The Hyper-Mandolin

Luca Turchet
Centre for Digital Music
Queen Mary University of London
London, United Kingdom
luca.turchet@qmul.ac.uk

ABSTRACT

This paper presents the Hyper-Mandolin, which consists of a conventional acoustic mandolin augmented with different types of sensors, a microphone, as well as real-time control of digital effects and sound generators during the performer's act of playing. The placing of the added technology is conveniently located and is not a hindrance to the acoustic use of the instrument. A modular architecture is involved to connect various sensors interfaces to a central computing unit dedicated to the analog to digital conversion of the sensors data. Such an architecture allows for an easy interchange of the sensors interface layouts. The processing of audio and sensors data is accomplished by applications coded in Max/MSP and running on an external computer. The instrument can also be used as a controller for digital audio workstations. The interactive control of the sonic output is based on the extraction of features from both the data captured by sensors and the acoustic waveforms captured by the microphone. The development of this instrument was mainly motivated by the author's need to extend the sonic and interaction possibility of the acoustic mandolin when used in conjunction with conventional electronics for sound processing.

CCS CONCEPTS

• **Applied computing** → **Sound and music computing**; • **Hardware** → *Sound-based input / output*; • **Human-centered computing** → Interactive systems and tools;

KEYWORDS

Augmented instruments, NIME

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1 INTRODUCTION

The family of the so-called "augmented-instruments" or "hyper-instruments" is composed by acoustic instruments that are enhanced at hardware level with sensor and/or actuator technology, and at software level with digital signal processing techniques [7, 9]. The main aim of builders of such instruments is the extension of the sonic capabilities offered by the instrument in its original version. In the case of augmentations by sensors, instruments are enhanced with sensors utilized to track various gestures of the performer in order for him/her to control the production of electronically generated sounds. These sounds can complement, modulate, or even substitute the sounds acoustically generated by the instrument. In the case of augmentation by actuators, the electronically generated sounds are delivered by actuation systems that mechanically control the resonating structure of the instrument itself [5, 11].

One of the research strands about such instruments has focused on plucked/strummed string instruments. Examples include augmentations of the guitar [1, 5, 6, 17], the sitar [4], or the ukulele [3]. However, to the best author's knowledge, no research has been conducted on the augmentation of one of the most widespread plucked string instruments: the mandolin [8, 13, 14, 18].

The mandolin evolved from the lute family in Italy during the 17th and 18th centuries. It is the soprano member of a family that includes mandola and mandoloncello. The mandolin family has occupied a prominent position in the performance of western music. These instruments have been widely employed in various musical genres including classical, folk, buegrass, and jazz. Various types of electric mandolin have been created starting from the 1920s, which are instruments tuned and played as the mandolin and amplified in similar fashion to an electric guitar. However, compared the electric guitar, the use of the mandolin in conjunction with electronics for sound processing has been rather limited, and also the interest of electronic music composers towards it has been relatively scarce.

This paper describes hardware and software enhancements to a conventional acoustic mandolin. The main objective of this research project was to unlock new degrees of expressivity beyond those offered by the plucked/strummed nature of the mandolin, while at the same time avoiding the disruption of the natural interaction occurring between the player and the instrument. The proposed augmentation also aimed to enable composers to explore novel pathways for musical creation with a new instrument.

This research originated from a twofold need of the author, who is a mandolinist. The first is to investigate new paths for individual musical expressions for the mandolin. The second is to research how to progress the possibilities for music creation with current electronic solutions that can be applied to the mandolin. These are typically the ones available on the market, which are used for processing the sound of other string instruments, especially the guitar. It is the author's humble opinion that novel expressive paths are not practically walkable using acoustic and electro-acoustic mandolins in conjunction with conventional and most widespread electronics for sound processing control (e.g., external devices with knobs and sliders, foot controllers, stompboxes, etc.): basically all the expression possibilities available with them have been already investigated. Thanks to the application of augmentation techniques to the mandolin, novel possibilities for musical research paths for this instrument are enabled, as well as novel approaches to composition and improvisation can be explored.

