Everyday Use of the Internet of Musical Things: Intersections with Ubiquitous Music

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Abstract. *Internet of Musical Things (IoMusT) is one of several subfields of the Internet of Things (IoT) and it relates to several areas of study, such as ubiquitous and mobile music, human-computer interaction, new interfaces for musical expression and participatory art. This paper makes a bibliographic review on the general definitions of this field, explaining what Musical Things are, classifying them according to their behavior and communication role, in addition to discussing their applications in Ubimus. Among the contributions to IoMusT research, the authors also discuss the social, economic and environmental challenges faced in this area.*

1. Introduction

Internet of Things (IoT) is a term that is widely publicized and debated, and gained numerous definitions and applications. The initial idea was developed by Kevin Ashton [Ashton 2009], in 1999, to refer to a Radio-Frequency IDentification (RFID) technology applied in supply chains, acting as pointers to databases on the Internet that contained information about the objects that were present in stock [Serbanati et al. 2011]. This context of use lasted until 2004, when Gershenfeld stipulated the concept of everyday objects with the ability to connect to a data network, also addressing the heterogeneity of devices and the stack of protocols used for communication [Gershenfeld et al. 2004].

Atzori [Atzori et al. 2010] further classifies the basic concept of the IoT as *"the widespread presence around us of a variety of objects, which through exclusive addresses, are able to interact with each other and cooperate with their neighbors to achieve common goals"*. In common, all of these definitions agree that the Internet of Things is a network infrastructure, related to the integration of the physical world with the virtual, using automatic connections and identifications, also applied for data collection. The central point of this technology is based on the automatic identification of objects and one of its most important aspects is breadth and scope [Borgia 2014]. Due to its versatility, IoT began to enter in the most diverse fields of application, such as supply chain management, the energy grid, health care, public safety [Haller 2010], and more recently, music [Turchet et al. 2018a].

In this paper, everyday objects refer to Information and communications technology (ICT) objects commonly found in the daily life of people in developed or developing countries. Thus, these can refer to electronic devices for communication and entertainment, such as smartphones, televisions and audio equipment, as well as wearable utensils, such as bracelets, watches, glasses and other devices that can be attached to the body. Among communications technologies, those aimed at wireless communication are more present, such as 3G, 4G, Wi-Fi, and more recently, 5G.

2. About the Internet of Musical Things (IoMusT)

Internet of Musical Things (IoMusT) is an area of research that also integrates aspects of ubiquitous music [Keller et al. 2014], mobile music [Gaye et al. 2006], artificial intelligence [Burgoyne et al. 2016], human-computer interaction [Rogers et al. 2011] and other fields of computing. It can be defined as an interconnected network of physical devices aimed at producing or receiving musical content. [Turchet et al. 2018a], in turn, attributes a broader meaning to the term, defining it as

> "*the ensemble of interfaces, protocols and representations of music-related information that enable services and applications serving a musical purpose based on interactions between humans and Musical Things or between Musical Things themselves, in physical and/or digital realms. Music-related information refers to data sensed and processed by a Musical Thing, and/or exchanged with a human or with another Musical Thing*".

The interconnection of objects and people is supported by networks such as the Internet, LANs (Local Area Networks) and protocols, as well as applications and services to assist musicians, audio engineers and audience members. This ecosystem ranges from computational devices, wired and wireless networks, musical instruments and means of sound production. Given this scenario, we will discuss Musical Things in the next subsections according to aspects like communication roles, devices, behavior, ecosystem, and target audience.

IoMusT Communication

In computer networks, one of the methods for initiating communication depends on an entity that requests data and one that provides and sends that data. In TCP/IP communication, these roles are called client and server, respectively. Once communication begins, these functions are no longer important, as the two entities can send and receive messages [Schiavoni 2017]. However, it is necessary to understand these roles and the flow of data exchange between musicians/audience and devices. Despite these classic roles in TCP/IP communication, some Musical Things will also send control signals to other Musical Things that receive and process these signals to do something.

Client/Server is a very common communication architecture to Internet services and it is a model centered in the server as the main resource provider, sometimes acting as a relay to interconnect user directly but always present in the communication process. However, the IoT communication can escape this centered architecture and use a peer to peer connection model where the presence of a central node in the network is not necessary and several nodes can provide resources to other nodes in the network. Thus, a resource provider can be the **source** of a information while other nodes can consume this information acting like a **sink**. It is also possible to have nodes that consume a information to provide another information, like a **filter**. These information flows can be real time audio data, control data, like MIDI and OSC or even musical files.

