The Potential Role of Internet of Musical Things in Therapeutic Applications

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Abstract. *The application of the Internet of Things (IoT) specific to Music technologies is referred to as Internet of Musical Things (IoMusT). This field is in its infancy but potential applications include wide network interactive music performances, smart and wearable instruments, and multi-person virtual music systems. There is no framework as of yet, but a number of technical hurdles have yet to be overcome. These obstacles reflect the fact that many devices will be wearable which means they must be lightweight, energy efficient, and possibly low cost, but must also be powerful. Music therapy is yet untouched by these new technologies of IoMusT. However, it offers great potential for devices that could be applied in assistive living scenarios that provide a non-invasive, individually attuned, form of treatment that is always available. For example, wearable devices that are driven by low cost computing could offer interactive music therapies that are delivered outside of the clinical setting. These could be used to enhance a patient's wellbeing in between instruction and practice sessions with a therapist. The usefulness of ubiquitous music technologies will be further extended with the development of machine learning algorithms that are designed specifically to have a low computational footprint. These could be used to analyze and predict user behavior and thus tailor the therapy exactly on each occasion. This paper will develop a review of what has been achieved in this domain so far. It will then look ahead to see which trajectories are most likely for the future, particular within the guiding framework of ubiquitous music and computing. It will close with a discussion on the key technological enablers and risks that could hamper their progress.*

1. Introduction

Technology is everywhere and thus it is not surprising that it has had a profound impact on everyday musical experiences. Technology influences musical interaction probably in all its forms starting from music education (Zhang and Sui 2017) and creation (Anderson et al. 2020) to all possible ways it could reach the audience. The late nineteenth century saw the emergence of electronics for musical interaction, followed by the appearance of computers to do the very same at the end of the twentieth century. This has led to the ability of making very sophisticated music, either as an individual, or in group scenarios, using computers through wired/wireless networks. The research in musicology and its subfields such as systematic, computational (research between music and computer science) Mor et al. (2020) and applied musicology underlies a dynamic of technology-mediated music applications in human health and wellness. Ubiquitous music (Keller et al. 2014) explores novel and ubiquitous musical experiences for musicians and non-musicians which adds value to previous contributions. As music technology and industry expand, technologies like ubiquitous computing, internet of things (IoT), machine learning and artificial intelligence can transform the ways in which music is created or consumed. The field of ubimus stresses the creative and active role of all participants in musical activities.

This paper will discuss the role of ubiquitous computing and internet of things in music technology, what research has been published so far, and how this integrated environment can trigger future music-oriented therapeutic applications. The next section will give the background to the Internet of Musical Things (IoMusT) and its evolution from IoT. It will also discuss the broad contributions of technology into music therapy applications. The section after this will describe the goals of ubiquitous computing and music and how they may intersect with the future trajectory of IoMusT, mention will also be given to developments in artificial intelligence (AI). The following section will posit a framework through which IoMusT and ubiquitous music (ubimus) may be integrated and discuss potential applications. An example will be specified. The paper will then close by summarizing with conclusions and outline the most pressing challenges for future work.

2. Ubiquitous Music: Where Ubiquitous Computing meets Music

2.1 Ubiquitous Computing (Ubicomp)

The area of ubiquitous computing draws together many different fields in computer science. An illustration is given in Figure 1. The challenge for ubiquitous computing is to know how to merge these fields and create computing devices that behave in a ubiquitous manner for users (Schiavoni and Costalonga 2014).

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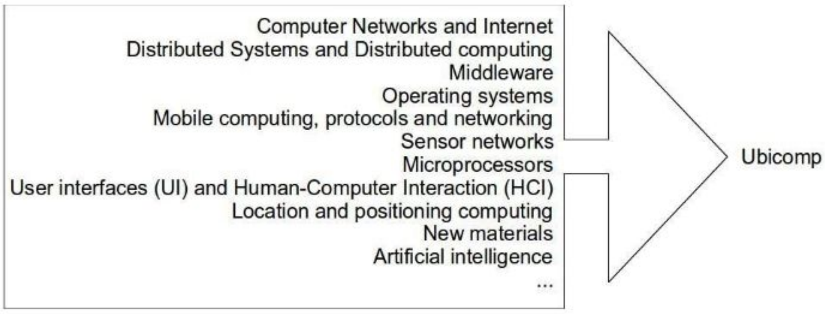

Figure 1. The research fields in Computer Science and Ubicomp (taken from Schiavoni and Costalonga (2014)).

