Virtual Robotic Musicianship: Challenges and Opportunities

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ABSTRACT

In the last few decades, robots have fostered unique possibilities for musical performance and composition, allowing novel interactions with musicians and memorable experiences for the audience. Robotic musicians can be built in many shapes and have diverse functionalities, making robot musicianship a fertile research field. However, building physical robots requires access to electrical and mechanical components, as well as laboratory equipment, which can make them financially unfeasible in peripheral countries. Moreover, building physical experimental devices quickly raises the problem of disposing of broken or outdated parts. Finally, the COVID-19 crisis has decreased access to laboratories and forced social isolation, which further harms physical robots' development. In this position paper, we argue that the current technology for robot simulation can be used to provide most aspects of physical robots, with considerable advantages related to the financial cost, the environmental impact, and the possibility of testing and sharing robots using the Internet. We also discuss previous work on virtual presence, which indicates that both the performers and the audience can feel being present in the same space as the virtual robots. Lastly, we anticipate challenges and research opportunities in this field of research.

1. INTRODUCTION

Robots are an important category of musical agents [1] and have been used in music-making for a few decades now [2–6]. Robotic musicians [7] use sensors, actuators, and electronic devices, bringing a diversity of new perspectives when compared to piano players and other mechanical actuators, like the visual cues that relate to their movements and sound qualities [8], and the possibility producing realistic sounds from physical movements [8].

Musical robots can also benefit from sensing their musical surroundings [9–11], which allows them to automatically respond to specific cues. Shimon [12], for instance, is a robotic marimba that is capable of interacting with a human musician in real-time. These autonomous responses can help mitigate the inevitable, even if short, actuator delays [13]. Bear in mind, that robotic musicians have mechanical delays caused by electromechanics components. Thus, these robots need to compensate them to keep in time. Dealing with delays and synchronization issues in robotic music performance is quite a challenge [14]. Also, autonomous musical cue anticipation can allow slower, more expressive gestures that allow human musicians to create expectations towards the robot's behavior [15].

However, robotic musicianship has some drawbacks. First, the cost of high-quality electronic parts in peripheral countries that can quickly make robot-making economically unfeasible [16]. Such a cost hinders the development of musical robots, and, consequently, of their surrounding elements: musical composition and performance, gesture and interaction design, and device building and control. Then there is the environmental impact of importing electronic goods from abroad and all the electronic waste that is produced during the process [17]. Finally, due to the social isolation enforced by the COVID-19 sanitary crisis, the access to the electronic laboratories and music studios has been compromised, as well as the possibility to collaborate in person with the multidisciplinary team that is required to build such robots.

In this paper, we propose using virtualization to enable robotic musicianship and their surrounding developments. For such, we use a simulator to devise robots and their behaviors. Then, musicians can interact with the robots in the same way as they would with hardware-based robots, which can be contradictory statement since robots, by definition, are indeed physical machines [18].

The idea of using virtual robots has been used in the past. In special, we note a marimba player designed within SolidWorks [19], and a virtual drummer that helps in music therapy for rehabilitation [20]. However, we are not aware of initiatives towards building virtual robot musicians for music production, research, and performance.

It is noticeable that recent technologies on physical simulation have allowed simulating realistic behavior that can be used either for games or for practicing real-life situations [21]. Also, recent developments in sound processing algorithms and hardware have allowed realistic sound synthesis and binaural spatialization. These conditions allow virtual robots to have a consistent behavior, which can lead to highly engaging and immersive experiences.

Virtual robots have the obvious advantage of overcoming economic costs, which is greatly relevant in peripheral countries. Also, they can be immediately replicated, allowing to create unlimited-size orchestras. They can be shared between developers and musicians in different locations, which greatly facilitates the interaction, in special during the pandemics and they have a smaller ecological footprint.

Following, we further discuss the challenges and opportunities related to virtual robotic musicianship.

