Examples of use cases with Smart Instruments

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

Michele Benincaso
MIND Music Labs
michele.benincaso@mindmusiclabs.com

Carlo Fischione
Department of Network and Systems Engineering
KTH Royal Institute of Technology
carlofi@kth.se

ABSTRACT

This paper presents some of the possibilities for interaction between performers, audiences, and their smart devices, offered by the novel family of musical instruments, the Smart Instruments. For this purpose, some implemented use cases are described, which involved a preliminary prototype of MIND Music Labs' Sensus Smart Guitar, the first exemplar of Smart Instrument. Sensus consists of a guitar augmented with sensors, actuators, onboard processing, and wireless communication. Some of the novel interactions enabled by Sensus technology are presented, which are based on connectivity of the instrument to smart devices, virtual reality headsets, and the cloud.

CCS CONCEPTS

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

KEYWORDS

Smart Instruments, Internet of Musical Things, Smart Guitar, Virtual Reality

ACM Reference Format:
Luca Turchet, Michele Benincaso, and Carlo Fischione. 2017. Examples of use cases with Smart Instruments. In *Proceedings of AM17, London, United Kingdom, August 23–26, 2017,* 5 pages.
https://doi.org/10.1145/3123514.3123553

1 INTRODUCTION

Guitars have been the object of various academic researches in the field of the so-called "augmented-instruments" or "hyper-instruments" [7, 10]. For instance, Bouillot et al. presented a mobile wireless augmented guitar combined with gesture-based continuous control of audio processing via a Nintendo Wii attached to the headstock [2]. Ladheoja proposed an electric guitar enhanced with various types of sensors (tilt, touch, pressure) and signal processing techniques [4, 6], as well as an acoustic guitar augmented with actuators attached onto its soundboard, which allowed to drive electronic sounds into the instrument, transforming the soundboard into a loudspeaker [5]. Reboursière et al. developed a toolbox for augmented guitar performances, targeting audio analysis, gestural control and audio synthesis, which was compliant with the Pure Data and Max/MSP environments [11].

As far as industry is concerned, recent years have seen the proliferation of guitar accessories for extending the sonic and interaction possibilities of the instrument, which depart from established guitar effects devices (e.g. stompboxes, pedalboards). Examples of this category are wireless MIDI controllers easy to attach to the guitar, such as ACPAD by ACPAD Instruments GmbH[1], REVPAD by GTC Sound Innovations[2], or Guitar Wing by Livid Instruments[3].

Recently a novel class of augmented musical instruments, the so-called "Smart Instruments"[4] , has been proposed in [15]. Such instruments are characterized by a sensors interface, embedded computational intelligence, bidirectional wireless connectivity, an embedded sound delivery system, and an onboard system for feedback to the player. Smart Instruments bring together separate strands of augmented instruments [7, 10], networked music systems [12, 16], and Internet of Things technology [1]. They offer direct point-to-point communication between each other and other portable sensor-enabled devices, without need for a central mediator such as a laptop. Such a connectivity feature allows for interconnection of and interaction between performers, audiences, and their smart devices. These interactions can

AM17, August 23–26, 2017, London, United Kingdom

ACM ISBN 978-1-4503-5373-1/17/08…$15.00
https://doi.org/10.1145/3123514.3123553

[1]www.acpad.com
[2]www.gtcsound.com/product/revpad
[3]www.lividinstruments.com/products/guitar-wing
[4]Our use of the term "Smart Instruments" is distinct from the IRCAM *SmartInstruments* active acoustics project (e.g. [8, 9]), though onboard acoustic actuation is one component of a Smart Instrument in our usage [15]. Full details on the IRCAM SmartInstruments can be found at http://instrum.ircam.fr/smartinstruments/

be both co-located when the human actors are in the same physical space (e.g., concert hall, public space), or remote, when they take place in different physical spaces that are connected by a network.