2.2 Ubiquitous Computing and Music

Ubimus also merges various research fields in sound and music computing. Typical devices are cell phones, tablets, netbooks, micro-controllers, and portable computers. Anything as long as they are open, programmable, connectable, independent, autonomous, wireless, user friendly and expandable. From an ubimus application point of view, software should be open source and adhere to open standards.

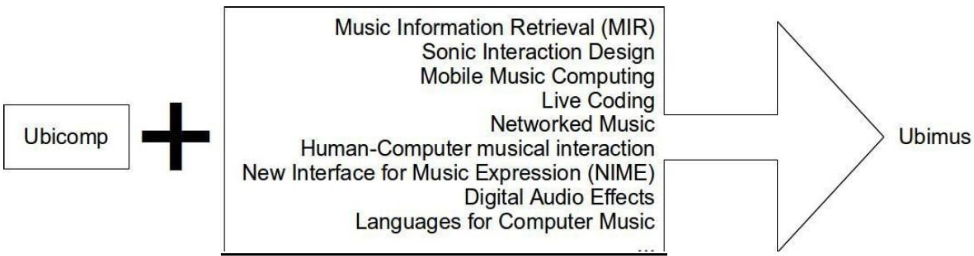

Figure 2. When Ubicomp meets music (taken from Schiavoni and Costalonga (2014))

2.3 Ubiquitous Music (Ubimus)

Ubiquitous music can be defined as a field of unbounded and creativity-supported musical environments, interactions and activities exploiting the concept and technology of ubiquitous computing. It enables artistic musical activities beyond co-located and conventionally tuned music venues. Music, in its nature, is not linear and so the definition of ubimus is multidimensional. It implicates different aspects of music, creativity and performing arts to articulate music as an ecological and creativity dominant field of research. These experiences are constructed by a combination of domains including cooperative composition, listening, and networked instrumental practice and performance either for musicians or non-musicians (Cogo-Moreira and Lamont 2018). This emergent field is grounded by the ubiquitous computing technology to establish the conceptual and theoretical models for technology supported musical interactions. These metaphoric representations are based on time and spatial facets of the musical context as given in Keller et al. (2011). Designing and building frameworks driven by this area of study require the integration of specific knowledge and methods, exploiting the fundamental synthesis of distinct techniques. In this regard, evolving computing research areas can offer new infrastructural opportunities for a wide range of individual or cooperative musical practices. In ubimus, the diversity of ecological backgrounds (social, artistic, and technological) endorse this field as an open developmental area eventually scalable to heterogeneous everyday contexts.

3. Internet of Musical Things (IoMusT)

3.1. Internet of Things

Internet of things brings together two terms 'Internet' and 'Things', where 'internet' carries the vision of a network and 'things' describe a layout for integrating and connecting the objects through different technologies (Atzori et al. 2010; Borgia 2014). As a system of identifiable objects, internet protocols, ubiquitous computing, communication technologies and sensing capabilities, it offers a shift from conventional internet approaches to connecting physical and digital objects. Things are embedded devices which not only sense the environment to collect data but also establish connections with each other and humans in the network (Gubbi et al. 2013). Some embedded smart objects, in IoT technology, draw on intelligent applications for several domains such as healthcare, smart cities, smart home and smart wearables (i.e. smart glasses, smart watch and smart speakers).

In an IoT network to make intelligent services more accessible, the user's data is captured continuously (e.g. personal data including names, phone number or location) ; emotional data is also accumulated and analyzed for personally preferred services. In this regard, IoT technology could eventually deliver music tuned to a user's emotional states (Seo and Huh 2019).

The sustainable IoT technologies have been envisioned to integrate health areas in a wider archetype for the development of human wellbeing (Salam 2020). This opens new perspectives on IoT frontiers to explore this technology to intersect with the advances in ubimus technologies. This will support evolving and interdisciplinary research trends in this field to make musical activities ubiquitous and more interactive.