2. PROBLEMS RELATED TO PHYSICAL ROBOTS

Non-human devices for music making have been part of the human imaginary since centuries-old legends like the singing harp of Jack and the Beanstalk. Real devices capable of playing music can be found in Leonardo DaVinci's sketches for mechanical drums, and, more recently, in the player pianos from the 19th Century. In the second half of the 20th Century, robots became increasingly present in a diversity of musical applications

Musical robots are now present in art, industry, academia, and in hobby projects, but their development is far from trivial. Building and using musical robots requires a series of skills that span between Engineering and Music, that is, the robot-building team must be skilled in a number of topic such as electronics, mechanics, programming microcontrollers, designing musical interactions, composing music, and playing music.

The development in electronics and mechanics requires special machinery, such as oscilloscopes or turnstiles, which can be inaccessible outside institutional laboratories. Also, each development cycle can require the acquisition of new electronic parts, which have a cost of their own. This makes the development cycle of physical robots considerably slow and expensive, in special in developing countries [16].

The need for a team and laboratory is a problem of its own during the COVID19 pandemic. In this context, social isolation calls for the temporary closing of working environments, and the impossibility of working together makes it unfeasible to join a team with all necessary skills.

Even in non-pandemic times, despite their expensive and time-consuming development, physical robots can quickly become outdated or malfunctioning, as any experimental electronic device. The constant development of musical robots generates clutter, which has an inherent problem related to the disposal of electronic components. Some parts of malfunctioning robots can be disassembled for usage in future experiments, and some robot components can be built from reclaimed hardware such as old printers or smartphones [22] [23] but others – especially malfunctioning electronics, soldered components, and 3D-printed parts – are simply discarded, which further contributes to already complicated environmental issues [17].

All of these difficulties can be overcome, as they have been, with an aim to bring to life the musical automatons that have long resided the human imaginary. However, we note that current technology allows simulating realistic physics and sound production, which has enabled, for example, virtual reality in games and other applications. This means that all of these difficulties can be mitigated by using virtual counterparts of physical robots, in a path that resembles the migration from physical synthesizers to virtual ones. Furthermore, we can have virtual (software) robots, which can be stored in hard drives, shared over the Internet, and built as a massive collaborative effort.

Next, we discuss the potential impacts of virtual robots in the context of musical performance.

3. PRESENCE AND VIRTUAL ROBOTS

Physical robots have been shown to provide a diversity of possibilities in musical creation and performance. Musicians and the audience are *present* in the same space as the robots. This section discusses the concept of Presence and the subsequent potential for using virtual robots in musical performance.

In literature, Presence is often referred to as telepresence, virtual Presence, or mediated Presence. In general, Presence can be understood as a psychological state or subjective perception in which an individual's experience mediated by technology, in part or whole, fails to accurately recognize the role of technology in his individual experience [24]. For Slater and Usoh [25], Presence can be defined as the virtual reality users' suspension of the disbelief that they are in a different world from where their bodies are physically located. We understand it is possible to use virtual robots in interactive music performances using the Presence concept. Thus, we foresee a virtual community implemented in mixed reality, inhabited by physical, remote, and virtual robots. This community raises the fundamental question of if such a virtual environment can generate and mediate real-time musical performances.

The term "Telepresence" was first defined by Marvin Minsky [26], who emphasized the possibility that humans could feel the sensation of being physically immersed or transported to a remote workspace through teleoperation systems. However, the definition coined by Minsky projected the development of high-quality simulation refinements and sensory feedback technologies. He predicted using telepresence in dangerous activities, the development of telemedicine technology, and the possibility of home office work – which anticipated the intense use of virtual technologies induced by the COVID19 pandemics. Further, Misky [26] defines social Presence as when users feel they are with other people locally or remotely, and copresence as when someone feels that they are co-located elsewhere with other people and are related to physical and social Presence.

Sheridan [27] used the term "Virtual Presence" to describe the feeling of "being present" caused by virtual reality technologies. When defining this term, Sheridan claimed to be possible to make a clear difference between virtual Presence (e.g. the sensation of Presence in a virtual environment), with the notion of telepresence, which is associated with teleoperation systems, as Minsky initially approached it. The delivery of Presence is closely tied to an understanding of consciousness and, in particular, of the interplay of implicit and explicit factors in the construction of human behavior and their relation with virtual space. Presence is constructed by the brain and expresses the consistency between the world model the brain maintains and the cues it is exposed to.