IoMusT Devices

The ecosystem underlying the IoMusT is based on Musical Things, which have been defined as "*a computing device capable of sensing, acquiring, processing, or acting, and exchanging data serving a musical purpose*" [Turchet et al. 2018a, Turchet et al. 2020a]. A Musical Thing has characteristics similar to other devices, such as sensors and actuators, extending to intelligent instruments, intelligent mixing consoles and speaker systems. Basically, a Internet Musical Thing must have a Internet Connection and capability to process musical information. The presence of sensors to receive data from the physical environment allow a node to act like sources of data, and the presence of actuators allow the node to give feedback to the real world, acting like sinks. A filter device can have only communication capability, receiving musical data and forwarding it to another node, just like an audio effect. An example of device is an equipment that assists in remote control rehearsals. This device will need the ability to reproduce and store audio, so that they can have better control of latency and allow communication between musicians.

The concept of Musical Things encompasses also digital/virtual things. Virtual Musical Things can be realised through software services capable of collecting/analysing, receiving/transmitting information serving a musical purpose (e.g. in a virtual environment) [Turchet et al. 2018a].

IoMusT Roles

Roles can be defined, in this context, as the set of actions that a device presents in a musical activity, for example: smart instruments [Turchet and Barthet 2019a], such as the Sensus Smart Guitar [Turchet et al. 2017] and Smart Cajón [Turchet et al. 2018b], used to create music; augmented/mixed reality glasses, used to increase the audience's immersion in a presentation (see e.g. [Selfridge and Barthet 2019]) and bracelets that vibrate according to the rhythm of the music (see e.g.[Turchet et al. 2019]). The role will directly impact the design of the device's hardware and software, since functionality and components are interrelated.

But since without the action of a user, non-autonomous objects are unable to perform an action, it can be essential that there is human action for them to work. Thus, the impact exerted by users and musicians in handling musical things is directly reflected in their roles. From the musical and technological capacity of each one, the equipment can only accomplish what was programmed or even fully exploit its capabilities. On the other hand, the creative use of these tools allows to extrapolate the field for which they were created and to contribute to other forms of art.

The software that makes up this device, in turn, allows greater adaptability of use, since devices with the same hardware configuration can run applications with different functionality, according to the user's desire. Software applications for musical things should take into account usage information over time and respond to the environment in which they are used. For this to happen, artificial intelligence techniques can be used to analyze the behavior of the device in different contexts and adapt it based on heuristics or the solving of optimization problems.

IoMusT Ecosystem

In the IoMusT ecosystem, it is no use just having one device that plays music if there is not another device capable of sending music to be played. Thus, the IoMusT is based on the idea of several interconnected devices working together, creating flows of information and creating an ecosystem or a musical environment. The advantages of planning the ecosystem in this way is that it improves the connection capacity and the project's workflow, since users will have several points in common, alignment of expectations with reality in musical creation and construction of flexible applications.

Therefore, this environment can be configured in a way that all the possible scenarios are possibly different, adapting the preferences and characteristics of users needs and comprising different profiles. This opens the way for small sound features to be combined with different types of architectures, such as pipes-and-filters, for example.

IoMusT Target Audience

[Turchet et al. 2018a] provides five main categories of users for IoMusT: musicians/artists, sound engineers, audience members, music students and music teachers. For musicians and artists, these tools can be useful allowing remote rehearsal, interaction with musical devices through local networks or cloud, and the use of smart instruments. For sound engineers, the possibility of intelligent productions arises, whether in studios or in live performances, in addition to the support of smart instruments [Turchet et al. 2020b]; for audience members, multi-sensory experiences of a concert can be envisioned, as well as allowing greater participation in the execution and creative process of a presentation [Turchet et al. 2019].

In view of the fact that Ubimus works to make music universal and accessible, the application of IoMust in this medium also allows us to think of helping lay people in musical creation, taking into account that everyday and easy-to-use equipment begins to adopt the ability to create and play sound. Finally, music students may be provided with means for remote learning and greater access to new sound interfaces while for music teachers, features can be provided for remote monitoring and learning feedback and web applications to assist in teaching [Turchet et al. 2018a].

3. Related Research Fields

There are several research fields that can be related to IoMusT, some of which are described below. Since IoT aims at developing smart environments for people, we reviewed fields which take into account users in the context of everyday activities as well as neophytes in computing and music, in addition to experts.

