Coretet: a 21st Century Virtual Interface for Musical Expression

Rob Hamilton[1]

Rensselaer Polytechnic Institute
hamilr4@rpi.edu

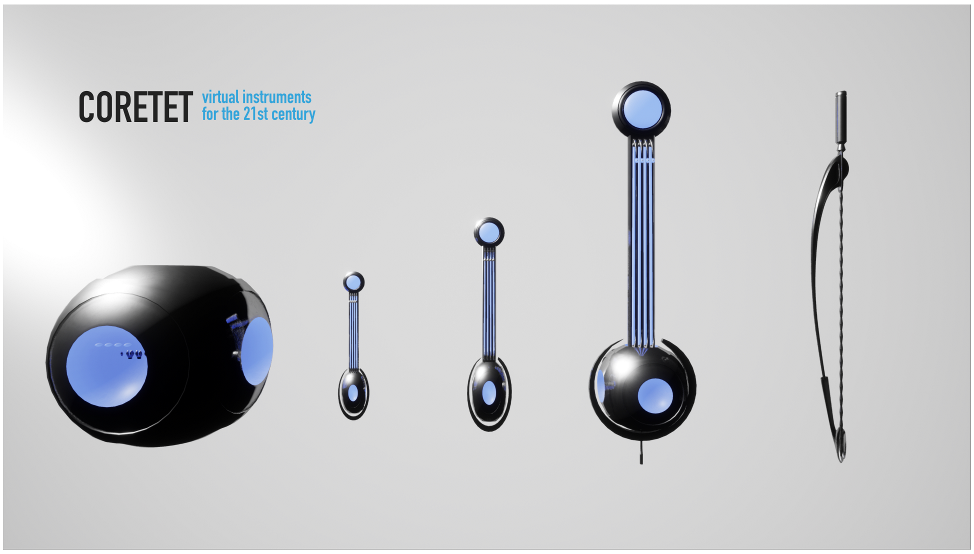

Fig. 1. (*from left to right*) Coretet instruments: the orb, violin, viola, cello, bow

Abstract. Coretet is a virtual reality musical instrument that explores the translation of performance gesture and mechanic from traditional bowed string instruments into an inherently non-physical implementation. Built using the Unreal Engine 4 and Pure Data, Coretet offers musicians a flexible and articulate musical instrument to play as well as a networked performance environment capable of supporting and presenting a traditional four-member string quartet. This paper discusses the technical implementation of Coretet and explores the musical and performative possibilities enabled through the translation of physical instrument design into virtual reality as realized through the composition and performance of the string quartet *Trois Machins de la Grâce Aimante*.

Keywords: Virtual Reality, VIME, VMI, instrument

1 Introduction

With renewed interest in virtual reality (VR) hardware and software systems in recent times by major companies such as Facebook, Google, HTC and Valve, consumers and artists alike have multiple low cost paths forward to investigate VR systems as a component in their personal and artistic practices. Commodity control devices for VR systems such as the Oculus Touch allow three-dimensional tracking of heads and hands with sufficiently low latency to allow for real-time gestural control of musical systems and instruments [19]. Laptops and graphics cards have likewise reached price points and speeds capable of delivering consistently high framerates for head-mounted displays (HMD) in packages that are portable and easily replaced.

These factors contributed to the design and development of Coretet, a real-time VR instrument modeling basic bow and string interactions and performance practices idiomatic to stringed instruments such as violins, violas, cellos and doublebasses. Commissioned by the GAPPP project [13] at the IEM in Graz, Austria, Coretet - and the first composition for Coretet *Trois Machins de la Grâce Aimante* for virtual reality string quartet - showcase commodity technologies such as Oculus Rift HMDs and the Unreal Engine 4 augmented with Open Sound Control (OSC) [23] and a Pure Data (PD) [18] audio engine driving a physical model of a bowed string from the Synthesis Toolkit (STK) [3].

2 Prior Art

Software instruments derived from traditional instrumental performance practice and the act of composing musical works for such instruments have long been a staple of computer music research and artistic practice. Computer-mediated and augmented stringed instruments have been explored [2, 15, 16] that blend digital control systems with traditional musical performance practices and leverage expert performers' learned instrumental mastery. Commercial gaming applications such as the Guitar Hero and Rock Band [10] game franchises introduced score-driven and rhythm reliant performance practices for pop and rock music, while mobile apps like Magic Fiddle [22] allowed performers to interact with a rendered violin neck and strings using finger gesture to activate a bowed or plucked string excitation on an iPad tablet interface. And immersive musical environments for musical composition and performance combining 3D graphics and procedural sound have been explored, both by extending existing software projects using Open Sound Control [8] or by creating entirely new projects using game development platforms like the Unreal Engine [9].

Virtual interfaces for musical expression have been explored using Cave-like 3D displays [14], haptic interactions [11] and by leveraging game-engines as mediating layers for user interaction [5, 21]. And as part of a 1993 exhibit on virtual reality at the Guggenheim Museum in New York, Thomas Dolby presented *The Virtual String Quartet*, a pre-recorded and non-real time animated performance of Mozart's String Quartet no. 18 in A Major viewable through HMDs and spatialized by tracking audience members' positions in a gallery space [4].