3.2. Defining the Internet of Musical Things (IoMusT)

IoMusT has grown out of many discussions among researchers and references to it then appeared in publications including Hazzard et al. (2014), Keller at al. (2014), Keller and Lazzarini (2017), and Turchet et al. (2017). A significant review paper was published in 2018 by Turchet et al. (2018). It considers computing networks embedded within the functionality of physical objects (that is, the musical things) that are dedicated to the production and/or reception of musical content. These musical things are connected in a way that enables multidirectional communication, both locally and remotely. IoMusT is both a subfield of ubimus and IoT. The underlying technological infrastructure enables ecosystems of interoperable devices connecting musicians and audiences, to support novel musician-musician, audience-musician, and audience-audience interactions. Ubiquitous music research has already contributed to the advancement of IoMusT-based creative proposals (Keller et al. 2019). The integration of multiple technological objects into ubimus ecosystems opens new opportunities for artistic applications of IoMusT and supports a creative usage of the internet.

3.3. Ubimus and IoMusT

Ubimus draws new ways of musical practices through technology assisted creativity support tools and relies on ubiquitous computing for this. Not only itself but can also provide grounds towards future music technology trends. This contribution is admired by a novel music technology, Internet of musical things (IoMusT) (Turchet et al. 2018). This technology can establish novel and robust systems to be adopted in creative arts therapies beyond co-located settings. Some of the current musical services (e.g. Networked Performances, Remote Rehearsals, new interfaces for musical expression), protocols for wireless communication and over-the-network audio processing (e.g. Bela board for low latency audio processing), and suitable smart instruments can be studied in Turchet (2019).

4. Music Therapy and Technology

4.1 Music Therapy: background

The power of music is widely accepted. It triggers people's emotions and its substantial impact on the human brain induces pleasurable responses (Zatorre et al. 2013). It drives music therapy, 'music as a therapeutic intervention in clinical settings', as a creative health profession to provide in-patient rehabilitation services. Music therapy can reduce anxiety and help patients to cope with stress in an in-patient setting as explained by Tan et al. Lin (2020). Its effectiveness has also been examined in mental health units for adolescents (Johnson et al. 2018). It improves their self- expression, boosting self-esteem and making them resilient to vulnerable situations.

At a larger scope, the above interventions can be extended to out-patient health care to promote remote and ubiquitous health services. According to the review in Schmid et al. (2010), home-based music therapies (HBMT) can be cost effective and accessible for everyone.

4.2 Technology Mediated Remote Music Therapies

Advanced health systems are incorporating telecommunication and information technologies to serve beyond the traditional settings. Technology supported creative and collaborative music activities have enough potential to be adopted as a technological intervention for music therapy. A relevant case study explained by Keller et al. (2014), reveals the importance of technology for music oriented artistic activities to build resilience (an ability to stay well and mentally healthy) among school students. The music jamming platforms, examples being jam2jam, CODES, and mixDroid, which allows cooperative audio production via Bluetooth connectivity to build improvisation skills, give motivation to build such technologies for holistic healthcare. This offers a multidimensional research paradigm to explore and establish integrated models of music and health technologies. The input from cross disciplinary fields such as: i) health technologies (e.g. telehealth and ubiquitous health); ii) information technologies (e.g. machine learning, artificial intelligence, ubiquitous computing and IoT), iii) music technologies (Digital Musical Instruments, MIDI, and machine improvisation, music information retrieval (MIR) and embodied music cognition (EMC)) can offer a great contribution to establish new technology models for music therapies.

5. The Model for IoMusT based therapeutic Environments

5.1. Definitions

a) Embodied Music Cognition (EMC)

Embodied Music Cognition is the study of corporeal musical interactions (physical movements) that are linked to the perception of a music player and their gestures with the intention of finding a more thorough understanding of the associated emotions as they perform. Thus, the bodily involvement determines the way in which the music is perceived, felt, or experienced, according to Leman et al. (2018).