According to the definition reported in [14], Smart Instruments are an embodiment of the so-called *Musical Things*, i.e., physical objects featuring wireless connectivity, which are dedicated to the production, interaction with or experience of musical content. The wireless network of Musical Things gives rise to the *Internet of Musical Things (IoMUT)*, which allows for interconnection of and interaction between performers, audiences, and their smart devices in both co-located and remote settings.

As an example of the Smart Instruments concept, [15] reported an early prototype of the Sensus Smart Guitar developed by MIND Music Labs[5] (see Figure 1). Such an instrument is a guitar augmented with sensors, onboard processing and wireless connectivity. This paper presents some of the implemented use cases enabled by the technology underlying the Sensus Smart Guitar prototype, as preliminary examples of the interconnection and interaction possibilities offered by Smart Instruments within the IoMUT.

2 SENSUS

The Sensus Smart Guitar is a guitar augmented with wireless sensors networks technologies [3], which are the essential component of the Internet of Things [1].

Sensus is equipped with different sensors embedded in various parts of the instrument, in addition to regular knobs, switches and buttons. Such sensors include an inertial measurement unit (IMU), six pressure sensors, two ribbon sensors, and an infrared proximity sensor. They are ergonomically placed in order to not disrupt the conventional interaction of the guitar player with the instrument (see Figure 1). They allow for the tracking of various types of gestures of the guitar player, which can be used for different purposes. The main one is to control the sound production of the instrument, by modulating the sound captured by strings pickups and generating additional sounds. This is achieved thanks to an embedded digital audio workstation (DAW) and a software architecture for the programming of a multitude of mappings between the guitar player's gestures and sound parameters (continuous, discrete, one-to-one, many-to-many, etc.). To name the most important, the tracked gestures include the position and acceleration of the instrument in the tridimensional space (e.g., resulting from tilting up-down or front-back), the distance of the hand from a specific part of the instrument located on the soundboard, fingers pressure and position in various instrument areas. A peculiarity of Sensus is the strip sensor placed along the back of the neck capable of tracking simultaneously position and pressure of fingers engaging with it.

All software, including the DAW, runs on a computation unit that is part of an embedded system. This system is also responsible for the analog-to-digital conversion of sensors data and for the wireless connectivity. It comprises a multichannel soundcard, a microcontroller board, and a PCB board, and is powered by a battery embedded in the instrument. The DAW employs a set of plugins for the processing of the guitar strings with a variety of effects, as well as for the generation of additional sounds by means of synthesizers, samplers, sequencers, arpeggiators, drum machines. It includes a loop station, and recording and playing features. It can be controlled via both MIDI and OSC messages. In addition, the software includes a module for real-time extraction of various features of both sensors and strings signals.

The sonic output, digitally processed or generated, is delivered by the instrument itself without the use of any external loudspeaker. This is achieved by means of a system of multiple actuators that transforms the instrument resonating wooden body into a loudspeaker. Such a system coupled with digital signal processing techniques, also allows a guitar player to alter the timber of the instrument in manifold ways. In addition to this, the instrument can deliver audio signals to a regular PA system via both standard jack cable and wirelessly.

Sensus is equipped with bidirectional wireless connectivity leveraging both local networks and the Internet. This allows for the transmission of different types of data from the instrument to a variety of smart devices and vice versa. The range of connected devices includes laptops, smartphones, tablet, virtual reality head-mounted displays, and even one or more Smart Guitars. In more detail, the connectivity technology includes standard Wi-Fi and Bluetooth Low Energy, and can support 4G. The data stream currently includes MIDI messages, OSC messages, and audio signals.

3 IMPLEMENTED USE CASES

Sensus is first of all a guitar in its own right and like any musical instrument can be used standalone or in ensemble. In the past year, the instrument has been involved in several demos and concerts in Europe and US. The first public solo live performance of Sensus occurred on the 30th of November 2016 at the Slush Music event in Helsinki[6]. Figure 2 shows a moment of that performance held by guitarist Valerio Fuiano.

