousness movement was characterized by the presence of both pitched and un-sounds, as well as harmony, melody, and rhythm. Specifically, this last movement made use of many elements appeared in the previous movements, it did not introduced new ideas, but it presented them with some variations.

Table 2 schematically summarizes the adopted associations between the musical parameters and the axes defining the human being's components according to Corrado Malanga's theory. The idea of using pitched and un-pitched sounds also originated by the consideration that the hurdy-gurdy is an instrument that can produce both sounds and noises.

	Harmony	Rhythm	Melody	Pitched Sound
Body	Yes	Yes	Yes	No
Mind	Yes	Yes	No	Yes
Spirit	No	Yes	Yes	Yes
Soul	Yes	No	Yes	Yes
Integrated Consciousness	Yes	Yes	Yes	Yes

Table 2: Summary of the musical parameters characterizing the five movements as the result of their association to the axes presented in Table 1 for each component of the human being according to Corrado Malanga's theory.

3.5 Compositional strategies

Beside to the choice of a particular form and structure, I attempted to render the various concepts at the basis of my piece through a variety of compositional strategies.

One of the strategies I adopted to render the concept of dualism concerned the use of the live electronics: in the whole piece the sounds of the hyper-hurdy-gurdy were always processed in real-time, while no processing was applied to those of the orchestra. Moreover, the sounds of the orchestra's instruments captured by the microphones were statically delivered on the eight loudspeakers while the sounds produced by the hyper-hurdy-gurdy were spatialized in various ways. In this way a dichotomy between static and dynamic sound delivery was accomplished.

One of the most important aspects of the whole composition is the presence of elements related to European folk music. First of all, the presence itself of a traditional instrument such as the hurdy-gurdy gave per se a touch of traditional music. Secondly, in some parts I utilized rhythms, melodies, and modal scales inspired by folk music. Specifically, the Mind movement is entirely based on rhythmical patterns of the Swedish polska. The Spirit movement finds inspiration for melodies and rhythms from different traditional dances such as the fandango from Basque Country, the kost ar c'hoad from Bretagne (with the typical question-answer structure between soloist and the rest of the group), and the bourrée à deux temps typical of Central France. The Soul movements uses extensively modal scales, as far as the soloist part is concerned. Moreover, in some parts of the piece some instruments of the orchestra, or even the voice of the musicians, are used to act as a drone. My idea was to use the resulting sounds as an extension of the hurdy-gurdy's drones. Along this line, the tuning of the drones as well as sympathetic strings was the source of inspiration for the material of the orchestra.

The reason to adopt elements from folk music was not only due to the fact that I have a background as folk musician, but also that the concepts of spirit, mind, soul are present basically in all traditions of cultures of the world. On the other hand, the use of the today's technology was chosen because those same concepts belong to the today's human beings, since they deal with the nature of human beings themselves. Therefore, in my aims the combination of folk music elements with contemporary electronic music elements was also well suited to express such ideas, as well as that of dualism.

Another important element of my piece is the large amount of improvisational parts that are assigned to the hyper-hurdy-gurdy. On the one hand, this was due to the fact that I wanted to exploit one of the most important and typical aspects of folk music, the improvisational character. On the other hand, the reason for a great presence of improvisation was motivated by my idea of creating a composition that was not static, that could change at every performance: with this compositional strategy I intended to express in music my idea that, beside some schematic definitions such as those of Malanga, the concepts of the four components cannot be entirely defined, but a mystery, a magic wraps them. The same mystery and magic that is present in a solo of a performer, in my modest opinion. Moreover, I wanted to give the performer the opportunity of interpreting him/herself the concepts of a body, a mind, a spirit, a soul, and an integrated consciousness.

3.6 Notation

One of the first issues I faced in writing a score for the instrument I developed was that of inventing a notation. Various types of notation for the conventional acoustic hurdy-gurdy have been proposed, the one I mostly relied on was that proposed by Valentin Clastrier in [24]. However, given the novelty of the instrument I also had to invent an additional notation that could complement the one used for the traditional instrument. Unfortunately, I was unable to find the scores of other hyper-instruments, from which I could have found some inspiration for the notation of the hyper-hurdy-gurdy.

My choice for notating in the score the use of the sensors and accelerometer consisted on the abbreviations S1, S2, S3, S4, Acc1, and Acc2 (as illustrated in Figure 9) and on a dotted line that expressed the duration of their use. The effect resulting by the application of the sound processing connected to the sensors and accelerometers was indicated at the beginning of the dotted line. Figure 11 illustrates the notation corresponding to the use of sensor S3 in the Max/MSP patch shown in Figure 6.

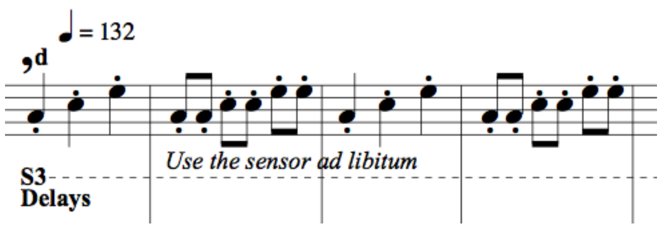

Figure 11. An example of notation for sensor S3. Pressing the sensor adds a delay effect to the sounds indicated in the score.

4 Discussion

On the one hand, the project aimed to provide hurdy-gurdy performers with an interface able to achieve novel ways for musical expression without disrupting the natural interaction with the traditional instrument. On the other hand, this project 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 improvisation and composition contexts. Novel timbres and forms of performer-instrument interactions were achieved, which can lead to an enhancement of the performance as well as to a variety of new compositional possibilities.

