# Ubiquitous Musical Activities with Smart Musical Instruments

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***Abstract.*** *The research field of ubiquitous music (UbiMus) investigates musical activities that are supported by ubiquitous computing concepts and technology. A recent field intersecting with UbiMus is the Internet of Musical Things (IoMusT), which refers to a system of interconnected embedded computers enabling users to produce, interact with or experience musical content (Musical Things). Musical Things embed electronics, sensors, data forwarding and processing software, and network connectivity enabling the collection and exchange of data serving a musical purpose. Smart musical instruments (SMIs) are a class of Musical Things that constitutes one of the building blocks of the IoMusT paradigm. SMIs are an emerging family of musical instruments characterised by embedded sensors, actuators, wireless connectivity, and on-board processing. We posit in this paper that SMIs have the potential to enable a wide range of ubiquitous musical activities. To support our claim, we present current trends in research on SMIs and we provide examples of use cases of SMIs in UbiMus contexts.*

## 1. Introduction

Ubiquitous music (UbiMus) [Keller et al. 2014] is a branch of the sound and music computing field which develops and analyse musical activities supported by ubiquitous computing concepts and technology [Satyanarayanan 2001, Weiser 1991]. A recent field intersecting with UbiMus is the Internet of Musical Things (IoMusT) [Keller and Lazzarini 2017, Turchet et al. 2017b]. Besides UbiMus, IoMusT originates from the integration of many lines of existing research including the Internet of Things [Borgia 2014], new interfaces for musical expression (NIME) [Jensenius and Lyons 2017], networked music performance systems [Rottondi et al. 2016], music information retrieval [Burgoyne et al. 2016], human-computer interaction [Rowland et al. 2015], and participatory music [Wu et al. 2017].

A definition of IoMusT was proposed in [Turchet et al. 2017b] as *"the network of physical objects (Musical Things) dedicated to the production, interaction with or experience of musical content. Musical Things embed electronics, sensors, data forwarding and processing software, and network connectivity enabling the collection and exchange of data for musical purpose"*. Keller and Lazzarini discussed a vision of the IoMusT in the context of a theoretical frameworks for UbiMus, where the IoMusT is seen as part of an ubiquitous music ecosystem [Keller and Lazzarini 2017].

The IoMusT technological infrastructure enables ecosystems of interoperable devices that connect musicians with each other, as well as with audiences. This multiplies the interaction possibilities between e.g., performers, composers, conductors, studio producers, live sound engineers, and audience members, both in co-located and remote settings. One of the building blocks of the IoMusT paradigm are the so-called "smart musical instruments (SMIs)" [Turchet et al. 2016], an emerging class of musical instruments characterised by embedded sensors, actuators, wireless connectivity, and on-board processing. The relationship between SMIs and UbiMus has thus far not been addressed by the NIME or UbiMus research communities. This position paper aims to fill this gap. We posit that the new class of SMIs has the potential to enable ubiquitous musical activities and involve audiences in creative processes. To support this claim we present current trends in research on SMIs and provide examples of use cases of SMIs in UbiMus contexts.

## 2. Instances of smart instruments

A proposal for a smart musical instruments family was formulated by Turchet and colleagues in 2016 [Turchet et al. 2016]. According to this proposal SMIs result from the integration of a variety of technologies and concepts such as sensor- and actuator-based "augmented instruments" [Miranda and Wanderley 2006, Turchet 2018] (e.g., [McPherson 2015, Overholt et al. 2011]), embedded acoustic and electronic instruments [MacConnell et al. 2013, Berdahl 2014], networked music performance [Rottondi et al. 2016], Internet of Things [Borgia 2014], as well as methods for sensor fusion [Pardue et al. 2015], audio pattern recognition [Dannenberg and Hu 2003], semantic audio [Slaney 2002], and machine learning [Fiebrink and Caramiaux 2016].