This information will be sent to the associated ubiquitous technologies (Desktops, PDAs or Mobiles) that possess additional add-ons to control or engage with the musical interactions. EMC has emerged as an influential area in music research and it was explicitly proposed as a musical research paradigm in Leman (2008). Its adoption is being facilitated by the improvement in sensor technologies, including camera systems, that have enabled the recording of body movements during musical activities and the subsequent data analysis, for example using multivariate, and functional data techniques. These methods have been integrated with novel approaches in audio analysis, which rely on feature extraction and machine learning methods. The EMC perspective is promising as a valuable contributor to the enhancement of remote music playing activities for users.

b) Embodied Musical Prediction Interface (EMPI)

With reference to Godøy and Leman (2010), a prototype technology for analysis of musical communication via bodily movements and gestures was presented in Martin et al. (2020). This was described as an Embodied Musical Prediction Interface (EMPI) which could streamline the pathway from musical interactions to predictions as a continuous and single input-output dimension. To connect physical and sonic predictions with performers' actions, this work employed a REcurrent Neural Network (RNN) model integrated into the physical music instruments. It contains a physical input lever (from the performer), and a similar motorized lever to represent predicted output from the RNN model. The goal of the study was to assess how these representations might impact their understanding of their instruments. /it was posited that this interface could be integrated with Smart Musical Instruments (SMI) for remote musical interactions. This could formulate an environment of predictions through real-time tracking of bodily movements, and suggesting future musical activity.

5.2. The Model

This paper employs a subset of IoMusT enabled interaction possibilities. We refer to this as a dyadic therapeutic interaction which mainly includes: i) client, ii) therapist and iii) Smart Musical Instruments (SMIs). The client-therapist dyad connects remotely to a ubimus therapeutic context. The proposed framework establishes remote connectivity through SMIs, which enable ubiquitous musical interactions, to perform a cooperative musical activity (e.g. free improvisation). For example, the in-session audio is transmitted to the therapist who in response can produce music to accompany their clients. The data from various sensors such as mobile sensors, wearable sensors and on-instrument sensors will then be used to monitor and analyze the musical output of a client. The aim is to track and analyze musical and physical activity of clients for prediction of their behavior, emotion, and future musical activity. This would enable the dyadic interaction that builds a virtual client-therapist relationship across the internet.

During the session, the data about clients can be collected in two manners; i) data captured through the sensors and ii) data about the music. The sensors employed can be biosensors to sense the client's physical actions (corporeal interactions associated with the musical activity) during the therapy session. The incoming data will be processed for Embodied Music cognition (EMC) and analyzed by the Embodied Musical Prediction Interface (EMPI) models to track and analyze a client's performance throughout the session (Martin et al. 2020). It will then try to recommend future musical activity in line with the overall therapeutic goals. The music performance provides data, for example his active and idle states during activity, associated behavior and emotions (Music Emotion Recognition). Then all this information is merged before it goes to the model informed by the therapeutic goals. The study of machine learning techniques is required to classify the data and map it to the therapeutic parameters. The data is unstructured, and AI techniques are widely proposed to deal with this situation, yet a deeper analysis for such applications is needed. The session outcome and visualizations are customized to the clients and their therapist. This will help therapists understand their clients even when there is no verbal communication. Ubimus creative practices can facilitate how and what type of music activities can be performed within a remote therapeutic session.

The quantitative analysis of musical activity depends on its definition and the data (musical features e.g. number and range of musical events used, the pitches used, and the time of activity) extracted through musical information retrieval techniques. The aim of IoMusT based music therapies would be to extend therapies from conventional clinical and in-patient environments to everyday life e.g. workspace, home or wherever is suitable and feasible.

