

PhysioPiano: An Immersive Virtual Piano Platform for Healthcare and Well-Being Applications

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Abstract—The relationship between musical practice, health, and well-being has become an increasingly relevant topic of interdisciplinary research. Two emerging concepts that may help advance investigations in this domain are the Musical Metaverse (MM) and the Internet of Multisensory, Multimedia, and Musical Things (Io3MT).

Grounded in these principles, this position paper presents PhysioPiano, an immersive and interactive musical platform designed to support applications in health and well-being while also addressing educational and artistic contexts. The system consists of a virtual piano environment implemented in Virtual Reality (VR), where users interact through natural hand-tracking techniques enhanced by wearable haptic feedback delivered through an off-the-shelf device.

By integrating auditory, visual, and tactile stimuli within a unified multimodal environment, PhysioPiano aims to foster sensorimotor stimulation, cognitive engagement, creativity, relaxation, and musical expression. The platform also seeks to support therapeutic and rehabilitative activities by promoting meaningful interactions that combine music, immersion, and multisensory feedback.

Furthermore, the paper discusses a set of design strategies intended to enhance playability, accessibility, personalization, and creative exploration for users with different levels of musical expertise and prior experience with immersive technologies. Through this work, we argue that immersive musical environments enriched with wearable haptics represent a promising research direction at the intersection of music, VR, health, and well-being.

Index Terms—Io3MT, Virtual Reality, Immersive Environments, Health Application, Virtual Piano

I. INTRODUCTION

The relationship between musical practice and initiatives aimed at promoting health and well-being has attracted increasing attention from the scientific community in recent years. This growing interest stems from the potential of music as a therapeutic resource capable of reducing or stabilizing symptoms and complications associated with a wide range of clinical conditions. Its applications extend from the treatment of chronic and degenerative diseases to interventions in fields

such as psychiatry, neurology, oncology, and palliative care. Furthermore, music has been employed in contexts involving temporary symptoms, particularly in healthcare settings prior to surgical procedures, where it has been shown to reduce anxiety and stress levels, as well as decrease the perception of pain during invasive medical interventions [1]–[4].

In addition, music has been associated with the promotion of relaxation, improvements in emotional well-being, the enhancement of cognitive and executive functions, and the mitigation of motor and cognitive decline. Among children and adolescents, musical engagement contributes to the development of discipline, concentration, self-esteem, and personal fulfillment. Also, musical experiences facilitate emotional expression and regulation, strengthen communication processes, and foster the development of more meaningful interpersonal relationships [2].

Indeed, the convergence of music, health, and well-being seeks not only to generate positive outcomes in clinical and psychosocial indicators but also to foster creativity and provide enjoyable, accessible, and inclusive experiences. Such an approach supports the development of innovative, non-invasive, and cost-effective interventions that are aligned with contemporary perspectives on health promotion [1].

In this regard, two emerging domains within Computer Music have the potential to drive the development of novel applications for health and well-being: the Musical Metaverse (MM) [5] and the Internet of Multisensory, Multimedia and Musical Things (Io3MT) [6], [7]. The MM represents the branch of the metaverse dedicated to musical creation, performance, and interaction, enabling geographically distributed musicians, technicians, and audience members to collaborate in real time through networked immersive environments. Such experiences are supported by technologies capable of providing multimodal communication and ultra-low-latency audio transmission, thereby expanding the possibilities for remote musical interaction and collaboration.

In turn, Io3MT represents a domain within the Internet of Sounds (IoS) [8] whose primary objective is to integrate musical, multimedia, and multisensory information within a unified digital ecosystem in a non-hierarchical manner. Within this paradigm, different types of data can influence one another and operate in a coordinated fashion, giving rise to a network of interconnected devices capable of sensing, acquiring, processing, and exchanging information that bridges the physical and digital worlds. As a result, novel applications and creative services can emerge, leveraging multimodal, cross-platform, and transmedia interactions.

Within this context, multisensory elements play a central role, as applications envisioned by both the MM and Io3MT frequently require users to perform complex and refined control gestures. Such interactions are mediated through multiple sensory feedback modalities, including auditory, visual, proprioceptive, and tactile stimuli. Among these modalities, haptic feedback stands out due to its potential to enrich musical experiences by enhancing immersion, intensifying aesthetic appreciation, and supporting more precise motor control during the execution of musical tasks [6].

In light of this backdrop, this position paper presents PhysioPiano, an immersive musical application designed to promote health and well-being, while also offering potential contributions to music education and artistic performance. The system is grounded in the principles of the Musical Metaverse and the Internet of Multisensory, Multimedia and Musical Things. The primary focus of this work is to explore the integration of haptic elements within this context. To this end, PhysioPiano features a virtual piano environment deployed through a Head-Mounted Display (HMD), in which interaction is performed via hand tracking and enhanced by an off-the-shelf wearable device that delivers haptic feedback during interactions with virtual keys. The application combines musical exercises aimed at piano learning and practice with dedicated spaces for free exploration, creativity, and musical performance.

The objective of this work is to demonstrate how the implementation of PhysioPiano fulfills the requirements proposed by its conceptual model by presenting contextualized examples of practical applications and discussing the main lessons learned throughout the development process. This work does not aim to conduct user studies or evaluate clinical outcomes. Rather, it seeks to establish a technological and conceptual foundation to support future research on health and well-being. In doing so, this paper aims to provide insights and guidance for researchers, artists, and industry practitioners interested in designing immersive musical experiences grounded in the principles of the Musical Metaverse and the Internet of Multisensory, Multimedia and Musical Things, particularly for applications focused on health and well-being.

The remainder of this paper is organized as follows. Section II reviews the literature on the use of music and haptic technologies in artistic, educational, and health-related contexts, as well as previous research on virtual piano systems. Section III presents the PhysioPiano platform, detailing its conceptual

foundations, architecture, interaction mechanisms, multimodal feedback components, and musical content management. Section IV discusses the system in light of these foundations, highlighting design implications, and lessons learned. Finally, Section V concludes the paper and outlines directions for future research.