An example of SMI is the Sensus Smart Guitar developed by MIND Music Labs [Turchet et al. 2016]. It consists of a hollow body guitar augmented with several sensors embedded in various parts of the instrument, on-board processing, a system of multiple actuators attached to the soundboard, and interoperable wireless communication (using state-of-the art protocols for wireless transmission and reception such as Wi-Fi and Bluetooth, as well as for exchange of musical data such as MIDI and OSC). The internal sound engine is based on the ELK music operating system[1] and affords a large variety of sound effects and sound generators, and is programmable via dedicated apps on desktop PCs, smartphones, and tablets.

Another instance of SMI, which has been developed within the context of academic research, is the Smart Cajón described in [Turchet et al. 2018a]. This instrument consists of a conventional acoustic cajón smartified with sensors, Wi-Fi connectivity and motors for vibro-tactile feedback. The Bela board is used for low-latency audio and sensors processing [McPherson et al. 2016] and runs a sound engine providing sampling and various audio effects. A peculiarity of the embedded intelligence is the use of sensor fusion and semantic audio techniques to estimate the location of the players' hits on the instrument's front and side panels, and to map this information to different sound samples simulating various percussive instruments [Turchet et al. 2018b].

## 3. Features of SMIs enabling ubiquitous musical activities

The term ubiquitous music (UbiMus) has been proposed to relate to "practices that empower participants of musical experiences through socially oriented, creativity-enhancing tools" taking benefits from mobile communication and information devices

[1] https://www.mindmusiclabs.com/ELK

and their distinctive capabilities of portability, mobility, connectivity and availability [Keller et al. 2014]. The features of smart instruments can facilitate various types of human-human and human-machine interactions: interactions between musicians and their instruments, between musicians and audience members, and/or between musicians. Such technologically-mediated interactions may occur not only in co-located settings but also remotely thanks to the Internet. Ubiquitous musical activities may be developed leveraging these possibilities. We discuss below three SMIs features that can contribute to facilitate UbiMus activities:

**SMI self-contained nature.** In contrast to other digital music interfaces (DMIs) such as augmented instruments [Miranda and Wanderley 2006, Turchet 2018], SMIs embed several components in a unique standalone device. Such a self-contained nature provides benefits which could not be obtained with the large amount of equipment otherwise needed to create a similar setup (e.g., by combining a soundcard, cables, microphones, loudspeaker, MIDI controllers, laptop). These benefits include easiness of setup, portability, reduction of required space, and freedom of movement which are aspects all deemed important by musicians. SMIs limit the amount of devices to connect and turn on. Musicians can simply turn on the SMI ready to use and easy to carry when traveling.

**SMI connectivity.** The wireless connectivity options embedded in a SMI enables the transmission and reception of content communicated via local and remote networks. Such a connectivity can be used to support collaborative music making from any locations provided with Internet networks (both with other musicians and audience members). This provides usage of ubiquitous resources such as online audio repositories and services [Font et al. 2016, Stolfi et al. 2018], cloud computing or ubiquitous musical interactions through web-based social networks.

**SMI embedded intelligence.**: The intelligent systems embedded in SMIs can provide useful proactivity and context-awareness capabilities for ubiquitous musical activities. Compared to augmented instruments, SMIs switch from being reactive to what the musicians play to being proactive, for example by assisting musicians to take musical decisions. To illustrate how UbiMus activities may benefit from proactivity and context-awareness features from SMIs, we describe two speculative scenarios: 1) *an SMI which proposes songs to play to the musician based on the musical tastes of the audience as characterised from Spotify profiles retrieved from smartphones*, 2) *a SMI which is aware of the audience's activity, as characterised from inertial measurement unit data from audiences' smartphones, and makes suggestions of tempo or styles of songs to play to the performer.*

## 4. Examples of use cases of SMIs in ubiquitous musical activities

This section describes two use cases of SMIs in the context of ubiquitous musical activities, which may be considered as examples of "ecologically grounded creative practice" as decribed by Keller and Lazzarini in [Keller and Lazzarini 2017].