An implemented use case, which has been utilized during demos and concerts, is that of wirelessly controlling

[5] www.mindmusiclabs.com

[6] www.youtube.com/watch?v=ePcLhRZ-PAg&t=17s

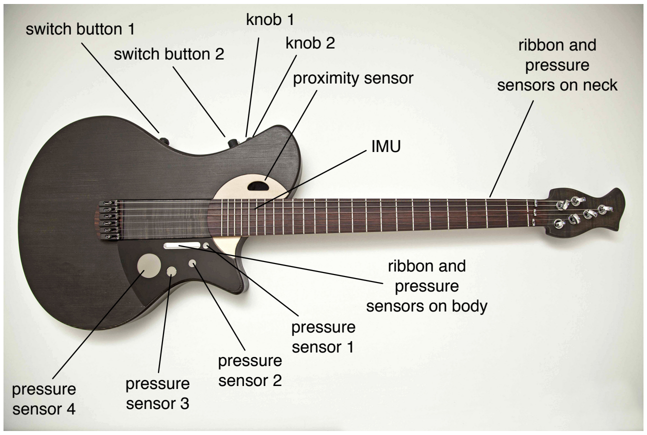

Figure 1: The Sensus Smart Guitar, with the indications of the sensors types and placement.

Figure 2: Sensus in action during its first public live performance at Slush Music 2016 by Valerio Fuiano.

visual content via the sensors interface. Visuals, created using Processing[7] or video jockey software such as VDMX[8] and displayed on a screen of a computer or by a projector, were interactively controlled by means of both OSC and MIDI messages.

The player's gestures tracked by the embedded sensors can be used to deliver wirelessly the supported data streams towards connected devices dedicated to audio production. For instance, Sensus can be used as a controller for DAWs running on computers by means of a dedicated plugin as interface (see Figure 3). Furthermore, Sensus can be fully configured via dedicated apps running on smartphones, tablets, and computers.

Like any Smart Instrument proposed in [15], the technological infrastructure of Sensus enables an ecosystem of interoperable devices connecting performers as well as performers and audiences. This ecosystem can support new

[7]www.processing.org
[8]www.vidvox.net

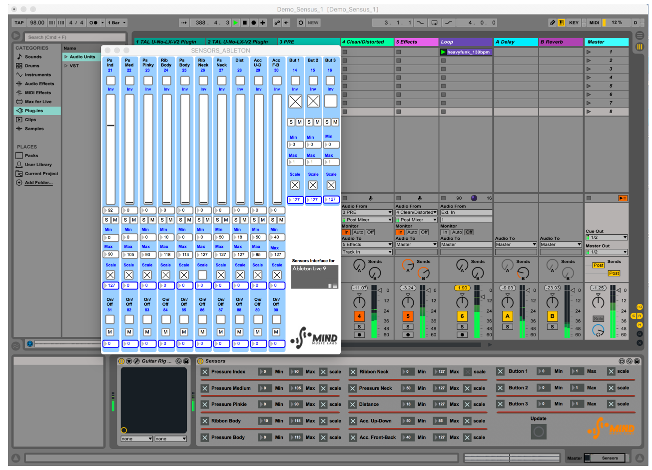

Figure 3: A screenshot of a Live Set of Ableton Live 9 interactively controlled by Sensus's embedded sensors via dedicated Max for Live devices.

performer-performer and audience-performer interactions. In the reminder of this section some of the use cases implemented by MIND Music Labs are reported.

Jam with Sensus, smartphones, and tablets

An app running on both Android- and iOS-based smartphones and tablets was designed and implemented to enable jamming with Sensus (see Figure 4). The app allows for the wireless real-time streaming of audio content and/or musical messages (e.g., via OSC or MIDI) towards Sensus. Such data are fed into the instrument's DAW and then reproduced by its sound delivery system, while the instrument itself is being played by its performer. More than one smart device running the app can be utilized simultaneously, allowing multiple players to take part to the jam session. In turn, the smart guitar player by acting on the instrument's sensors can change the behaviour of the app running on one or more smart devices in possession of as many users (for instance, changing presets or the interface layout).