II. RELATED WORK

Based on a comprehensive review of the scientific literature, industrial reports, and complementary sources, the related work was categorized into two main groups: artistic and therapeutic applications enhanced by haptic technologies, and virtual piano systems. The following subsections present and discuss the most representative works identified within each domain, highlighting their contributions, limitations, and relevance to the development of immersive musical experiences for health, well-being, education, and artistic performance.

A. *Haptic Technologies Applied to Arts and Health*

Early evidence suggests that haptic devices have the potential to enrich artistic experiences by expanding the sensory modalities involved in the interaction with artworks [9]. Building upon this premise, a growing body of research has investigated the role of haptic feedback in artistic creation, appreciation, and performance. A representative example is SensArt [10], a multimodal device that combines music, vibrations, and temperature variations to convey emotional aspects of visual artworks, aiming to strengthen the affective connection between audiences and artistic content. Similarly, McDowell and Furlong [11] introduced the concept of haptic listening, exploring how vibrations captured directly from a classical guitar can be reproduced through wearable actuators. Based on the principles of embodied cognition, the study suggests that the tactile reproduction of instrumental vibrations enhances musical mediation and contributes to more immersive and engaging experiences.

Beyond enhancing immersion, research has also shown that haptic technologies can increase the enjoyment associated with music appreciation. In this context, Giroux et al. [12] observed that participants exposed to music accompanied by synchronized vibrotactile feedback reported higher levels of psychological arousal and greater subjective appreciation of the experience. Similar findings were reported by Hodges [13], who demonstrated that the use of haptic devices during musical game sessions increased both participant engagement and task performance.

The combination of artistic experiences and haptic stimulation has also demonstrated significant potential for health-related applications. In this regard, Turchet et al. [14] investigated the effects of exposure to music synchronized with vibrotactile stimulation in individuals with cochlear implants. The authors examined not only potential improvements in audiometric performance, including pitch and speech recognition, but also the impact of these multisensory stimuli on emotional responses, subjective experiences, and standardized audiometric assessments.

Complementing these efforts, Nanayakkara et al. [15] developed a system consisting of a haptic chair and a visual interface synchronized with musical content, specifically designed for individuals with hearing impairments. While the chair translates acoustic features into vibrations transmitted to the body, the visual interface presents graphical elements synchronized with the music. The results highlight the potential of haptic technologies as a mechanism for accessibility and inclusion, enabling richer and more engaging musical experiences for users with hearing loss.

Overall, the studies reviewed converge on the notion that haptic feedback can serve as a complementary channel for artistic communication, enhancing expressiveness, immersion, and users' emotional engagement across a variety of cultural, educational, and therapeutic contexts. Nevertheless, none of the analyzed works incorporates immersive virtual environments or relies on commercially available hardware, both of which could facilitate the broader adoption and integration of haptic technologies into diverse applications. These limitations are directly addressed by PhysioPiano.

B. Virtual Piano Systems in eXtended Reality (XR)

Within the domain of virtual piano systems, the literature encompasses applications spanning artistic, educational, and therapeutic contexts, often leveraging immersive and multi-modal technologies. From an artistic perspective, a notable example is AirPiano [16], a system designed to provide tactile musical experiences in Virtual Reality through mid-air haptic feedback. The solution combines a HMD with an ultrasonic haptic system capable of generating resistive forces that simulate the sensation of pressing physical piano keys. The study specifically investigates the effects of different haptic feedback strategies, namely constant and adaptive feedback, on the musical performance experience.

Also targeting musical performance, the work presented by Santini [17] explores the use of Augmented Reality (AR) as a mechanism for instrumental augmentation. The proposed system transforms the piano into a hybrid platform that combines acoustic and digital elements, enabling the control of sound synthesis, audio processing, spatialization, and multimedia events through three-dimensional interfaces distributed around the instrument. In this way, the physical environment becomes an extension of the piano itself, expanding its expressive and compositional possibilities and creating new opportunities for immersive musical performance.

In the educational domain, the work presented in [18] proposes a set of wearable devices designed to support Passive Haptic Learning (PHL). The study compares different tactile stimuli, including vibration, stroking, and tapping, with the goal of understanding their effects on the passive learning of piano note sequences. The devices are based on Arduino Uno microcontrollers and employ 3D-printed structures to facilitate attachment to the user's body, enabling the delivery of controlled haptic cues during the learning process.

Complementing these efforts, the system proposed in [19] employs Augmented Reality (AR) to project instructional

information directly onto a physical piano keyboard, reducing reliance on traditional sheet music while providing continuous visual guidance for novice learners. Similarly, Amm and colleagues [20] investigate the potential of Mixed Reality (MR) to support remote piano instruction and self-directed learning. The proposed platform incorporates features such as hand-movement visualization, real-time visual feedback, music theory instruction, and gamification mechanisms. Its primary objective is to overcome limitations commonly associated with conventional videoconferencing-based lessons, including challenges related to practical demonstrations, posture correction, and the perception of co-presence between instructors and students.

Finally, applications targeting health and well-being have also explored the integration of piano-based activities with immersive technologies. The work presented in [21] investigates the use of VR as a psychological training tool for pianists, with a particular focus on reducing performance anxiety and enhancing emotional preparedness for public musical performances. To achieve this goal, the authors developed a virtual environment capable of recreating realistic concert halls, enabling users to engage in immersive rehearsal sessions under conditions that closely resemble those encountered during live performances.

In a different direction, Castellini and collaborators [22] proposed a VR system aimed at motor rehabilitation and neuromuscular training. The solution employs forearm ultrasound imaging as a human-machine interface, enabling the real-time estimation of individual finger forces and the control of a virtual piano without requiring sensors to be directly attached to the hands. The authors discuss a range of potential applications, including motor rehabilitation, upper-limb prosthetic control, phantom limb pain treatment, and fine motor skill training.

Although the reviewed works provide valuable contributions, most of them focus primarily on only one of the three main domains: arts, education, or health. Furthermore, many of the proposed solutions rely on proprietary hardware or custom-built prototypes developed specifically for experimental purposes, which can hinder their reproducibility and adoption by other researchers.