3.1. Ubiquitous Music

[Keller and Lazzarini 2017] defines Ubimus as an environment that supports multiple users, devices and sound sources in an integrated manner. It should also provide ways to improve social interaction and device independence. The authors use the term for music or musical activities present in everyday life supported by ubiquitous computational concepts. Ubiquitous music research generates creativity support tools (CST), focusing especially on lay-musicians.

Like other domains of research, Ubimus proposes its own ecosystem. This ecosystem supports the integration of audio with tools that allow the interconnection of equipment and people, support local and remote interactions and provide means that spread the computational load over a heterogeneous collection of units. In this way, Ubimus not only contributes to the expansion of the IoMusT, but also opens up new opportunities for artistic applications in this field [Turchet et al. 2018a].

Another contribution that Ubimus provides concerns the means of implementation and reachability. Aiming at concepts that do not depend on specific implementations and focusing on high level methodologies, helps in the development of new technologies, such as reducing technology cost. Thus, it allows a widespread implementation of IoMusT without requiring large investments in resources [Turchet et al. 2018a, Turchet and Barthet 2019b].

3.2. Interactive Performance

Another theme related to the IoMusT is the Technology-Mediated Audience Participation (TMAP) [Hödl et al. 2017, Wu et al. 2017], which uses technology to facilitate the creation of music and increase public engagement in live performances. Among the presentations that fit this topic can be mentioned "Chaos das 5", an audiovisual performance that uses three layers for audience immersion, two of which are related to technology. The first one, based on music, allows the audience to take part of a composition of the program's soundtrack from a web application. The second one, turned to the digital medium, uses images in real time to compose the scene. After the production, the people who contributed to the play are credited together with the artists [Schiavoni et al. 2019].

Another presentation of this type is SWARMED [Hindle 2013], which uses smartphones from the audience as a Digital Music Interface (DMI). TweetDreams, a system for interactive concert, uses tweets collected during the presentation to generate melodies [Dahl et al. 2011]. This type of approach differs from the others, since a tweet is not directly related to other people, but to the feeling captured by posting on the social network. Thus, music is not constructed in a lexical way. Mentions should also be made of other presentations, such as Open Symphony [Wu et al. 2017] and Mood Conductor [Fazekas et al. 2013]. The similarity is that they support audience-performer interaction through mobile devices and visualisations, communication protocols and computational applications to allow the public greater immersion and/or participation in the works presented.

4. Challenges

IoMusT faces the same problems as the comprehensive IoT field, such as issues involving security and privacy [Køien and Abomhara 2014]. There are also specific challenges in this area, such as technological and artistic, as pointed out in [Turchet et al. 2018a]. Then, we propose and discuss other challenges related to this field.

4.1. Technological Challenges

The challenges discussed here are divided into three different parts, where the first deals with **latency and synchronization** between equipment, which is perhaps the most critical point to be addressed. This is due to the fact that the current state of equipment and network technologies does not meet some basic needs of IoMusT, such as providing good quality to multimodal content, allowing synchronization between devices at different times and offering good audio/video quality over remote connections.

The solution to this issue would be to develop new devices and communication protocols or to optimize those that already exist and direct them to this field. However, this can represent a commercial challenge, since the wireless communication protocols, such as WI-FI, Bluetooth and 5G are already well defined, in addition to requiring a large investment to adapt to other forms of performance [Mitchell et al. 2014].

However, when thinking about the IoMusT local environment, these issues have less impact since in a local area network it is possible to increase network speed if it is necessary upgrading the devices involved in the communication. The latency in a network connection is strongly attached with the hops (network devices) in the network path between two nodes and in a peer to peer connection it is possible to connect devices directly, without extra network hops.

A second challenge is the **interoperability and standardization** of the devices and communication protocols, representing a pillar of this field and being extremely important to make its implementation viable. This is because it is the application that will grant compatibility between devices and operations at local and global scales and in a distributed environment maybe it is not possible to have previous information about which devices and operations are part of the environment. In this context, it is interesting to create or adapt protocols and interfaces aimed at creating music. It can be extremely important to have group communication, like multicast or broadcast to discovery devices and announcement protocols to auto setup devices in the same network.

A third technological challenge to be faced is the **design of the equipment** used in this activity. Given the diversity of its ecosystem and the application of music outside traditional environments, the devices used do not always have a direct relationship with music, as defined by Keller and Lazzarini [Keller et al. 2014]. Among the issues related to the creation of new interfaces and Musical Things are energy consumption, the need to support connection between users and the requirement for devices to have low latency, sound processing and communication [Miranda Carpintero et al. 2015, Koreshoff et al. 2013a, Koreshoff et al. 2013b].