Presence has long been a critical concept in teleoperation and virtual reality (VR) and has been defined as the "sense of being in a virtual environment" [28]. However, it is not clear how this "sense" is generated, and it is not uncommon to see it explained with the notion of "the suspension of disbelieve", coined in the early 19th Century by the poet and philosopher Coleridge. In recent literature, the notion of Presence results from the interplay of both central and peripheral factors and that it should be assessed through many convergent measures that include measures of the subjective, physiological and behavioral state of the user [28, 29]. Therefore, Presence, induced by virtual or physical sources of stimulation, is governed by several principles that underlie human experience, creativity and discovery.

The constructions of a meaningful relationship between agents and environmental stimuli in a virtual space and the exploration of their interactions can be anchored on the proposition that "interactive media within mixed reality environments induces an agent coupling with the space and it is defined as the sensing of Presence" [30]. Presence can also be studied as the relation between the implied identity of an organism/agent and its environment within the following perspectives: i) self-environmental (the agent exists in relation to the environment); ii) virtual objects (the object exists in relation to the agent); iii) social (the other agents exist in relationship to the agent). Physical Presence is when someone feels they are physically somewhere.

Presence also indicates that there are essential inputs for the construction of self-referral agencies. Thus, it is essential to deploy methodological efforts focusing on interactive media within a mixed reality environment to study the constructions of meaningful relationships between agents and virtual stimuli [31, 32]. The assumption is that the interaction of an agent or group of agents with an immersive space, using various interactive devices, indicates how these processes affect their behavior and the meaning that they construct. Such experience was approached by the interactive installation Ada: intelligent space developed and exposed at the Swiss National EXPO.02 [33].

Therefore, it is possible to project that the audience and musicians can feel present in the same space as the virtual robots. The challenge of devising a human-accessible mixed reality environment where humans and virtual robots are performing music together is that the interactions within such an environment dynamically shape musical performance. Thus the musician's virtual Presence is affected by the virtual robotic behavior. Both environments (virtual and physical) can access and influence each other, establishing an interaction. This possibility gives equal importance to both the physical and the virtual place in the performance outcome. In this exchange, the virtual world provides for limitless expression, and the real world defines physical grounding and the boundaries of interpretation. The virtual robots act in the virtual space, generate and react to sounds and human gestures. The musicians, in turn, generate meaning in the acoustic space and virtual one from these interactions with the virtual robots.

For our article's purpose, we will refer only to the term "Presence." In our case, we discuss the possibility of developing systems in which virtual robots interact with live musicians. We intended to study how such interaction affects the notion of real-time performance and how the inclusion of virtual robots can also enlarge musical aesthetic possibilities. In this way, virtual robots can be seen as a way to move from the notion of interactive performance to the concept of performance in a mixed reality in which musicians and virtual robots participate in a symbiotic process. We project that such experience would a) create a unified experience where virtual robots and musicians are merged in the virtual performance space (i.e. a mixed reality experience); b) the sound material generated by both evolve coherent in time; c) the resultant performance explore and exploit both implicit and explicit cues from musicians in their individual and collective interaction with the virtual robots; d) the use of novel multi-modal sensing and effector systems to boost interaction with and understanding of the dataflow generated during virtual robots-musicians interplay. In these processes, we also acquire that the virtual robots act as an adaptive sentient agent that helps humans explore creative spaces and discover novel patterns driven by both their implicit and explicit interactions.

Finally, it is important to notice here that the nature of musicians' interaction with digital technology involves behavior, perception, manipulation, and interaction. Perception leads musicians to identify and interpret acoustic and spatial relationships (e.g., among others) with the technological objects they are experiencing. For example, in live electroacoustic music, there is technological manipulation by the interpreters in other to sound processing. Otherwise, when someone changes the spatial location of an object in a virtual game, there is a level of experience in which the gamer perceives and acts on the virtual space. If users and virtual objects affect each other, the experience expands the physical world; therefore, the interaction occurs between these two domains, physical and virtual.