PhysioPiano seeks to address these limitations by integrating artistic, educational, and therapeutic elements within a single platform. Unlike previous approaches, the system leverages commercially available haptic devices, thereby enhancing accessibility, reproducibility, and adoption across diverse communities of users and practitioners. Also, the platform is released as open-source software, enabling researchers, artists, designers, and industry practitioners to reproduce, adapt, and extend the system according to their specific requirements and application scenarios. This approach not only facilitates scientific reproducibility but also promotes the broader dissemination of immersive musical technologies within the fields of health, well-being, education, and artistic performance.

III. PHYSIOPIANO

In this section, we describe the design and implementation of PhysioPiano, an immersive virtual piano platform developed to provide tangible and multisensory experiences during musical interaction. The system was conceived with a particular focus on health and well-being applications, integrating VR, hand-tracking interaction, and wearable haptic feedback. The following subsections detail the system architecture, interaction mechanisms, multimodal feedback components, and musical content management strategies that underpin the PhysioPiano platform.

A. Design Concepts

PhysioPiano¹² was designed in accordance with the five design guidelines proposed for immersive applications within the Io3MT framework [23]. These guidelines, summarized below, served as the conceptual foundation for the system's design and implementation:

- **Design for Functionality:** Although musical applications often incorporate playful and exploratory elements, they must remain robust, reliable, and purpose-driven. In the context of PhysioPiano, this involves supporting effective musical interaction through low-latency processing, synchronized multimodal feedback, ergonomic interaction mechanisms, and a comfortable user experience;
- **Design for Immersiveness:** The system should provide coherent sensorimotor contingencies while clearly communicating its capabilities and limitations. Immersion is fostered through the integration of high-quality auditory rendering, natural hand-tracking interaction, visual fidelity, spatialized content, and multisensory stimulation, all of which contribute to a stronger sense of presence within the virtual environment;
- **Design for Feedback:** Feedback plays a fundamental role in supporting user engagement, learning, and interaction. Accordingly, PhysioPiano combines auditory, visual, and haptic feedback mechanisms to reinforce user actions, facilitate musical practice, and enrich the overall immersive experience;
- **Design for Social Connection:** Musical experiences are inherently social and collaborative. Therefore, immersive musical applications should be designed to support shared experiences, enabling communication, collaboration, and participation among geographically distributed users. Although the current implementation focuses on single-user interaction, this guideline informs future developments of the platform;
- **Design for Creativity:** Beyond supporting musical performance, immersive applications should encourage experimentation, learning, self-expression, and creative exploration. In this regard, PhysioPiano combines structured educational activities with opportunities for free explo-

ration and artistic performance, accommodating users with different levels of musical expertise and experience.

In addition, aspects inherent to music therapy should also be considered in the development of immersive applications for health and well-being [2]. In this context, such systems should incorporate specialized therapeutic mediation, safe and structured virtual environments, the integration of psychological and neuroscientific foundations related to cognition, emotion, and sensory perception, as well as interactions capable of fostering emotional engagement, individual expression, and meaningful experiences. It is also important to combine active and receptive musical approaches, including performance, improvisation, sound exploration, and guided listening, in order to stimulate motor, cognitive, and sensory aspects such as motor coordination, attention, memory, and sensorimotor integration. Furthermore, immersive musical experiences are expected to contribute to the reduction of anxiety, stress, and psychological symptoms, while promoting relaxation, well-being, communication, social interaction, and emotional regulation. At the same time, they should incorporate assessment mechanisms related to user experience, motor performance, emotional responses, and potential therapeutic outcomes.

B. Setup

Learning to play the piano has been associated with a variety of benefits, including improvements in executive functioning, reductions in depressive symptoms, and enhanced mood states among adults. In children, piano practice contributes to the development of discipline, concentration, personal fulfillment, and self-esteem [24].

For this reason, we developed a virtual piano application designed to be experienced through a HMD. The system was implemented in Unity (version 2022.3.30) and employs the Meta Quest 3 together with Meta Interaction SDK 1.3.2 for hand tracking and gesture detection. The application runs on a Dell G15 laptop equipped with an NVIDIA GeForce RTX 4050 graphics card, an Intel i7 processor, and 16 GB of RAM. The platform provides two distinct virtual piano configurations: a full version consisting of 88 keys distributed across seven complete octaves and a minor third, and a reduced version comprising only two octaves, totaling 25 keys. This dual configuration was designed to accommodate different user profiles and application scenarios. While the full piano offers greater musical expressiveness, enabling the performance of more complex repertoires, broader harmonic exploration, and closer fidelity to the traditional instrument, the reduced version aims to minimize cognitive and spatial demands for novice users and therapeutic contexts, thereby facilitating initial learning, motor coordination, and spatial localization of keys within the immersive environment.

Interaction is performed through hand tracking, allowing users to press the virtual piano keys using their fingers. To enhance the sense of presence and physicality within the experience, users wear an off-the-shelf device, specifically the bHaptics TactGlove DK2. The glove incorporates vibrotactile actuators distributed across the fingertips and wrist regions,

¹<https://github.com/Biel675/PhysioPiano>

²Demonstration Video: <https://youtu.be/Nxk786pz-b8>

enabling the delivery of tactile stimuli synchronized with musical interactions. In PhysioPiano, these pulses are triggered at the moment a virtual key is pressed, creating a tactile cue associated with contact onset. When synchronized with the corresponding piano sound and the visual response of the key, the feedback provides temporally congruent auditory, visual, and tactile information about the interaction. This multimodal correspondence is intended to make each action more perceptible, reinforce the association between finger movements and their musical consequences, and increase the perceived physicality of playing a virtual instrument.

Communication between the application and the haptic glove is established through the proprietary bHaptics Application Programming Interface (API) using a low-latency Bluetooth connection. The API enables the transmission of parameterized haptic patterns to specific regions of the glove, allowing real-time control over the intensity, duration, and spatial distribution of vibrotactile stimuli. Within the context of PhysioPiano, each keypress can trigger different levels of tactile feedback, categorized into low, medium, and high intensity settings, which are configured by the user prior to the start of the experience. This flexibility allows the system to be adapted to different user profiles and therapeutic scenarios, accommodating individual preferences, sensory sensitivities, and specific intervention requirements.