The author's artistic reflection on the development of an augmented mandolin started from considerations on the history of the instrument (for details see [8, 13, 14, 18]), and aimed at continuing its developmental path. In Section 2 a brief description of the conventional acoustic mandolin is provided to render this paper more intelligible to those unfamiliar with the instrument and its playing techniques.

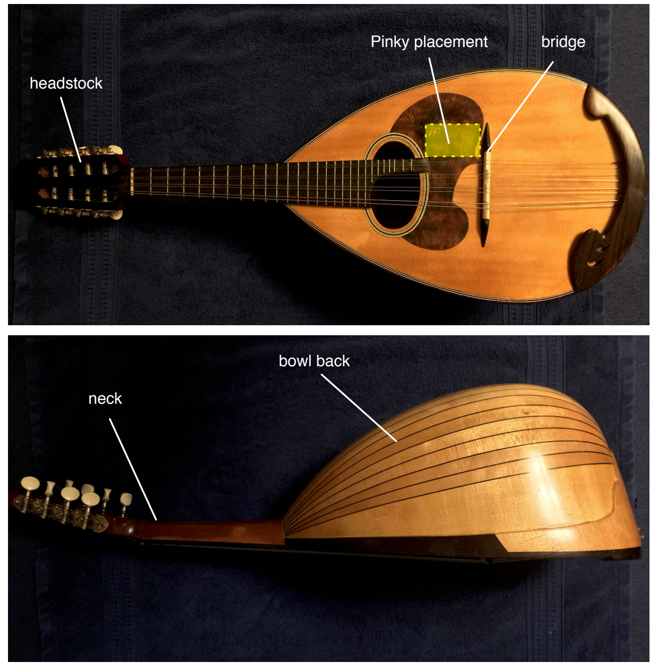

Figure 1: Front view (top) and side view (bottom) of an exemplar of Neapolitan mandolin.

2 THE MANDOLIN

The mandolin is a stringed musical instrument whose sound is produced by plucking the strings, usually with a plectrum [13, 18]. Mandolins are composed by a body that acts as a resonator, which is attached to a fretted neck supporting the strings (see Figure 1). The most common shapes of resonating body are two: bowl and box. Round-backed mandolins, such as the traditional Neapolitan mandolin, (commonly used in classical music) belong to the first category, while carved-top mandolins (commonly used in bluegrass music) and flat-back mandolins (commonly used in Irish folk music) belong to the second. Usually, there is one or more sound holes in the soundboard (e.g., round, oval, or shaped like a calligraphic F).

The strings extend from mechanical tuning machines at the top of the neck to a tailpiece. They are suspended over the neck and soundboard, and pass over a floating bridge. The bridge is kept in contact with the soundboard by the downward pressure from the strings. In its most common form, the mandolin comprises 8 metal strings, which are divided in 4 pairs. Each string in the pair is tuned in unison and such pairs are normally tuned in a succession of perfect fifths in the same tuning as the violin (from the lowest to highest pitch: G3, D4, A4, E5).

The mandolin can be played sitting or standing (with or without a strap). It is an instrument well suited to playing melody, harmony, fill-in notes, and chords for accompaniment. Typically it is played with a plectrum (held lightly but firmly, resting on the first finger between the tip and first joint and clamped lightly with the thumb), rarely with fingers/nails and rasgueado style typical of guitar playing. Like any plucked instrument, the notes of the mandolin decay to silence and the decay time is shorter than that of larger instruments such as the guitar [2, 19]. To create sustained notes or chords mandolinist use the so-called "tremolo" technique, which consists of rapidly picking of one or more pairs of strings alternating up and down strokes. It is a rather common practice among mandolinists to play while placing the pinky of the picking hand on the area at the bottom of the strings in order to achieve a better control (see the yellow area in Figure 1).

3 DESIGN

The design of the augmentation of the mandolin was conceived as result of a long-lasting research on how to overcome the found expressive limitations offered by the most widespread current technologies for sound processing control applicable to the mandolin (i.e., various types of external devices). Such a research was entirely based on the author's personal needs as a performer to avail himself of a novel interface for musical expression, able to open unexplored paths for composition, improvisation, and performance. These needs led to the following requirements that guided the design:

- In presence of the augmentations the instrument could have been still played in the normal acoustic way, and the added hardware technology should have affected as little as possible the original acoustic sound;
- The added hardware technology should have been easy to put on and remove, and installable in most mandolins independently of the shape of their back;
- The augmentation should have kept unaltered all the conventional sets of gestures to play the instrument, while at the same time enabling new gestures that would not interfere with the natural act of playing;
- The hardware and software technology should have allowed mandolin players to achieve unprecedented musical expressions such as sound modulations, sound spatialization, and generation of additional synthesized sounds;
- No additional external equipment (e.g., footswitches) should be involved for the control of the sound engine;
- Reasonable hardware costs.