This project was motivated by my 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. At the conclusion of the project I can state that the developed instrument was 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 my modest opinion, 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 compositions that I wrote and performed are a proof of these statements.

This project originated from my two passions and interests: folk instruments and music technology. The development of the hyper-hurdy-gurdy represents my challenge of combining these two far worlds. The project is expression of my background as a folk musician, classical music performer, contemporary music composer, and computer scientist. In the compositions I wrote for the developed instrument I sought to combine all my expertise in those fields. By having simultaneously the roles of creator of the hyper-hurdy-gurdy, composer, and performer my standpoint was capable of taking into account all the aspects related to the music creation and production involving such an instrument. This allowed me to fully understand both the power and the limitations of the involved technology, the way of playing the instrument and, as a consequence, the compositional strategies that might be more effective.

During the composition process I faced the challenge of making choices concerning the privilege or the exclusion of some of the many new possibilities offered by the instrument. The technology in part influenced my way of composing. Indeed, in some cases my compositional intentions collided with the actual possibilities and easiness to play the new instrument. As a consequence I had to revisit my compositional ideas towards solutions that could provide the performer (in first place myself) with an affordable and effective usage of the instrument. Having understood the boundaries given by the limitations in the technology and in the use of the developed instrument, I could explore and take advantage of all the new expression possibilities inside such boundaries.

Another challenge I faced during my artistic research was that of creating a bridge between folk music and music technology. This was the occasion for a reflection about such a challenge. The hyper-hurdy-gurdy might be seen as the current last step in the evolution path of the hurdy-gurdy that originated in Middle Age. Augmented instruments are the result of enhancing an acoustic instrument with hardware and software technology. In the particular case of this project a folk instrument was involved. The hurdy-gurdy has been and is still used in the traditional music of various European countries. By augmenting this instrument I certainly did not want to go against such traditions, which I respect very much [25]. But my research in the augmentation of the instrument was motivated by my need as a composer and performer to find new ways for musical expression by means of the hurdy-gurdy.

As far as future works are concerned, I see many possibilities for extending the results of this project. Currently the instrument is still on a prototype stage (although it is a stable and fully working version), and various solutions could be implemented to improve it. A first extension would consist of adding more sensors and of a different type. Nevertheless, this would have the side effect of increasing the complexity of the technology at both software and hardware level, as well as of the way of playing the instrument since a greater number of new gestures will have to be learnt by the performer. A second extension would be that of increasing the number of sound processing algorithms in order to be able to produce a large palette of available timbres and sound effects. A third extension would consist of using the sensors and the accelerometers to control programs different from the one I used so far (Max/MSP), such as digital audio workstations. This would allow not only to process in different ways the sound coming from the instrument, but also to use synthesizers or samples. One of these could be Logic X Pro, which is OSC compatible. Finally, on a general and visionary level, the collaboration with an instrument maker would be beneficial in order to craft from scratch a hurdy-gurdy with the sensors embedded in it.

5 Conclusions

The main objective of this master thesis project was to provide hurdy-gurdy performers and composers with a novel type of instrument and related software tools that allow to achieve a totally new experience in terms of sound production and control, and open new pathways for composition and improvisation purposes. The implementation of the instrument, its extensive validation, its positive evaluation expressed by a hurdy-gurdy performer different from me, and its use in both compositional and performance contexts are the proof that these goals have been fully achieved.

The current version of the hyper-hurdy-gurdy is liable to improvements and many are the possibilities of extension at both hardware and software levels. More importantly, I am aware that a large number of possibilities for new performer-instrument interactions and especially for musical creation and production offered by the developed instrument have not been explored yet. Therefore, I feel that my artistic research in playing and composing for hyper-hurdy-gurdy is just at the beginning and I foresee new developments and improvements of the current version in the immediate future.

Overall, I feel satisfied with my work and of the results achieved during these two years at the KMH Royal College of Music in Stockholm. It is my hope that the results of this project could inspire other digital luthiers, performers and composers to continue the research I started on augmenting the hurdy-gurdy as well as on composing for it.

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Appendix

Audio-video examples of mappings between performer's gestures and audio effects parameters

Effects on the melodic strings

Mapping 1:

The tilted position of the instrument controls the presence of a pitch shifting effect set to produce an octave up. The finger's pressure force continuously controls the amplitude of a delay effect. By simultaneously tilting the instrument and pressing the sensor will produce a delay on the pitch-shifted signal.

Mapping 2:

The finger's position on the ribbon sensor continuously controls the amount of frequency shift of a pitch shifting effect. The finger's pressure force continuously controls the amplitude of the effect.

Mapping 3:

The tilted position of the instrument controls the presence of a pitch shifting effect set to produce an octave low. The finger's pressure force continuously controls the amplitude of a pitch shifting effect set to produce a fifth up.

Effects on the trompettes

Mapping 1:

The finger's pressure force continuously controls the amplitude of a delay effect set only on the buzzing noise.

Mapping 2:

The finger's pressure force continuously controls the amplitude of a reverb effect.

Effects on the sympathetic strings

Mapping 1:

The finger's position on the ribbon sensor continuously controls the frequency of modulation of a tremolo effect, as well as the amount of frequency shift of a pitch shifting effect. The finger's pressure force continuously controls the amplitude of the resulting tremolo plus pitch shifting effect.

Mapping 2:

The finger's pressure force continuously controls the amplitude of a delay effect.

Effects on the drones

Mapping 1:

The finger’s position on the ribbon sensor continuously controls the frequency of modulation of a tremolo effect. The finger’s pressure force continuously controls the amplitude of the effect.

Mapping 2:

The finger’s position on the ribbon sensor continuously controls the amount of frequency shift of a pitch shifting effect. The finger’s pressure force continuously controls the amplitude of the effect.

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