From a usability perspective, the application is organized into two primary interaction modes: musical exercises and musical performance. The former is designed to support the development of fundamental piano skills, including scale practice, hands coordination, note recognition, rhythmic pattern training, finger independence, simple harmonic progressions, and the reproduction of basic melodic sequences. This set of activities enables novice users to become familiar with the instrument, while users with prior musical experience can employ the system for technical training and motor skill practice.

The second mode is dedicated to musical performance. In this scenario, users can select songs available within the application for free execution. Initially, the system provides a tutorial mode in which the keys corresponding to the notes of the selected piece are highlighted using different colors and automatically reproduce their associated sounds, assisting users in understanding the spatial and temporal structure of the performance. Subsequently, during guided practice sessions, visual cues remain active to support execution. When a user correctly presses a key, it changes to a blue color and emits green particle effects, providing positive visual feedback and reinforcing the multimodal interaction experience.

With regard to the musical options, the selection of the repertoire was informed by both evidence reported in the literature [16], [18] and consultation with a piano specialist. As a result, three musical pieces were chosen: *Twinkle, Twinkle Little Star*, *Chopsticks*, and *Happy Birthday to You*. These compositions were selected to encompass different levels of motor complexity and a variety of finger combinations, involving performance with one or both hands. Furthermore,

the pieces include both melodic passages and patterns that require more refined motor coordination, thereby providing an initial basis for investigating the potential benefits of haptic feedback during piano practice in immersive environments. The complete execution workflow is illustrated in Figure 1.

An important technical contribution of this work is the spatial note visualization mechanism. Rather than relying on traditional sheet music notation, the system renders colored three-dimensional blocks that descend toward the corresponding piano keys, following an approach similar to rhythm-based applications such as *Synthesia* and *Guitar Hero*. The color assigned to each note follows the model originally proposed by Alexander Scriabin in the *Clavier à Lumières*, as illustrated in Figure 2.

To enable the selection of both the piano configuration and the desired mode of use, a simple user interface was developed to support intuitive interaction. The interface includes a menu through which users can access the available functionalities and configure their experience with minimal effort. This interface, along with the application in operation and the wearable devices employed to provide haptic feedback, is illustrated in Figure 3.

It is important to emphasize that the goal of this project is not to fully replicate all the physical and performative characteristics of a traditional piano within a virtual environment. Certain advanced techniques, such as *staccato*, refined dynamic control, and the continuous use of sustain pedals, still present significant challenges in VR environments and are difficult to reproduce with high fidelity. Instead, the system draws upon metaphors derived from the traditional instrument to create an intuitive, accessible, and engaging user experience. In this context, the application has the potential to support a variety of therapeutic practices related to fine motor coordination, cognitive stimulation, sensorimotor rehabilitation, attention training, relaxation, emotional regulation, and the promotion of well-being. An overview of the system architecture is presented in Figure 4.

C. JSON Music Parser

The practical exercises and musical pieces available in PhysioPiano are stored in files structured using the JavaScript Object Notation (JSON) format, which serves as an intermediate representation between the original sheet music and the events executed within the virtual environment. Initially, musical compositions are converted from their original sheet music into Musical Instrument Digital Interface (MIDI) files. Subsequently, the MIDI data are translated into JSON format, highlighting information related to musical tempo (BPM), temporal events, and execution commands associated with each note. This approach decouples musical content from the application logic, enabling the addition of new songs and exercises without requiring modifications to the source code.

The JSON files are processed by a component referred to as the Music Parser. Its primary role is to interpret the temporal structure of a musical composition and translate it into events that can be understood and executed by the virtual

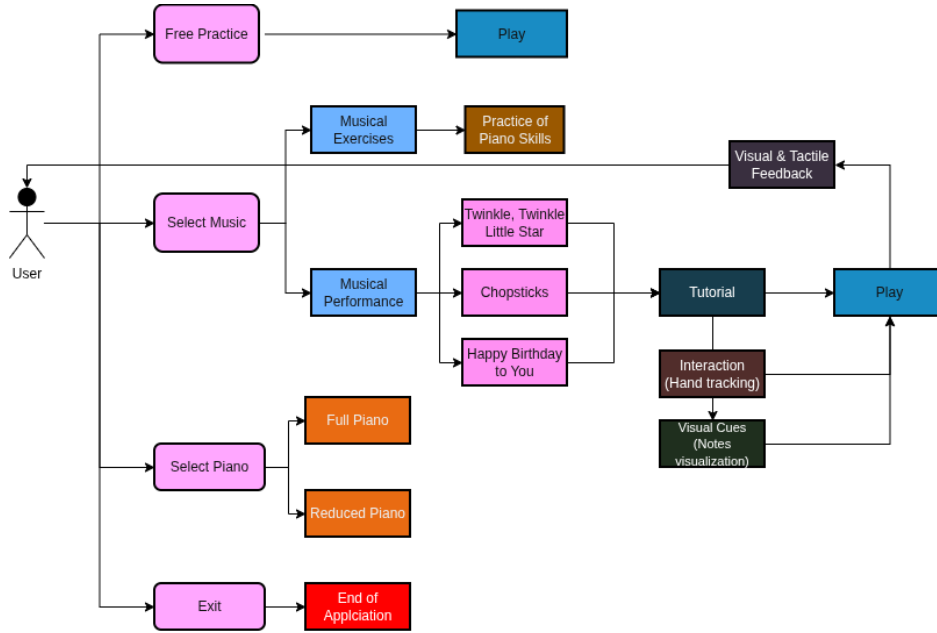


Fig. 1: PhysioPiano usage workflow.