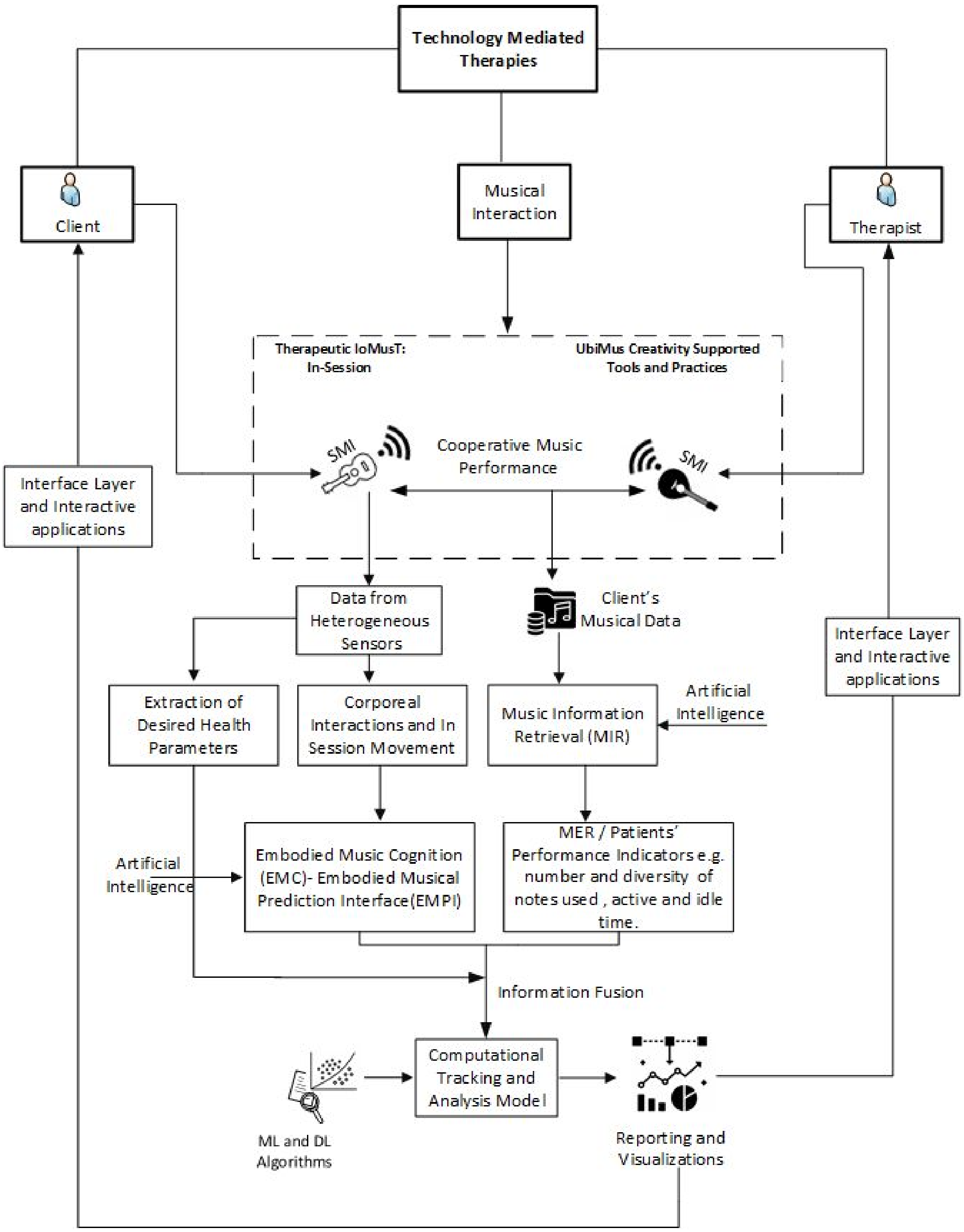

Figure 3. An abstract representation for the proposed framework; the client, therapist and remote musical interaction are primitive entities of the model.

5.3. Sample Application: Technology-led Free Improvisation

a) Theoretical Explanation

When providing music therapies, there are scenarios where IoMusT, as an intermediate layer, can provide a bridge between patient and therapist. Let us think about a IoMusT mediated music therapy session in which a client and a therapist freely improvise music in collaboration with each other. Free improvisation is an expressive and non-verbal technique adopted in active music therapy (Albornoz 2011). The therapist directs the patients to play music without imposing any rigorous rules letting them engage through their own feelings and creativity. The creative instincts of all human beings enable them to generate spontaneous musical sounds The improvisational activities are accessible: this approach does not require any formal technical skill. The IoMusT framework ensures the effectiveness of the communications on the infrastructure. In the health context, the parameters of musical improvisation need to be underpinned by their overall effects on human health and wellbeing (MacDonald et al. 2014). The performance measurement of such therapeutic improvisations requires a complex analysis of improvisational parameters. These parameters could be calculating or measuring: i) the amount of time spent in active or idle state; ii) the number of notes used and keys pressed in a specific time; iii) octave patterns; iv) dynamics; v) selected pitch classes and vi) synchronization between pressing a pedal and other events (Liang et al. 2018). Sandak et al. (2019) use these parameters to establish a tracking model for computational music therapy.