As a consequence of the set of requirements listed above, the main design choices were the following:

- Use of easily removable supports holding sensors interfaces, to be placed onto the instrument without entailing physical modifications of the instrument with holes or carvings;
- Use of a modular architecture for connecting sensors interfaces (to be placed in various parts of the instrument) to a unique microcontroller board for the analog to digital conversion of the sensors data;
- Use of two sensors interfaces, the first dedicated to the expressive control, the second to settings (e.g., bank select and preset select);
- Placement of the expressive control interface at the bottom side of the soundboard, between the bridge and the point where the neck is attached, with minimal impact on the soundboard vibrations;
- Placement of the settings interface in the region of the top side of the soundboard;
- Placement of the microcontroller board at the back of the soundboard in the region opposite to the neck.

The overall setup was designed according to the classic paradigm of augmented instruments, that is involving the augmentation technology, a soundcard, a laptop for the processing of both audio and sensors signals, and a system of loudspeakers for the sound diffusion. The hardware technology involved in the augmentation was designed to consist of a contact microphone to capture the strings vibrations propagated in the soundboard, sensors used to track the set of new gestures, a microcontroller board for the digital conversion of the sensors analog values and a PCB board for the routing of the sensors data to the microcontroller board.

The PCB board was designed in order to have as analog and digital input/otuput, a series of removable connectors for cables with multiple wires, each cable for a different sensors interfaces. In the same vein, such interfaces were designed to be equipped with a same connector, attachable to an ad-hoc board where the sensors could be hooked-up. Such a modular nature of the architecture for the technological augmentation was designed to allow for an easy interchange of sensor interfaces with different layouts (but equipped with the same type of connector). In addition, it could support the integration of additional interfaces or their removal. This design also accounted for portability between different mandolins, as well as for easiness of setup and carriage.

The position of the expressive control interface was inspired by analogous solutions for guitars (e.g., REVPAD by GTC Sound Innovations[1], Guitar Wing by Livid Instruments[2], or the Sensus Smart Gutar by MIND Music Labs [17]). Different types of layouts for the expressive control interface were designed in order to track various sets of gestures. Each layout had in common the presence of sensors for both discrete and continuous interactions. The function of such discrete controls, however, was designed to be different from the ones of the settings interface: they were dedicated to fast interactions (e.g., to control a loop station), while the latter were dedicated to interactions where fast access was less constrained.

Regarding the sensors for continuos interactions, the design focused on those capable of tracking a set of gestures that could be reasonably added to the normal playing technique without disrupting it. These included pressure/position/sliding of a finger on an area of the instrument, motion of the instrument in the tridimensional space, distance of the hand from the instrument, and the combination of thereof. The number and placement of the identified sensors represented a challenging problem due to the small size of the instrument and the hardware limitations of the sensors themselves. Various layouts for the expressive control interface were designed and implemented. The one that currently the

[1] www.gtcsound.com/product/revpad
[2] www.lividinstruments.com/products/guitar-wing

author considers the best to cater to his needs is illustrated in Figure 3 (center).

4 IMPLEMENTATION

Hardware

Figure 2 shows the developed Hyper-Mandolin. The designed augmentation was achieved at hardware level by involving the following components. As contact microphone the HotSpot by K&K Sound was chosen and utilized in conjunction with the related pre-amplifier Pure Preamp. A PCB board was designed and printed to accomodate a Teensy 3.2 manufactured by PJRC, and 48 analog/digital inputs and 16 digital outputs (using multiplexing techniques). Those inputs and outputs were accessible in groups of 16 via a connector for cables with 16 wires.