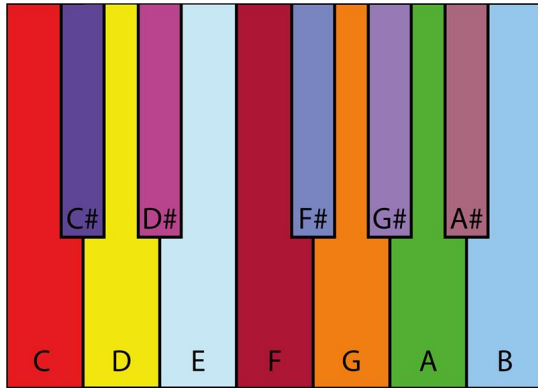


Fig. 2: *Clavier à Lumière* by Alexander Scriabin, used as the reference model for mapping colors to musical notes.

environment. To achieve this, each composition is organized as a sequence of temporal units called *ticks*. Each *tick* stores a time interval relative to the preceding event, along with a set of commands specifying which notes should be activated or deactivated at that particular moment.

The parser continuously interprets the musical events and determines when each command should be executed. These commands represent actions such as the activation or release of specific notes, as well as the indication of the hand responsible for their execution. Based on this information, the system automatically maps each musical event to its corresponding virtual piano key, ensuring that the musical content is accurately represented within the immersive environment.

Beyond simple note triggering, the parser functions as a multimodal synchronization mechanism. Each musical event is used to coordinate multiple forms of feedback simultaneously

within the application. Consequently, whenever a note is scheduled to be performed, the system updates the corresponding visual elements, reproduces the audio associated with the virtual key, and activates the appropriate haptic stimuli. Through this process, auditory, visual, and tactile information remain synchronized throughout the entire musical performance, ensuring a coherent and integrated multisensory experience.

It is important to emphasize that the objective of this musical and multimodal notation is not to replace MIDI, a well-established and widely adopted protocol within the music technology ecosystem. The decision to develop this approach was primarily motivated by implementation considerations, as the authors found it more practical to represent and manipulate the required information through JSON files rather than directly processing MIDI data. Furthermore, the proposed notation incorporates multimodal elements by explicitly specifying when visual and haptic feedback events should occur, information that cannot be directly represented through standard MIDI messages. Consequently, the JSON Music Parser serves as the core component responsible for transforming abstract musical representations into interactive multimodal experiences, ensuring temporal synchronization among musical content, visual interaction, and haptic feedback within the virtual environment. An overview of the JSON Music Parser structure is presented in Figure 5.

IV. DISCUSSION & LESSONS LEARNED

The analysis of the platform's development reveals relevant contributions to both the field of Computer Music and the design of health and well-being applications grounded in the principles of the Musical Metaverse (MM) and the Internet of Multisensory, Multimedia and Musical Things (Io3MT).

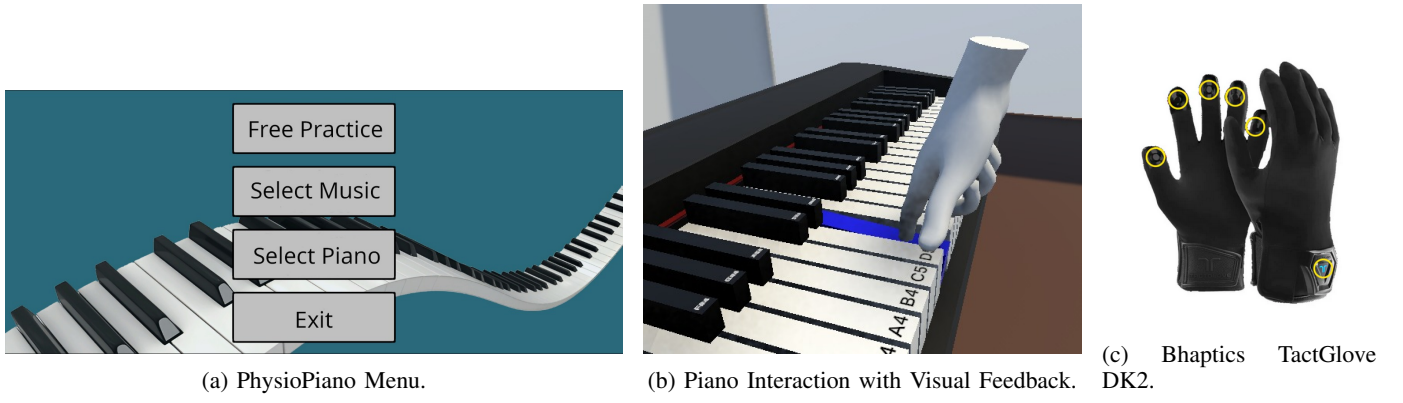


Fig. 3: PhysioPiano Virtual Scenario and Equipment.

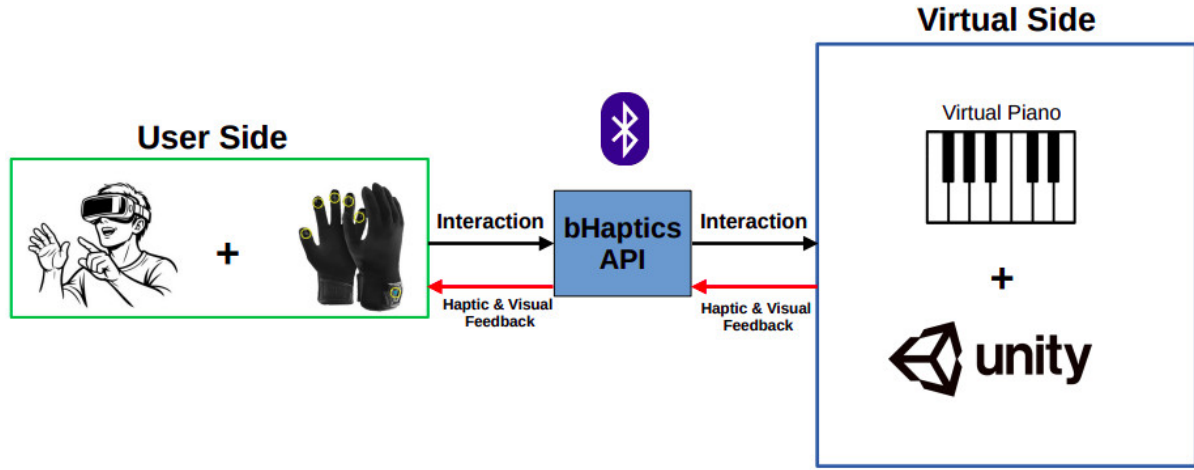


Fig. 4: PhysioPiano Architecture.