Thus, in our article's proposal, the musical interaction with virtual robots provides the exchange of musical information in real-time and induces responsive actions between robots and musicians. In this way, we project such musical experience to bring new meanings to performance experiences, such as a mixed music concert with the Presence of virtual robots.

As we discuss in this section, virtual robots can provide a sense of Presence, similarly to physical robots. This makes virtual robots a rich field for exploring interactions, which can foster – without physical parts – musical interactions similar to those provided by physical robots. Next, we discuss the current technological tools that can help achieving virtual robotic musicianship.

4. CURRENT TECHNOLOGY FOR VIRTUAL MUSICAL ROBOTS

The design of musical robots can be divided into three parts: a) establishing/developing the controlling interfaces, which ultimately supports the interaction between the musicians and the robots; b) designing the communication strategy, such as the protocols, redundancies, bandwidth, etc; and finally, c) designing and building the musical robot itself. Each of these aspects is discussed in a separate subsection, as follows.

4.1 Controlling robots

The interaction design for a particular robot is unique. It is virtually impossible to anticipate all the features a robot will have.

Interfaces to control musical robots can vary from custom-build software, wearable devices, MIDI-controllers, APIs, up to live programming languages - the latter with a very interesting application to real-time music performance. An important aspect to be considered is that programming languages specialized for sonic purposes, such as those that manipulate oscillators, filters, and other electronics for sound production, might not be the ideal candidate for the job, even though it usually provides OSC support. The reason behind this idea, is that musical robots do not manipulate sound signal directly ally. Usually, it does by manipulating the mechanics that produce the acoustic signal, meaning that controlling robots in more similar to conducting an orchestra than the usual electronic music live-coding. While the first activity uses gestures to communicate musical actions (musical terms) the latter use commands to manipulates the signal itself. In other words, robotic music performance has particularities that mimic human music performance. In that sense, the Octopus Music API [34], written in Java, is a viable option beacuse it models the performance using musically-related terms.

Octopus provides classes within three categories: a) musical data structures; b) musical data interpreters (performers); c) instrument classes. The musical pieces are structured using the classes of the musical data structures, similarly to a musical score. Such "object" is then played by the different levels of interpreters. A Musician is the Interpreter of the highest level, meaning that it "knows" how to play the piece in its crude form. A Guitarist is an example of an low-level Interpreter, meaning that it adapts the piece (in its persistent form) to their own capabilities, including restrictions of the its Instrument, in that case, the Guitar (instrument category). This metaphor is adequate to a Robotic performance, because, in this scenarion, a Robot can be seen as an instrument.

A major drawback of using an Java API such as Octopus is that the developed algorithm must be "compiled" before the program make any sound. In addition, Java is known to be a verbose language so, even if it possible to run in real-time using a REPL console (jshell), adjustments must be made to improve writability and make it more user-friendly to the final user (i.e. musicians) and this has been done using a musicality centred approach to the interaction design.

4.2 Communication protocols

The RoboMus framework [35] covers the whole musical robot production but has a special focus on its communication side. The RoboMus framework uses a predefined musical message format, built over the OSC protocol, to enable robot control and mutual collaboration.

It goes further by proposing macro and micro synchronization strategies by the use of a Musical Message Synchronization Server (MMSS) and onboard algorithm, respectively. Synchronization is particular sensitive matter considering that multiple robots are generally used in real-time music performance [14], and each robot takes a different time to react to its controller's inputs.

In order to support the interaction with all sort of musical robots, even those yet to be built, the RoboMus Framework used a handshake approach that allow the robots to introduce themselves to their human-performer by communicating all the "actions" they can perform using Open Sound Control (OSC), thus, any "client" that supports it could be used. This is as far as the RoboMus can go but it does not necessarily guarantee a good user experience in controlling the robots in musical activities. This, however, is out of the scope of this paper.

4.3 Robot design and physical simulation

Current physical modelling engines have proven powerful tools for real-time simulation and gaming. Tools specifically catered for robotics have added other functionalities to it, such as directly simulating specific types of engines, joints, and sensors. They have the advantage of corresponding to real-world objects, henceforth their behavior is predictable and understandable.