The settings interface consisted of six Standalone Toggle Capacitive Touch Sensors manufactured by Adafruit, placed in the configuration illustrated in Figure 3 (left). Those sensors were selected in place of switch buttons because their use does not cause any click, which in the case of switch buttons produce vibrations on the instrument that get inevitably captured by the contact microphone. In addition these capacitive sensors come with an integrated led for visual feedback (that by default does not need to be programmed to work, with consequent simplification of the circuitry). These features were preferred despited the lack of proper haptic feedback, which instead characterizes switch buttons. The four adjacent capacitive sensors were dedicated to preset select, while the two in the row below to bank select.

The expressive control interface (see Figure 3 (center)) consisted of seven Force Sensing Resistors of various sizes and types manufactured by Interlink Electronics (precisely, one squared FSR 406, three rounded FSR 402, two small-rounded FSR 400, and one strip FSR 408), one Soft Pot ribbon sensor manufactured by Spectra Symbol, one 3-Space inertial measurement unit (IMU) manufactured by Yost Labs, and one Sharp GP2Y0A41SK0F Infrared Proximity Sensor Short Range manufactured by Sharp.

All pressure sensors were covered by a foam rubber for enhancing the tactile feedback. In addition a coloured plastic film was glued on top of each foam rubber in order to visually differentiate the sensors (and therefore improving the interaction of the player), as well as to enhance the aesthetic level of the augmentation. The design exploited the common practice among mandolinists of playing with the pinky of the picking hand placed on the area at the bottom of the strings. That area was designed to be covered with a squared sensor tracking the pressure of the pinkie. The two small pressure sensors were designed in order to be used mainly as discrete controls. They were chosen in place of the capacitive sensors due to a much faster access interactions and to a better tactile interaction. In addition, their small size allowed a player to distinguish them from the other three rounded sensors whose function was instead mainly dedicated to continuous interactions. Furthermore, their use could anyways be configured for continuous controls. The ribbon sensor was attached, thanks to its adhesive film, on top of the strip pressure sensor in order to create a unique device capable of providing simultaneous information about position and pressure of the finger interacting with it.

With exception of the IMU, all other sensors were glued to a plastic rigid support that was ad-hoc created by means of a 3D printer. This support was designed also to include a cover for the electronic circuit linking the involved sensors to the interfacing connector. Such a cover served the purpose of both protecting such electronics and to hide it for aesthetic reasons. Furthermore, the top of it was utilized to host the ribbon-pressure strip.

An additional box was 3D-printed to hold the PCB and microcontroller boards, and was designed to be open and closed in order to attach and remove the cables for the sensors interfaces via the connectors (see Figure 3 (right)). The IMU was attached to the top wall of such a box. The reasons for placing it there rather than on the expressive control interfaces were manifold. First of all, motion tracking was a feature always needed, regardless of the adopted expressive interface layout. Secondly, the utilized IMU was rather expensive. Thirdly, the placement near the microcontroller board allowed to optimize the motion tracking by minimizing crosstalking effects, which were found using longer cables.

In order to avoid ruining the wooden parts of the acoustic instrument, a specific low-impact scotch tape strip was placed on the parts of the instrument where the plastic supports were attached. Specifically, a velcro strip was placed on top of the regions covered with the scotch tape, as well as the velcro side counterpart was placed on the plastic supports in the corresponding part of them. Finally, pieces of foam were involved to increase the stability of the plastic supports.

Software

A series of applications were coded in Max/MSP. These implemented a variety of ad-hoc sound effects (collected in the Sound Effects Library for Hyper-Mandolin), as well as mapping strategies to control them or other software applications. The latter included the digital audio workstations Logic Pro X and Ableton Live and a variety of plugins running on them (e.g., sound effects, synthesizers, etc.). For this purpose, Max/MSP patches as well as Max for Live devices were implemented, in which the sensors data where processed and converted into MIDI messages. Any other digital workstation responsive to MIDI input can be controlled via