**Smart Instruments as hubs for collaborative music making.** SMIs may be equipped with an embedded loudspeaker or a system that mechanically acts on the vibrating components of the instrument which radiate the sound (such as a system of multiple actuators attached on a guitar's soundboard). This feature, coupled with the capabilities of exchanging data with connected Musical Things as well as processing and generat-


**Figure 1. A schematic representation (left) and a picture in a real setting (right) of a jam between three musicians involving the Sensus smart guitar and dedicated apps running on an iPad Air 2 and an iPhone 6s.**

ing audio signals, enables the ubiquitous use of a SMI as a hub for collaborative music making (such as jam sessions). A connected Musical Thing may transmit to the SMI messages that interactively control a sound generator (e.g., synthesizers or drum machines), the sounds of which are reproduced by the SMI itself when the player is playing it. More than one Musical Thing can be connected to the same SMI so different performers could jam together thanks to a unique SMI.

Such a use case has been implemented with the Sensus Smart Guitar. In [Turchet et al. 2017a], the authors report that an app running on both Android- and iOS-based smartphones and tablets was created to enable jamming with the Sensus guitar (see Figure 1). The app allowed participants to wirelessly stream audio content and/or musical messages (via OSC or MIDI) towards the instrument. Such data were fed into the instrument's sound engine and then reproduced by its sound delivery system, while the performer was playing on the instrument. More than one smart devices running the app were used simultaneously, which allowed multiple players to take part to the jam session. In turn, the smart guitar player by acting on the instrument's sensor interface could change the behaviour of the app running on one or more smart devices from users (by changing presets and/or the interface layout).

**Cloud-based smart instruments interaction.** Thanks to their wireless connectivity features, SMIs can receive and reproduce audio signals streamed from remote repositories. This may be achieved either via a direct connectivity of the instrument to the Internet, or by leveraging another Internet-enabled smart device as a bridge towards the cloud (e.g., a smartphone). This may allow SMI players: (i) to play over downloaded audio content, while reproduced by the instrument (e.g., for improvisation or rehearsing purposes), or (ii) to select sounds that can be used as tones produced by the instrument through sample-based synthesis. The Internet provides access to very large amount of digital audio content, from instrument samples and sound effects, to human- and nature-related environmental sounds and produced songs ready to use in performance. An emerging online community has forged fostering a culture of sharing of creative artefacts (video, audio, photos, etc.). Creative Commons (CC) appears as a legal framework enabling the reuse and remix of creative artefacts. The Audio Commons Ecosystem (ACE), developed

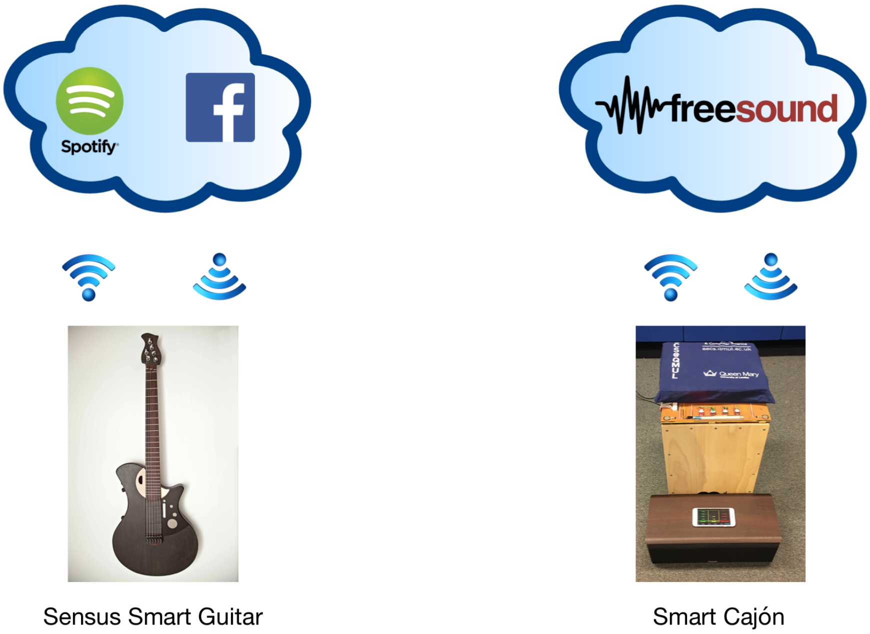


**Figure 2. A schematic representation of the interaction between smart instruments and the cloud. Each smart musical instrument (Sensus Smart Guitar on the left, Smart Cajón on the right) is capable of communicating and exchanging online audio information with cloud platforms such as Spotify, Facebook and Freesound.**

as part of the European project Audio Commons[2] [Font et al. 2016], refers to the network made up of interconnected audio content, users (e.g. creators, consumers) and software systems for audio retrieval and processing. Such ecosystem can be of benefit for SMIs leading towards UbiMus activities involving the repurposing of online audio content. Figure 2 provides a conceptual representation of two use cases discussed below.