4.2. Artistic Challenges

One point that differentiates IoMusT from IoT fields is its concern with artistic applications. In view of the infinite number of objects that make up this field and the different forms of artistic expressiveness, some discussions arise. One to stand out is the creation of geographicallly-distributed music. As the process of music performance depends on a great exchange of sounds and information, challenges to be faced range from preventing the musicians involved from having their performance impaired due to their devices, to reducing latency and creating a system of backup in case of loss of connection. Still, this new form of artistic creation allows new styles and manifestations of art to emerge.

Currently, technological developments in mobile devices and wireless communication networks have allowed lay musicians to use new tools to create music in an easy and intuitive way. The help provided by computational means, such as software for creating and editing music and scores, helps both in the theoretical part, instructing the user in the formation of chord sequences, in the composition of base melodies and keeping the music in the correct tempo, as well as in the practice part, by providing the musician with samples and pre-programmed sound sequences, which would be difficult for a layman to perform. Examples of software that provide these functions range from MuseScore, Guitar Pro, Ableton Live and GarageBand, to mobile applications, such as Caustic and SoundPrism.

The infrastructure to be configured to support this new art creation model is also a point to be discussed. Public policies that deal with communication systems should be developed or improved to make electronic devices that help to create music cheaper and more accessible to the population. There are also investment issues, which require a lot of time and resources for this to happen. The collaborative creations that emerge from this structure can also imply copyright problems, as there would be debates about who owns the work and whether a recording and possible sale of it would be legal.

[Martinez-Avila et al. 2019] proposes other challenges and artistic benefits from the use of IoMusT, e.g. the potential lack of ergonomics if an instrument needs to be handled along with a separate technological artifact. However, smart musical instruments are envisioned as standalone instruments integrating both the instrument and the technological components enabling augmentation, intelligent sound analysis/production processes and network communication [Turchet and Barthet 2019a]. Sensus Guitar is pointed out as a possible solution for this, since it allows control of the Digital Audio Workstation (DAW) through gestures captured by the guitar itself.

4.3. Social Challenges

One of the first philosophers to analyze the impacts of technology was Herbert Marcuse [Marcuse and Kellner 2001]. According to him, technological development has formed awareness or rationality in patterns of individuality, which have been disseminated in society. In this way, technology has become a social process. Among the impacts mentioned by the author, the following stands out: abundance of technology for a portion of the population and continued scarcity for another; establishment of standards and demands by the ruling class, which are not always in accordance with most of the interests of the individuals themselves; submission of workers to large companies; economic power retained in the hands of those who control production and loss of individuality of thought. All of these problems are influenced by the advancement of IoMusT.

Allied to this, three other problems can be accentuated by IoMusT. The first one is the non-heterogeneous access to technologies, since people living in more densely populated territories have easier access. The second one is the lack of infrastructure, which can lead to an increase in socio-cultural differences between urban centers, peripheries and the rural population [Lysloff 2008]. Here, there is a point of contact with Ubimus, which, among others, also depends on the communication networks and technologies present on the web. There is also a concern with excessive consumption, constant need to generate innovation and social apartheid, as defended in [Junior and Schiavoni 2019a].

Still according to [Junior and Schiavoni 2019a], possible solutions to these problems lie in the idea of the Solidarity Economy, which consists of reciprocal exchanges of knowledge and non-hierarchical relationships between suppliers and users. Adapting to new cultures and generating accessible products are also practices that help to reduce this gap.

Positive social impacts around technologies related to the concept of the IoMusT can be observed. The emergence of open source software is one of them. Take Elk Audio OS[1] as an example, an operating system that runs plugins on hardware or on low latency audio systems. The idea around Elk is to create a new generation of digital instruments and experiences through computer networks. It also intends to connect people around the world and allow the creation of new forms of musical creativity, in addition to being a low-cost solution. Another positive factor is the possibility of personalization through the analysis of user data [Turchet and Barthet 2019a]. For example, the smart speaker Prizm monitors people's moods in an environment and recommend adapted playlists [O'Brien 2015]. It is also important to highlight the independence granted to artists in the management of their careers, allowing the control of the inventory of instruments through the smartphone and also applications to control their merchandising stores.