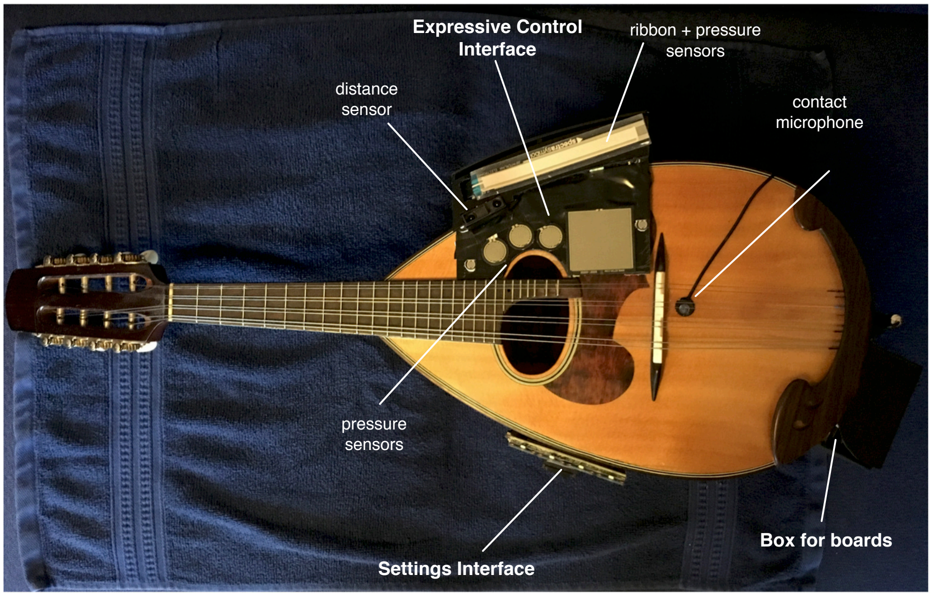

Figure 2: The developed Hyper-Mandolin.

Figure 3: Views of the Settings Interface at the top-side (left), the Expressive Control Interface at the bottom-side (center), and the box (containing the PCB board, microcontroller board, and IMU) at the bottom (right).

the developed interface. Algorithms for sound spatialization on multichannel surround sound systems included the "Ambisonic Tools for Max/MSP" [12], which allow one to spatialize virtual sound sources along bi-dimensional and tri-dimensional trajectories.

A set of mapping strategies between the player's gestures and the sound production was investigated. The mappings were based not only on the processing of the data gathered from the sensors, but also on features extracted in real-time from the audio signal captured by the microphone. The mandolin 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 microphone. These controls were used in conjunction with those resulting from the interaction with sensors.

It was important to define mappings that were intuitive to the performer and that took into account electronic, acoustic, ergonomic, and cognitive limitations. In order to decide on a particular setup, many questions needed to be answered, such as for instance how many parameters of a sound effect the performer could be able to simultaneously control, or how long a performer would need to practice to become comfortable with a particular setup. These mappings were carefully designed to accomplish a good integration of both acoustic and electronic components of the performance, resulting in an electronically-augmented acoustic instrument that is respectful of the mandolin tradition[3].

5 SELF EVALUATION: LESSONS LEARNED

During the whole development process, the Hyper-Mandolin was subjected to extensive tests as well as used in performances and recordings, which aimed to validate the implemented augmentation from the technological and expressive standpoints. Such tests were conducted exclusively by the author, since the initial "target user" of this instrument was the author himself. However, an evaluation with other mandolin players is planned. To this regard, the main obstacle faced so far lied in the recruitment process: to the author's best knowledge, currently very few mandolin players worldwide have a strong electronic music background or interests.

In an effort to make this study more useful to the community of researchers, performers, and composers, the following reports details and resulting observations of the author's own tests conducted to investigate the extent to which this augmentation allowed him to explore new artistic options. The perspective here reported is that of a performer who is also the composer of the music he plays, as well as the designer of the instrument. Inspired by O'Modhrain's framework for the evaluation of digital musical instruments [10], observations are reported according to the standpoints of these three roles.

From the designer's point of view, the prototype was found to be robust and reliable in all its aspects. Notably, the evolution of hardware and software design went hand-in-hand with the development of performance practice and a dedicated Hyper-Mandolin repertoire. Six months of usage with the final version of the prototype revealed the effectiveness of its design in supporting virtuosity as well as the current author's expressivity needs. These included for instance the simultaneous tracking and mapping of manifold sensors to complex sound processing algorithms. To this regard, the choice of placing the sensors in a way optimized for a simultaneous use was found to be very appropriate. Several tests stressed the system in order to ensure that even the most complex scenarios could be fully supported. Moreover, tests were run on different computers and with different soundcards in order to prove a high level of performance of the system under different conditions.