An example of this use case is reported in [Turchet et al. 2017a] to find backing tracks with the Sensus Smart Guitar. An application running on iOS-based smartphones was implemented, which streamed towards the Sensus guitar some songs selected from Spotify via Bluetooth. The smart guitar players could jam on top of the tracks of their favorite artists thanks to the instrument capability of reproducing (via the actuators attached to the soundboard) both the downloaded audio and the performed guitar sounds. In addition, thanks to recording features accessible through the switch buttons embedded in the instrument, the players were enabled to record their jam and stream the resulting audio file back to the smartphone. Such file could then be shared on Facebook.

Along the same lines, the Smart Cajón [Turchet et al. 2018a, Turchet et al. 2018b] has been used in interaction with the Freesound[3] online audio content repository [Font et al. 2013] to expand the sound palette of the instrument and create backing tracks. Thanks to a Python module leveraging interfaces from the EU Audio Commons project [Font et al. 2016] and a GUI displayed on the touchscreen of the instrument, players can send requests to the Freesound database to download specific sounds. The downloaded

[2]https://www.audiocommons.org/
[3]https://freesound.org/

audio content can then be looped and structured in various layers so that players can jam with it. This approach is complementary to the one reported in [Stolfi et al. 2018] which presents a web-based application (Playsound.space) to compose music with sounds from Freesound using semantic queries and spectrogram selection on a screen-based interface. SMIs offer a gesture-based approach to interact and repurpose online audio content turning musicians into audio *prosumers* (producers and consumers).

## 5. Discussion and conclusion

This position paper explored some of the relationships between the UbiMus and smart musical instruments fields. To date, ubiquitous musical activities have mostly involved mobile devices such as smartphones or custom-built devices according to do-it-yourself practices typical of the maker community [Keller et al. 2014, Lazzarini et al. 2015, Brown et al. 2018]. The authors' endeavor here is to provide arguments showing how SMIs can support ubiquitous musical activities. In Section 3, we presented three SMIs features (self-contained nature, connectivity and embedded intelligence) that we deem well suited for ubiquitous musical activities. The UbiMus research community has so far mostly targeted creative practices involving non-professional musicians, and focused a great part of its vision on accessibility aspects [Brown et al. 2018]. In a complementary way, SMIs enable UbiMus activities that can target professional performers using smartified versions of traditional instruments. Although SMIs are not ubiquitous yet, they can be used in conjunction with ubiquitous technologies such as smartphones. Contrary to mobile devices such as smartphones, SMIs based on traditional instruments benefit from the improvements made to the instruments over the years through lutherie and which provide musicians with great control intimacy, an aspect often limited in current digital music interfaces [Wessel and Wright 2002].

To date, only a handful of SMIs have been developed in industrial contexts and only little academic research has been conducted in this area. This implies that SMIs-based UbiMus activities have been less widespread compared to other approaches relying on smartphones. Interesting use cases for SMIs can be envisioned in UbiMus contexts such as technology-mediated audience participation [Hödl et al. 2017, Wu et al. 2017]. For instance, SMIs could be used to create performer-audience interactions by letting the audience produce accompaniment according to musical information sent from SMIs to connected smartphones.

Several challenges remain to be solved to enable the seamless integration of SMI technology in UbiMus activities including interoperability, the development of intelligent services using Artificial Intelligence, the miniaturization of embeded systems and latency. It is the authors' hope that this work can stimulate further discussions on this topic and that researchers and practitioners in the two fields can develop new SMIs and apply them to UbiMus activities.

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