Sensus and Virtual Reality

A series of virtual reality scenarios were coded in Unity 3D in order to be controlled via OSC messages streamed from Sensus. Those scenarios included landscapes and stages of concert venues, which were designed to be associated to musical compositions of different emotional character. The resulting audio-visual contents were conceived not only for creative purposes, but also for further scientific studies targeting the neuroscience and perception domains.

Figure 5 illustrates a Sensus player and a listener viewing one of the landscape scenarios delivered by means of a Oculus Rift head-mounted display. The elements of such

Figure 4: A jam with three musicians involving Sensus and dedicated apps running on an iPad Air 2 and an iPhone 6s.

Figure 5: A guitar player using Sensus to deliver both sound and visuals to a listener wearing Oculus Rift.

a scenario are modified (in position, color, shape, etc.) according to defined mappings engaged by the interaction of the performer with the Sensus sensors. Figure 6 shows a screenshot of a concert venue scenario, where, among other mappings, the tridimensional position of the actual Smart Guitar is mapped to the position of the visualized virtual guitar played by the virtual musician.

Play over music streamed from the cloud and share recordings

Thanks to its wireless connectivity feature, Sensus can receive and reproduce audio signals streamed from remote repositories via a smartphone, allowing a smart guitar player

Figure 6: A screenshot of a stage concert scenario interactively controlled by Sensus's sensors interface.

to play over them (e.g., for improvisation or rehearsing purposes). Currently, an application running on iOS-based smartphones has been implemented, which streams via bluetooth towards Sensus songs selected from Spotify. The guitar player can jam with his/her favourite artists, and thanks to recording features accessible through the switch buttons can record his/her jam and stream back to the smartphone the resulting audio file. The latter can then be shared.

4 DISCUSSION AND CONCLUSIONS

This paper aimed at showing some performer-performer and performer-audience interaction possibilities offered by a preliminary implementation of the IoMUT concept [14]. For this purpose some implemented use cases were described, which involved MIND Music Labs' Sensus Smart Guitar, the first exemplar of Smart Instruments [15]. A formal validation of the use cases listed in Section 3 is in progress and will be presented in future publications describing qualitative and quantitative results about the experience of users interacting with this technology.

Several other use cases can be envisioned involving Sensus in conjunction with other smart devices. For instance, Sensus technology allows one to wirelessly stream/receive musical content towards/from other Smart Guitars. This would enable two or more Sensus players to exploit the instrument features for jams in both co-located and remote settings (with obvious latency limitations with the increase of the geographic distance between the players). Those players could wirelessly stream between each other, and in real-time, both audio signals and OSC messages that could be reproduced by the sound delivery system of the respective Smart Guitars. Moreover, each player could control via the sensors interface the mixing of the received audio streams. Along the same lines, Sensus technology could enable remote rehearsals (at relatively close distances) where two or more players can stream and receive in real-time the sounds they generated, and the received audio stream is then reproduced and mixed directly by the instrument.

As another example, Sensus players, by interacting with the sensors interface, not only can modulate the instruments sound production, but also deliver additional multimedia content to audience members in possession of smart devices. These can produce multisensory feedback involving e.g., visual, textual or tactile stimuli. On the other hand, the feedback from the audience could be exploited by Sensus players to modulate various aspects of the performance (e.g., the Smart Guitar timbre). The audience's feedback could be gathered, for example, by tracking body movements of each member using wearable devices designed for participatory live music experiences.

The proposed connectivity of Smart Instruments to virtual reality technologies is a promising avenue for both artistic and scientific research. Nevertheless, the involvement of augmented instruments in virtual reality interactive contexts is a challenge still scarcely addressed both at academic and industrial level, as well as both at scientific and artistic level. Novel forms of musical interactions can be envisioned between a Smart Instrument player and a listener interacting with a virtual scenario. For instance, virtual musical instruments [13] could be involved for this purpose, although latency issues currently represent a major obstacle to credible and sensitive interactions.

In future work we plan to implement and validate several other use cases to further investigate the potentialities of Smart Instruments and show the potentialities of the IoMUT framework.