Building an effective instrument implied at first an optimal tracking of all possible new gestures, including the most complex ones (e.g., pressing two pressure sensors at the same time when tilting down the instrument, pressing rapidly and repeatedly a pressure sensor with one hand while sliding on the ribbon sensor with the other). Therefore, a considerable amount of time was needed for the tuning of the responsiveness of sensors by means of coefficients for low-pass filtering, thresholds, and scaling functions. The covering of the pressure sensors with the foam rubber with the plastic film on its top was a fundamental choice driven by the need of enhancing the poor tactile interaction of the finger with the naked sensor. Indeed, after playing for hours and with a daily practice not only the involved fingers of the right hand got tired quickly (especially the pinkie which is the weakest), but also the feeling of pressing a hard material hindered accuracy of the gesture and the enjoyment of playing.

A need that emerged when the pressure sensors were configured as discrete controls, was that of having an associated visual feedback directly on the instrument. For instance, such a need was evident when using those sensors for controlling a loop station. For this purpose a miniature RGB led placed next to each of those sensors could be involved (in order to account for displaying up to four different stati), although this would imply a considerable redesign of the circuits. Along the same lines, with the time emerged the need of having a visual indication of the bank and preset name placed onto the instrument, as well as a simple way to navigate between banks and presets. This could be achieved by adding a touch display, which would substitute the settings interface.

During the design process it was noticed that the headstock is a region of the instrument that could be exploited for placement of additional sensors (see Figure 1). Placing sensors in such a region, however, would require necessarily an additional microcontroller board with a wireless system, which is independent from the one used for the expressive control and settings interfaces. This is due to the fact that several wires would need to pass along the neck to reach the microcontroller board, therefore impeding the ease of the act of playing. The use of sensors placed onto the headstock could be more appropriate for the control of sounds not generated from the immediate interactive processing of the strings signals (for instance long background sounds, backing tracks, accompaniments, to be processed with effects whose parameters could be modulated by those sensors). Indeed, interacting with such sensors would necessarily imply the use of the non-picking hand.

The added weight of the augmentation components was perfectly manageable. Nevertheless, the size of the box and of the cover of the sensors circuits could be minimized to further limit obtrusiveness when lifting the instrument up and when rotating it forward. This would entail a more sophisticated design of PCBs involving surface-mounted components. More importantly, the presence of the USB and jack cables was found to be too cumbersome in the long run, thus revealing the need for a fully wireless design. However, all

[3]An audio-visual example of some of the implemented mappings is available at www.youtube.com/watch?v=0djjXVs-Dqw. Other audio-visual examples are available at the author's YouTube channel https://www.youtube.com/channel/UCC8s8x0R_L3o6ZAScNd6kiQ.

these possible avenues for improvement, besides a greater amount of development time would imply much higher costs, thus going against the initial affordability requirement that is instead met by the current design: the total cost for the augmentation hardware amounts to about 400 EUR.

As as pointed out by O'Modhrain *"performance should be considered as the ultimate evaluation of any instrument design"* [10]. From the performer's standpoint, the developed instrument was found to be effectively capable of responding to the author's expressive needs. The accuracy, resolution, response time, and placement of the sensors, as well as the intuitiveness of the defined mapping strategies and quality of the produced sounds, were all factors that contributed to achieve such a goal. This, however, entailed a radical rethinking of the instrument and its practice. Certainly the author was facilitated in this process given his previous experience in playing augmented instruments designed by himself (e.g., [15, 16]), but the Hyper-Mandolin profoundly changed his rehearsal and performance experience. Indeed, the incorporation of new gestures into the usual playing technique gave rise to a new technique. To define it, several research efforts were directed at finding tradeoffs between the wanted results and the most comfortable gestures to achieve them.

The system was conceived to be flexible and adaptable to the pieces to be composed and performed, therefore no fixed mappings between sensors and sound parameters were involved. If on the one hand this enabled a wide gamut of mappings and interactions with sounds, on the other hand it was necessary to relearn for each composed piece how to play the instrument. This implied, therefore, lot of practice to master and remember the instrument in different configurations. Nevertheless, the instrument fully accomplished one of the fundamental project aims, that is to produce a system that could facilitate enjoyment of the musician using it.