The following discussion adopts a design analysis perspective, highlighting which elements of the theoretical concepts are addressed by the proposed environment. In addition, a comparative analysis with related work is presented, emphasizing the differences introduced by PhysioPiano and how the platform may contribute to advancing the state of the art and fostering the development of immersive musical systems for health-related applications.

A. Design Analysis

The system demonstrated the ability to consistently integrate hand tracking, musical interaction, three-dimensional visualization, and haptic feedback within a single virtual

environment. The use of commercial devices, such as the Meta Quest 3 and the Bhaptics TactGlove DK2, enabled the development of a relatively low-cost solution with the potential to be replicated by other research groups. Furthermore, the adoption of the JSON Music Parser decoupled musical content from the implementation logic, simplifying the incorporation of new songs, exercises, and therapeutic protocols without requiring structural modifications to the system.

The guideline related to immersiveness was primarily addressed through the combination of natural hand-tracking interaction and synchronized multisensory feedback. Unlike applications that rely on physical controllers, the use of the users' own hands contributes to a more intuitive experience that more closely resembles interactions performed on conventional musical instruments. The integration of auditory, visual, and tactile stimuli strengthens sensorimotor contingencies and enhances the sense of presence within the virtual environment. In addition, the spatial note visualization system, inspired by contemporary music games, provides an alternative to traditional sheet music notation, reducing entry barriers for novice users and increasing the accessibility of the application.

Feedback constitutes one of the central elements of Phys-

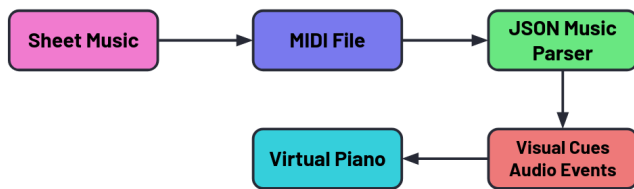


Fig. 5: JSON Music Parser Structure.

ioPiano. The literature [9] indicates that the combination of multiple sensory channels can support learning processes, engagement, and perceptions of realism in virtual environments. In this regard, the system simultaneously coordinates auditory, visual, and haptic feedback during musical performance. Auditory feedback is provided through sound samples triggered when users interact with the keys, whereas visual feedback relies on dynamic key illumination, particle effects, and the spatial representation of musical notes. In parallel, the vibrotactile actuators distributed throughout the haptic glove deliver stimuli synchronized with user interactions. The JSON Music Parser plays a fundamental role in this process by ensuring temporal synchronization among all these elements, enabling the creation of multimodal experiences.

The social connectivity guideline was the least explored in the current implementation. Although the system was conceived as an individual experience, its architecture supports future extensions aimed at remote music instruction, collaborative instrumental practice sessions, therapist-mediated interventions, and shared environments within the context of the Musical Metaverse and Io3MT.

With respect to creativity, PhysioPiano is not limited to the mechanical reproduction of musical exercises. The co-existence of structured learning modes and spaces dedicated to free exploration enables different forms of interaction with the virtual instrument. In addition to technical training, the platform supports improvisation, sound experimentation, and artistic expression, characteristics commonly associated with the development of musical creativity. The possibility of incorporating new content through external files further expands this potential, allowing researchers, educators, and therapists to adapt the platform to the specific requirements of their respective contexts of use.

From a health and well-being perspective, several aspects deserve attention. First, the use of the piano as an interaction instrument can offer advantages related to the development of fine motor coordination, attention, memory, and motor planning. When combined with immersive technologies and multisensory feedback, these benefits may be further enhanced. The reduced 25-key configuration is designed to decrease the spatial complexity of the task while preserving the fundamental musical experience. Its potential suitability for novice users and therapeutic settings should therefore be understood as a hypothesis to be examined in future user studies, particularly regarding usability, engagement, accessibility, and possible health-related outcomes.

Another relevant aspect concerns the incorporation of principles traditionally associated with music therapy. The system includes practical activities, such as musical performance, melody reproduction, and instrumental exploration, while also supporting receptive experiences through guided listening and observation of audiovisual stimuli. This combination is supported by the music therapy literature [25], which emphasizes the importance of integrating musical expression, cognition, emotion, and sensory perception to promote meaningful experiences. Furthermore, the immersive nature of the application

may foster high levels of engagement, a factor frequently associated with the effectiveness of technology-mediated therapeutic interventions.

The presence of haptic feedback also deserves attention. In traditional acoustic instruments, tactile perception constitutes an important source of information for motor control and the development of musical expressiveness. Although the vibration provided by the glove does not fully reproduce the mechanical characteristics of a physical piano key, it establishes an additional sensory channel capable of reinforcing the relationship between action and consequence. From the perspective of the Musical Metaverse and Io3MT, this mechanism contributes to bridging the physical and digital worlds, fostering richer and potentially more meaningful musical experiences for users.

B. Comparison with Related Work

When compared to AirPiano [16], both systems share the objective of providing immersive musical experiences enriched by tactile feedback. However, the approaches adopted are substantially different. AirPiano focuses on investigating mid-air haptic feedback mechanisms, employing ultrasonic arrays to simulate the physical resistance of piano keys during interaction. The primary focus of the study lies in analyzing tactile perception and the sensation of pressing virtual keys. In contrast, PhysioPiano prioritizes the use of commercial wearable devices, exploring not only aspects of tactility but also issues related to musical learning, multisensory stimulation, well-being, and technological accessibility. Moreover, whereas AirPiano remains restricted to artistic and experimental contexts, PhysioPiano extends its scope to educational and therapeutic scenarios.