ACKNOWLEDGMENTS

This work of Luca Turchet is supported by the Marie-Curie Individual fellowship of European Union's Horizon 2020 research and innovation programme under grant agreement No. 749561[9]. The work of Carlo Fischione is supported by the TNG SRA ICT project "TouCHES". The authors wish to thank all MIND Music Labs team members.

REFERENCES

[1] L. Atzori, A. Iera, and G. Morabito. 2010. The Internet of Things: a survey. *Comput. Netw.* 54, 15 (2010), 2787–2805. https://doi.org/10.1016/j.comnet.2010.05.010

[2] N. Bouillot, M. Wozniewski, Z. Settel, and J.R. Cooperstock. 2008. A Mobile Wireless Augmented Guitar. In *Proceedings of the International Conference on New Interfaces for Musical Expression.* 189–192.

[3] W.W. Dargie and C. Poellabauer. 2010. *Fundamentals of wireless sensor networks: theory and practice.* John Wiley & Sons. https://doi.org/10.1002/9780470666388

[4] O. Lähdeoja. 2008. An Approach to Instrument Augmentation: the Electric Guitar.. In *Proceedings of the international conference on New Interfaces for Musical Expression.* 53–56.

[5] O. Lahdeoja. 2015. An Augmented Guitar with Active Acoustics. In *Proceedings of the Sound and Music Computing Conference.*

[6] O. Lähdeoja, B. Navarret, S. Quintans, and A. Sedes. 2010. The electric guitar: an augmented instrument and a tool for musical composition. *J. Interdisc. Mus. Stud.* 4, 2 (2010), 37–54. https://doi.org/10.4407/jims.2010.11.003

[7] T. Machover and J. Chung. 1989. Hyperinstruments: Musically intelligent and interactive performance and creativity systems. In *Proceedings of the International Computer Music Conference.*

[8] T. Meurisse, A. Mamou-Mani, R. Causse, B. Chomette, and D.B. Sharp. 2014. Simulations of modal active control applied to the self-sustained oscillations of the clarinet. *Acta Acust united Ac.* 100, 6 (2014), 1149–1161. https://doi.org/10.3813/AAA.918794

[9] T. Meurisse, A. Mamou-Mani, R. Caussé, B. Sluchin, and D.B. Sharp. 2015. An active mute for the trombone. *J Acoust Soc Am* 138, 6 (2015), 3539–3548. https://doi.org/10.1121/1.4936901

[10] E.R. Miranda and M.M. Wanderley. 2006. *New digital musical instruments: control and interaction beyond the keyboard.* Vol. 21. AR Editions, Inc.

[11] L. Reboursière, C. Frisson, O. Lähdeoja, J.A. Mills, C. Picard-Limpens, and T. Todoroff. 2010. Multimodal Guitar: A Toolbox For Augmented Guitar Performances.. In *Proceedings of the international conference on New Interfaces for Musical Expression.* 415–418.

[12] C. Rottondi, C. Chafe, C. Allocchio, and A. Sarti. 2016. An Overview on Networked Music Performance Technologies. *IEEE Access* (2016). https://doi.org/10.1109/ACCESS.2016.2628440

[13] S. Serafin, C. Erkut, J. Kojs, N.C. Nilsson, and R. Nordahl. 2016. Virtual Reality Musical Instruments: State of the Art, Design Principles, and Future Directions. *Comput. Music J.* 40, 3 (2016), 22–40. https://doi.org/10.1162/COMJ_a_00372

[14] L. Turchet, C. Fischione, and M. Barthet. 2017. Towards the Internet of Musical Things. In *Proceedings of the Sound and Music Computing Conference.* 13–20.

[15] L. Turchet, A. McPherson, and C. Fischione. 2016. Smart Instruments: Towards an Ecosystem of Interoperable Devices Connecting Performers and Audiences. In *Proceedings of the Sound and Music Computing Conference.* 498–505.

[16] Gil Weinberg. 2005. Interconnected musical networks: Toward a theoretical framework. *Comput. Music J.* 29, 2 (2005), 23–39. https://doi.org/10.1162/0148926054094350

[9] www.iomut.eu