From the composer's perspective, the instrument enables a novel language based on a variety of gestures trackable by the sensors to be incorporated in the usual playing technique. Like for all augmented instruments with a high degree of complexity, composing for this instrument is challenging. Besides the knowledge of the space of electronic sounds the composer is required to know both the playing technique of the conventional mandolin and the wide gamut of possibilities for sound control enabled by the different sensors placed in a specific layout. Moreover, during the compositional practice it is necessary to take into account also all the gestures that would simply not work (in relation to a given layout). For instance, considering the expressive control interface layout displayed in Figure 2, the use of the distance sensor to alter the strings sounds requires the player to first pick the strings and only subsequently move the piking hand in front of the sensor. Indeed, it is impracticable to pick the strings and at the same time alter the sound with the same hand. The author's compositional research on the novel language offered by the Hyper-Mandolin resulted in novel forms of notation[4]. To date, five compositions for solo Hyper-Mandolin have been produced by the author. All of these involved the layout illustrated in Figure 1. One composition, *The beauty of fireflies in Central Park*, has been selected for the program of the New York City Electronic Music Festival[5]. The Hyper-Mandolin was premiered at the Fylkingen concert venue in Stockholm in April 2017 during the event Kulturnatt Stockholm. A 8-channel composition, named "Omaggio a Stoccolma", for solo Hyper-Mandolin was performed. Videos documenting the usage of the Hyper-Mandolin in live performances are available on the author's YouTube channel[6].

Finally, as suggested by O'Modhrain regarding the design of a digital musical instrument *"a measure of the success can be seen as the audience response"* [10]. Based on audience members' comments and response, the author reports that the live performances held so far have been welcomed by audiences. It is the author's opinion that part of this success is attributable to the novelty of the instrument, which certainly impressed the audience in first place and resulted in a higher level of attention. Interestingly, such a consideration was basically the same observed during the performances held with other augmented instruments previously developed by the author himself, such as the Hyper-Hurdy-Gurdy [15] and the Hyper-Zampogna [16].

6 CONCLUSIONS AND FUTURE WORK

The Hyper-Mandolin is a hybrid acoustic-electronic instrument extending the capabilities of a conventional acoustic mandolin. The design reflects trade-offs among high level of expressive control, low cost, ease of installation, and portability. The augmentation is achieved by means of different types of sensors and a microphone, as well as the real-time control of digital effects during the performer's act of playing. The instrument allows for real-time control of various ad-hoc and standard effects processing the strings sounds, as well as the generation of additional sounds (e.g., via synthesizers or samplers). The player can generate a wide variety of sounds using new gestures that well integrate with existing mandolin performance technique, in no way impeding traditional mandolin playing.

The author envisions various avenues to extend the results of this project. Software-wise, a larger palette of sound effects and mapping strategies for their control can be created.

[4]Examples of the scores are available at www.lucaturchet.it/en/downloads-en/scores.html
[5]www.nycemf.net
[6]https://www.youtube.com/channel/UCC8s8x0R_L3o6ZAScNd6kiQ

At hardware level, novel layouts for the expressive control interface can be designed and built. Secondly, an actuated system could be added in a way similar to that proposed for the actuated violin presented in [11]. Thirdly, a small touch display could replace the settings interface here presented. Fourthly, the instrument could be equipped with wireless connectivity in order to avoid the use of cables for both audio signals and sensors data.

The author plans to augment, with techniques similar to those proposed in the present paper, other instruments belonging to the mandolin family, in particular mandola and mandoloncello. In an ideal scenario, the collaboration with a luthier of such instruments would be beneficial in order to craft from scratch instruments with embedded microphones, sensors, and actuators embedded.

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 mandolin 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. It is the author’s true hope that this instrument will be a valuable creative tool for both performers and composers. The author also hopes that the results of this research could inspire other builders of augmented instruments to focus on the augmentation of the mandolin and the other instruments belonging to its family. More information about the Hyper-Mandolin can be found at the author’s personal website[7].

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