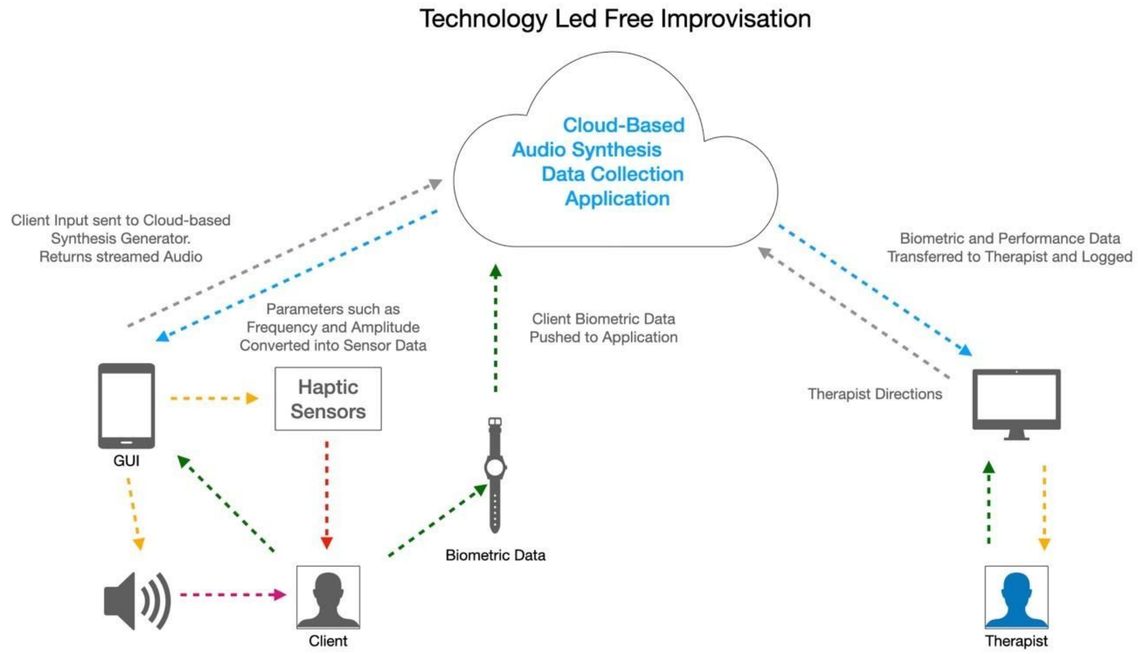

Figure 4. An abstract representation of client-therapist interaction in a Technology Led Free Improvisation musical therapy session.

b) Visualization and Technical Description

In practice, ubimus technologies combined with biometric data sent over the internet are well placed to develop creative music therapies. If the aim is to reduce anxiety and to enhance wellbeing, a form of improvised, non-pulse-based music could be successfully created with current infrastructure. This could be an audio signal generated by server-based synthesis applications, with a graphical user interface loaded on a touchscreen device, and equipped with haptic feedback sensors, motion sensors or fitness trackers to transfer patient biometric data. This data can be logged on the therapist system. In a scenario such as this, tempo, time and key signature may be irrelevant. Therefore, as long as the patient has a good sense of gestural control, any latency in the system will not impact the musicality of the application.

Networking of Musical Events

For creative and collaborative efforts which may rely on pulse-based music, the streaming of musical event data would be more efficient than server-based audio synthesis. Musical event data can be sent in many forms such as MIDI or Open Sound Control (OSC). Physically modelled synths, and Digital Audio Workstations installed on each device in the collaboration could receive the musical event signals over the internet, giving rich timbres at low latency. Experiments have been conducted using MIDI sending data through the internet from Australia to Scotland with roughly 100-150ms of latency (Bray 2017). Depending on the session parameters such as tempo, time signature, this translated as a semiquaver or 16th note latency. However, it is possible to adjust the system to compensate for a measurable delay. This would lead to both the sender and receiver to believe that the events are happening in real time but are in fact different moments in time.

An AI-based system could manage the signal flow and anticipate latency and dropouts to keep the continuity of the performance (Camporez et al. 2018). Training an AI to interpret a music event data stream would allow the AI to monitor the data stream for technical errors. For example, it is common in networked musical sessions for event messages to be lost or to arrive in a cluster. An AI system trained on such data could anticipate such a situation. Hypothetically the AI would pick up the tempo and see that a cluster of musical events with associated control messages are about to arrive to be delivered not as the performer intended. By scanning the timestamp at the source, the AI could release the notes as intended or if unable to connect to the source, the cluster could be deleted. A delayed or non-existent note-off message could be inserted by the AI. Furthermore, an AI also trained in composition, aware of the initial input sent by the performer, could insert musical materials based on what was played. For both the sender and the receiver there would be no musical dropout and the session would continue. In such a scenario, real-time musical collaboration could possibly enhance the well-being of the patients giving them a sense of connectedness and purpose.