With respect to the work presented in [17], both systems explore the expansion of traditional piano capabilities through immersive technologies. However, the first approach is primarily focused on advanced artistic performance, sound synthesis, and interactive multimedia composition, targeting experienced musicians and performance-oriented contexts. PhysioPiano adopts a more inclusive approach, encompassing novice users, students, therapists, and researchers. Likewise, the incorporation of haptic feedback and visual guidance mechanisms makes the system more suitable for learning processes and motor skill training.

In the educational domain, the contrast becomes even more evident. The Passive Haptic Learning approach presented in [18] focuses exclusively on the investigation of tactile stimuli for the passive learning of musical sequences, employing wearable devices specifically developed for the experiment. Although it provides important contributions to the study of motor cognition, the scope of the application remains limited to learning. In contrast, PhysioPiano combines active learning, guided practice, free exploration, and multisensory feedback within a single environment. Moreover, it relies on widely available commercial hardware, thereby enhancing the reproducibility of the proposed solution.

Similarly, the systems presented in [19], [20], [24] primarily aim to enhance educational processes related to piano in-

struction. These approaches explore augmented visualization, gamification, remote teaching, and support for instrumental practice. However, they do not explicitly address aspects related to health, well-being, or multisensory stimulation through haptic feedback. PhysioPiano distinguishes itself by simultaneously incorporating teaching mechanisms, musical practice, tactile feedback, and potential therapeutic applications, thereby establishing a bridge between the fields of music education, music computing, and digital health.

In turn, the ultrasound-based system for motor rehabilitation presented in [22] exhibits a strong alignment with clinical and health-related applications. Nevertheless, its primary focus lies in investigating an alternative human–computer interface based on ultrasound imaging for estimating finger movements. Although the approach demonstrates considerable potential for neuromuscular rehabilitation, it requires specialized infrastructure and high-cost medical equipment. In contrast, PhysioPiano seeks to democratize access to immersive musical applications for well-being through the use of commercial devices, significantly reducing the technological barriers associated with adoption and replication.

In general, three main differentiators emerge from the comparison between PhysioPiano and the related work. The first is the simultaneous integration of artistic, educational, and therapeutic domains within a single platform. The second is the use of commercial (off-the-shelf) hardware, which reduces costs and increases the reproducibility of experimental studies. Finally, the third differentiator is the availability of the platform as open-source software, a characteristic rarely observed among the analyzed works. These factors position PhysioPiano not merely as a virtual piano application, but as a research infrastructure capable of supporting future investigations in musical learning, multisensory experiences, music computing, rehabilitation, and well-being within immersive environments.

The main points discussed in this comparison are synthesized in Table I.

V. CONCLUSION

This position paper presented PhysioPiano, an immersive musical platform grounded in the principles of the Musical Metaverse and the Io3MT, designed primarily for health and well-being applications while also encompassing aspects related to music education and artistic performance. To achieve this objective, a proof of concept was developed based on a virtual piano implemented in a VR environment, where interaction is performed through hand tracking and supported by a commercial wearable device responsible for providing haptic feedback synchronized with the actions performed on the instrument.

Although PhysioPiano is built upon commercially available hardware and established software components, its contribution lies in their purposeful integration into a configurable immersive musical environment oriented toward future health and well-being research. Rather than proposing a novel HMD, haptic glove, or music-data format in isolation, the system combines hand tracking, localized vibrotactile feedback, dual

piano configurations, guided visual notation, and a JSON-based musical-content pipeline into a single platform. This integration provides an adaptable infrastructure for investigating how multimodal musical interaction can support motor, cognitive, and affective applications in immersive environments.

In addition to the implementation of the virtual environment, this work presented a JSON-based music parser responsible for interpreting musical information and synchronizing it with visual and haptic events throughout musical performance. This approach enhances the extensibility of the platform, enabling the incorporation of new exercises, musical repertoires, and usage protocols without requiring modifications to the core system functionalities.

From the perspective of digital health, the platform demonstrates how immersive technologies can be employed to stimulate motor, cognitive, and sensory aspects associated with musical practice. The combination of auditory, visual, and haptic feedback creates favorable conditions for the development of fine motor coordination, attention, memory, and sensorimotor integration, while simultaneously promoting engagement, individual expression, and potentially meaningful experiences for users. In this way, PhysioPiano contributes to the growing discussion on the role of VR technologies in the development of applications aimed at promoting well-being, rehabilitation, and therapeutic musical experiences.

However, some limitations were identified. The current version of the system has not yet undergone formal experimental evaluation with users, preventing the empirical validation of aspects related to usability, presence, quality of experience, effectiveness of haptic feedback, and potential therapeutic benefits. Likewise, quantitative metrics related to system latency, hand-tracking accuracy, user musical performance, and error rates during task execution have not yet been investigated.

As future work, these limitations will be addressed through the development of quantitative and qualitative studies involving different user profiles, including musicians, students, therapists, and individuals participating in rehabilitation programs. Future investigations will also examine the impact of haptic feedback on musical learning, motor coordination, cognitive workload, engagement, and perceived presence in immersive environments. From a functional perspective, planned improvements include the incorporation of dynamic key animations, adaptive haptic models capable of varying vibration intensity and patterns according to the musical context, automatic performance assessment mechanisms, advanced exercise customization, multi-user support, and collaborative features aligned with the concepts of the Musical Metaverse and the Io3MT. Additionally, the integration of other multisensory stimuli will be explored.

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TABLE I: Summary of the comparison with related work.

Feature	AirPiano [16]	Santini et al. [17]	Fang et al. [18]	Educational Systems [19], [20], [24]	PhysioPiano
Goal	Study tactile perception in a virtual piano.	Support artistic performance and multimedia composition.	Investigate passive haptic learning of musical sequences.	Support piano learning and instrumental practice.	Provide an immersive musical platform for learning and future health and well-being research.
Interaction and feedback	Mid-air interaction with ultrasonic haptics.	Interactive audiovisual resources for performance.	Purpose-built wearable tactile stimulation.	Visual guidance, gamification, and instructional resources.	Hand tracking, visual guidance, and wearable vibrotactile feedback.
Application context	Experimental and artistic contexts.	Advanced musical performance.	Musical learning experiments.	Music education.	Music education and multisensory experiences; infrastructure for future health-related studies.
Hardware approach	Specialized ultrasonic infrastructure.	Specialized performance-oriented setup.	Custom experimental wearable devices.	Varies according to the proposed system.	Commercial off-the-shelf VR headset and haptic glove.
Open-source	Not reported.	Not reported.	Not reported.	Not consistently reported.	Yes.