4.4. Economical Challenges

The music industry always undergoes drastic changes. The gradual replacement of LP by CD, even the sharing of songs in mp3 format and the emergence of streaming platforms, forced musicians to adapt to a new reality, often requiring a certain independence from them in the management of their business.

This independence can be aided by the IoMusT. An example to be cited is Sonibal SmaRT EQ[2], an equalizer plugin that, through an artificial intelligence system, collects information passed to the mixer and changes the sound, like a mixing engineer. On one hand, this can be seen as reduction of production cost removing the need of a sound engineer, on the other hand, such technology could negatively impact the creative sector by replacing human creative roles by machine-based solutions (along with a potential loss in artistic quality). In any case, there is a change in working relationships [Matthews 2020].

Another important contribution concerns decision-making, based on data obtained from streaming platforms and social networks. Using artificial intelligence techniques and sentiment analysis algorithms that could emerge in IoMusT ecosystems, artists would be able to understand in which regions their music are most popular, the average characteristics of listeners, what activities they perform while listening to music and with which device they prefer playing songs [Martinez-Avila et al. 2019]. This could help musicians make better decisions about their careers and how to generate more impact and revenue [Matthews 2020]. Crowdsourcing, crowdcomputing, crowdfunding and other initiatives have also allowed an exchange of cultures and professional experiences of those involved in the music area, in addition to leaving this environment financially healthy.

[1]Available on: `https://elk.audio`.
[2]Available on: `https://www.sonible.com/smarteq2/`.

IoMusT could lead to economical growth in the music industry sector and may imply changes in the speed and in the way music is produced, also involving public and private services. From this, some questions arise, such as: what will this emerging market look like? Would this large amount of machinery have a negative impact on music and other arts or on the contrary enhance creativity for the better? Would prices be restrictive for the poorest people? Would prices be restrictive for the poorest people or affordable solutions can emerge?

4.5. Environmental Challenges

With the increase in equipment and "things", there is also a growing concern about the environmental risks that they can cause from the production process to disposal. Among the problems generated by technological means are: pollution; chemical composition of materials; consumption of renewable resources or not; generation of waste resulting from the disposal of obsolete electronics; disturbance in ecology and health hazards [Cubitt 2016, Eren 2002].

Possible solutions are: sustainable technologies [Junior and Schiavoni 2019b], such as materials that consume less energy or are able to perceive a routine of use and automatically turn off when no one is using; monitoring of production meshes, in order to avoid waste; virtualization of activities and implementation of recycling and device reuse policies.

IoMusT can bring scalability to a music environment where devices can be added and set up according to the need. The possibility to reprogram a device is another interesting fact that can bring possibilities to reuse devices and fights against programmed obsolescence. When compared with large systems, an IoMusT ecosystem can save energy consumption and also bring new forms to reuse devices, saving resources and the environment.

5. Conclusion

In this paper, we present an overview of an IoT subfield, known as the Internet of Musical Things. This field is related to several areas of Computer Science and the Arts, such as ubiquitous music, human-computer interaction, new interfaces of musical expression and participatory art. The techniques discussed here aim to facilitate communication between musicians, audio engineers, lay-musicians and the public, whether they are in the same place or not, and facilitate the process of musical performance and composition. The emergence of IoMusT and these musical devices also extend some possibilities of research to other fields, such as music education, where this technology can help teachers and students to learn music, making the play process cheaper and faster.

From a technical point of view, IoMusT proposes a new path in the Information Age, creating objects and intelligent instruments that will help in the understanding of music and the process of creating and consuming music. In this paper, we brought some considerations about the devices involved in this field, the communication between these devices, the possible roles, the ecosystem and the target audience fo this technology. However, all proposed concepts presented here are still experimental and shows what we think that this technology could be and do not intend to define what it might or should be.

We also discussed the impacts and challenges that this new area faces in the social sphere, such as the possibility of increasing the disparity between urban and rural areas; economic, indicating how the IoMusT will interfere and suffer interference from the private market, having to deal with issues of copyright, patents and industrial secrets, in addition to concern about the availability of this technology in underdeveloped countries and how they help musicians and artists to manage their businesses and cut expenses. Finally, environmental issues are discussed, showing concern with material disposal and recycling.

An important concept that we want to disseminate in this paper is how important IoMusT is in many ways and how it can be related to Ubimus concepts, using everyday objects to generate music and new artistic expressions. The results of this directly affect human life and how we understand the concept of creating, performing and participating in musical events.

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