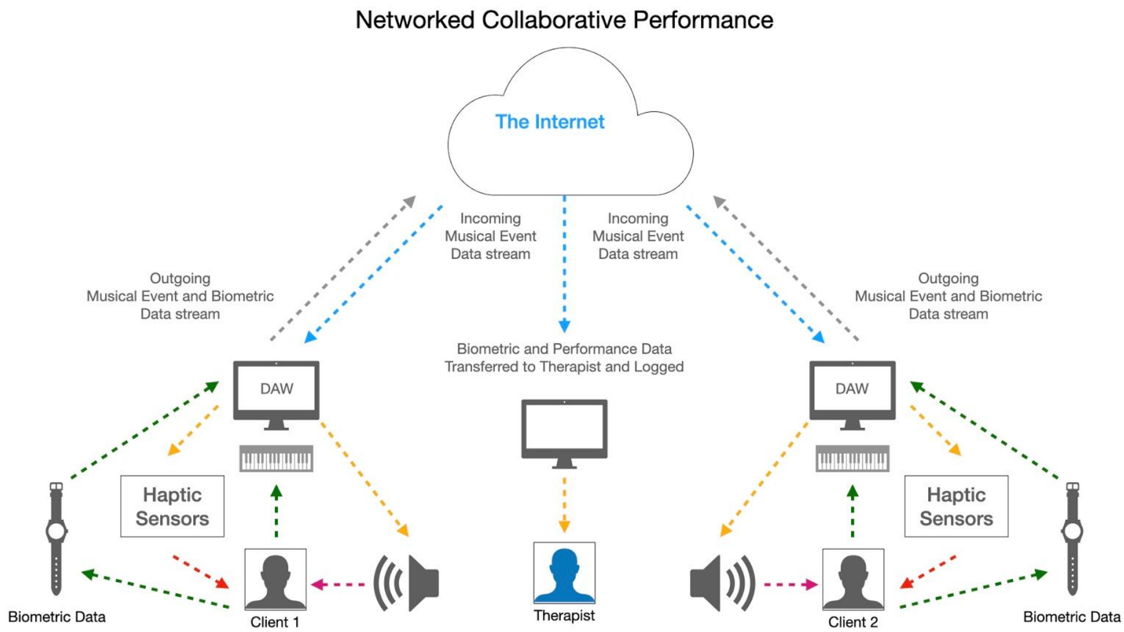

Figure 5. An abstract representation of possible client-client collaboration over the Internet monitored by the therapist.

5.4. Value of Artificial Intelligence (AI) to IoMusT and Ubimus

Artificial intelligence (AI) is emerging as an influential technology for the analysis and prediction of musical activities. There has been a dramatic increase in the integration of AI and machine learning technologies in the last 5 years. Deep learning has been a major driver for this. Awareness by the public in this technology has come from media publicity for applications such as Siri and AlphaGo. A strength of deep learning is its ability for unsupervised learning with unstructured data. The Music-as-medicine Sync project uses Deep learning (Ahtisaari 2020). Another example includes predicting music therapeutic effectiveness using Decision trees and Random Forests (Raglio et al. 2020). Also, the Sound Control project developed at Goldsmiths, University of London uses K-nearest neighbors and Neural networks in UI design for children with disabilities (Parke-Wolfe et al. 2019). Therefore, it is certain that the coming years will see more IoMusT applications with integrated AI components, and will add extra value to the user experience.

6. Conclusion and Future Work

This paper has considered the new developments in the Internet of Music Things and how they relate to ubiquitous music. Using the example of music therapy, a framework was presented illustrating the interaction between a client and a therapist. This was further illustrated through a technology-driven, improvisation-based therapeutic proposal for an application. With respect to the future work, this framework can be described using a modeling language. More research into the benefits that AI, beyond Deep Learning, can bring new elements to therapeutic applications. AI technology could drive the effectiveness and user-value of future applications. Lastly, it would be highly desirable to develop a relationship with the clinical community to find a way to gather data and obtain user feedback.

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