REFERENCES

- [1] R. A. MacDonald, "Music, health, and well-being: A review," *International journal of qualitative studies on health and well-being*, vol. 8, no. 1, p. 20635, 2013.
- [2] A. Raglio and O. Oasi, "Music and health: what interventions for what results?" p. 230, 2015.
- [3] J. Bradt, C. Dileo, and N. Potvin, "Music for stress and anxiety reduction in coronary heart disease patients," *Cochrane Database of Systematic Reviews*, no. 12, 2013.
- [4] M. S. Cepeda, D. B. Carr, J. Lau, and H. Alvarez, "Music for pain relief," *Cochrane database of systematic reviews*, no. 2, 2006.
- [5] L. Turchet, "Musical metaverse: vision, opportunities, and challenges," *Personal and Ubiquitous Computing*, vol. 27, no. 5, pp. 1811–1827, 2023.
- [6] R. Vieira, "Internet of multisensory, multimedia and musical things (io3mt) environments: Requirements, use cases, and evaluation," Ph.D. thesis, Fluminense Federal University, Niterói, Brazil, 2025.
- [7] R. Vieira, D. C. Muchaluat-Saade, and P. César, "Towards an internet of multisensory, multimedia and musical things (io3mt) environment," in *2023 4th International Symposium on the Internet of Sounds*. IEEE, 2023, pp. 1–10.
- [8] L. Turchet, M. Lagrange, C. Rottondi, G. Fazekas, N. Peters, J. Østergaard, F. Font, T. Bäckström, and C. Fischione, "The internet of sounds: Convergent trends, insights, and future directions," *IEEE Internet of Things Journal*, vol. 10, no. 13, pp. 11 264–11 292, 2023.
- [9] T. Venkatesan and Q. J. Wang, "Feeling connected: the role of haptic feedback in vr concerts and the impact of haptic music players on the music listening experience," in *Arts*, vol. 12. Basel, Switzerland: MDPI, 2023, p. 148.
- [10] D. B. Faustino, S. Gabriele, R. Ibrahim, A.-L. Theus, and A. Girouard, "Sensart demo: A multisensory prototype for engaging with visual art," in *Proceedings of the 2017 ACM international conference on interactive surfaces and spaces*. New York, USA: ACM Digital Library, 2017, pp. 462–465.
- [11] J. McDowell and D. J. Furlong, "Haptic-listening and the classical guitar," in *Proceedings of the International Conference on New Interfaces for Musical Expression*. Virginia, USA: NIME, 2018, pp. 293–298.
- [12] F. Giroux, J. Boasen, S. Sénécal, M. Fredette, A. Q. Tchanou, J.-F. Menard, M. Paquette, and P.-M. Leger, "Haptic stimulation with high fidelity vibro-kinetic technology psychophysically enhances seated active music listening experience," in *Proceedings of the 2019 IEEE World Haptics Conference (WHC)*. IEEE, 2019, pp. 151–156.
- [13] B. S. Hodges, *The Effects of Haptics on Rhythm Dance Game Performance and Enjoyment*. Brigham Young University, 2018.
- [14] L. Turchet, R. Rosaia, A. Diodati, and M. Carner, "Exposure to vibrotactile music improves audiometric performances in individuals with cochlear implants," *Scientific Reports*, vol. 15, no. 1, p. 20054, 2025.
- [15] S. C. Nanayakkara, L. Wyse, S. H. Ong, and E. A. Taylor, "Enhancing musical experience for the hearing-impaired using visual and haptic displays," *Human-Computer Interaction*, vol. 28, no. 2, pp. 115–160, 2013.
- [16] I. Hwang, H. Son, and J. R. Kim, "Airpiano: Enhancing music playing experience in virtual reality with mid-air haptic feedback," in *2017 IEEE world haptics conference (WHC)*. IEEE, 2017, pp. 213–218.
- [17] G. Santini, "Augmented piano in augmented reality," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2020, pp. 411–415.
- [18] L. Fang, T. Müller, E. Pescara, N. Fischer, Y. Huang, and M. Beigl, "Investigating passive haptic learning of piano songs using three tactile sensations of vibration, stroking and tapping," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 7, no. 3, pp. 1–19, 2023.
- [19] A. Simion, A. Iftene, D. Gifu et al., "An augmented reality piano learning tool," *RoCHI*, vol. 2021, pp. 134–141, 2021.
- [20] V. Amm, K. Chandran, L. Engeln, and M. McGinity, "Mixed reality strategies for piano education," *Frontiers in Virtual Reality*, vol. 5, p. 1397154, 2024.
- [21] Y. Zhang, "Vr technology to the adjustment of piano playing mentality," *Mathematical Problems in Engineering*, vol. 2021, no. 1, p. 5844118, 2021.
- [22] C. Castellini, K. Hertkorn, M. Sagardia, D. S. González, and M. Nowak, "A virtual piano-playing environment for rehabilitation based upon ultrasound imaging," in *5th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics*. IEEE, 2014, pp. 548–554.
- [23] R. Vieira, S. Wei, T. Röggla, D. C. Muchaluat-Saade, and P. César, "Immersive io3mt environments: Design guidelines, use cases and future directions," in *2024 IEEE 5th International Symposium on the Internet of Sounds (IS2)*. IEEE, 2024, pp. 1–10.
- [24] W. Molloy, E. Huang, and B. C. Wünsche, "Mixed reality piano tutor: A gamified piano practice environment," in *2019 International conference on electronics, information, and communication (ICEIC)*. IEEE, 2019, pp. 1–7.
- [25] K. S. Aigen, *The study of music therapy: Current issues and concepts*. Routledge, 2013.