We give special attention to the Webots [36, 37], which is an open-source and multi-platform software. It provides a large asset library with pre-built robots, sensors, actuators, objects, and materials. Also, Webots allows programming the simulations in many languages: C, C++, Python, Java, MATLAB, or using a Robot Operating System API. Because it allows programming in several languages, it can use their libraries to send and receive information to and from the simulation using usual musical protocols, such as OSC or MIDI.

We used Webots to create a musical simulation to evaluate some of its possibilities. In this simulation, whose environment in shown in Figure 1, a generic robot moves within a limited space with objects. When it collides with an object, a sound is played. This robot musicality is similar to that found in Roboser [6].

We used a virtual sensor to measure the impact force, so that stronger collisions can generate stronger sounds. This measured impact force is sent to a SuperCollider script, which in turn synthesizes sounds using a physical model.

This short simulation raises an interesting dichotomy regarding the virtual robots: they are simulated within a physical modelling toolbox, which emulates realistic behavior; however, their output depends on musical composition and sound design, which can be (or not) realistic depending on the composer's intentions. Realism could

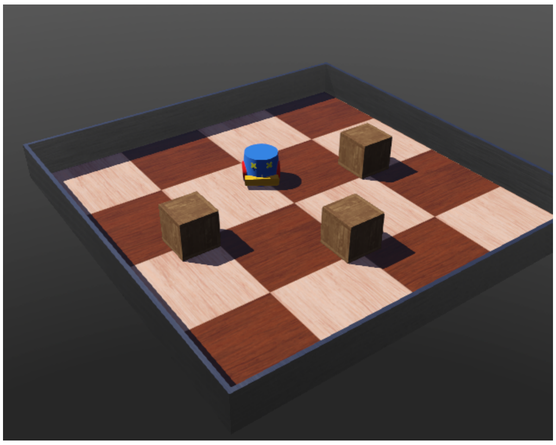

Figure 1. Robot simulation. The mobile robot (blue cylinder) navigates through the environment, and when it collides with an obstacle (brown boxes), the system emits a sound.

be even improved by using acoustic virtual reality techniques [38], which allow emulating object positioning in a sound scene that can be reproduced either via headphones or loudspeakers. In other words, this allows us to raise questions about bringing to the realistic physical model, and then the ability to enjoy artistic freedom, since the accessibility provided by virtuality cross barriers of reality, but allow verisimilitude even with non or ultra-realistic artistic options.

Next, we present concluding remarks.

5. CONCLUSION

In this position paper, we discuss the difficulties and possibilities brought by using virtual robots instead of physical ones in the context of musical performance. Nowadays, this change is possible because of the technologies related to physical simulation, and it can be greatly facilitated by previous work on tools for robotic musicianship.

Virtual robots can be effective as musical performance tools because they can foster Presence, that is, the sense that humans and virtual robots share the same environment. This happens because the feeling of Presence happens due to particular fluxes of consciousness, which do not necessarily depend on a physical presence. This phenomenon has been greatly explored in the last few years in the context of virtual reality, and it could be used to foster meaningful experiences in virtual robotic musicianship.

Also, nowadays, there are many tools and techniques that can help building virtual musical robots. These tools range from robot simulators to specific frameworks for music, and they can be explored even faster because the development of virtual robots is much faster and cheaper than that of physical ones.

Virtual robots are, also, more economically viable and environmentally-friendly than their physical counterparts. They do not require buying high-quality parts or finding ways to dispose of old ones. Moreover, they do not wear off with time, and they can be easily upgraded if needed.

Finally, because they exist as software, they allow collaborative work even during the social isolation required by the COVID19 pandemic. Furthermore, they allow larger, world-wide collaborations to happen, as it is the case of any piece of software. Furthermore, the technology stack used for the virtual robots can be revisited, and solutions different from those discussed in Section 4 can be used in a more integrated way than the one shown in this work.

For this reason, we propose that virtual robots can be effective tools for music making, and can be more viable than physical ones. Virtual robotic musicianship draws challenges of their own, such as questions regarding maintaining the environment's verisimilitude, designing the interactions and sounds synthesis related to the robot, or evaluating the sense of presence they could foster in musical interactions. All of these questions can be prolific fields for future explorations in art and research.

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