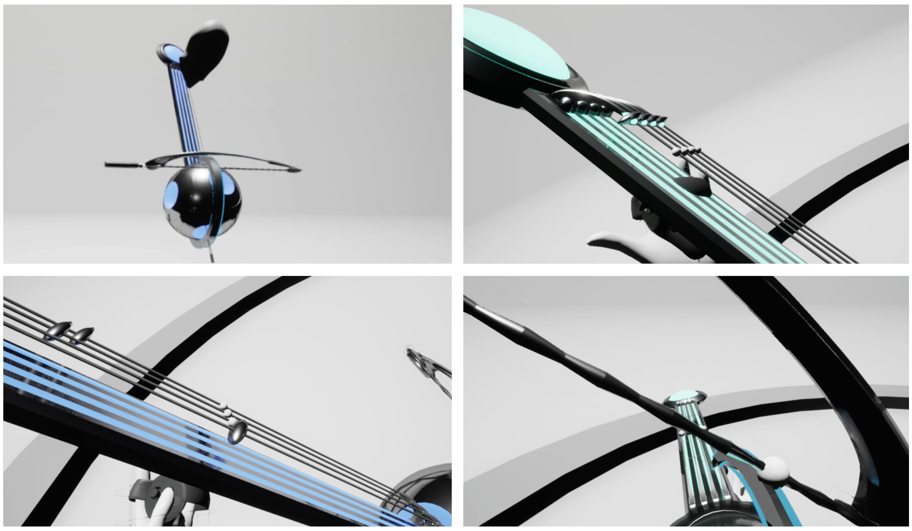

Fig. 2. (*clockwise from top left*) Figure 2a: Coretet client's head, bow and cello viewed on the server; Figure 2b: client view of left-hand at the top of the instrument neck; Figure 2c: the bow contacting the bowing bar; Figure 2d: left hand selecting a pitch on the lowest string.

3 Design and Development

With deliberate reference to traditional stringed instrument performance practices, Coretet was designed as a futuristic '21st Century' implementation of the core gestural and interaction modalities that generate musical sound in the violin, viola, cello and doublebass. Coretet's primary design goals focus on the creation of virtual musical instruments intended for expert users, defined here as trained musicians with substantial history playing and tacit knowledge of traditional bowed string instruments. And through the leveraging of trained performers' tacit learned knowledge of traditional stringed instrument performance practices, Coretet's design aims to allow performers to achieve a high level of skill on the instruments eventually leading towards virtuosity.

3.1 Control and Interface

By coupling the real-time fluid interactivity offered by the Unreal Engine 4 game engine with procedurally driven STK physical string models in Pure Data, Coretet offers musicians a flexible and articulate musical instrument capable of supporting improvisation as well as notated solo or ensemble performance. Fundamentally Coretet is a single instrument which can be shaped and scaled by performers into different configurations (see Figure 1). Parameters such as neck length, body size, and number of strings are manipulated to recreate traditional stringed instruments such as violin, viola, cello or doublebass or to create new and physically impossible instruments. For ease of use during performance parameter presets for violin, viola, cello and doublebass can be chosen and recalled instantly as can an experimental spherical percussive instrument configuration known as the Orb.

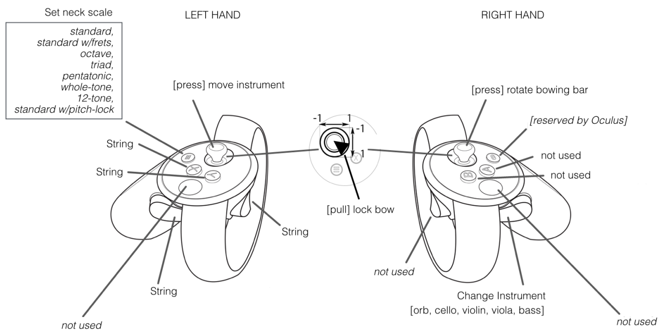

Fig. 3. Left and right hand Oculus Touch controller mappings for the Coretet instruments.

Performers use a virtual bow (see Figure 2a) modeled after a traditional violin bow which activates the bowed string physical model when it comes into contact with a specific bowing bar on the instrument. Figure 2c shows a blue outline around the bowing bar indicating a collision between bow and bar, and a tracking marker indicating the collision is represented as a white sphere on the bow. Bow pressure is controlled by calculating position along the bowing bar with one end representative of a high level of bow pressure and the other end representative of a low level of bow pressure. Similarly, bow speed is calculated by windowing bow positioning deltas over a short time frame.

By pressing buttons on the Oculus Touch's left hand controller, performers choose which string will be activated (see Figures 2d and 3). By moving their left hand along the instrument's neck and pressing each string's associated button, performers change the pitch of the current sounding note. String positions activated by button presses are marked in real-time by dark-grey oval markers (see Figure 2b and 2d). For *Trois Machins de la Grâce Aimante* each string of Coretet is tuned to the same fundamental frequency as the corresponding string on the violin, viola and cello in concert A 440 Hz tuning.

3.2 Networked Environment

Coretet leverages the Unreal Engine's native network layer to create a networked virtual performance environment capable of supporting and presenting a traditional four-member string quartet to performers through head-mounted displays and to audiences through an auxiliary screen or projector. In a concert performance such as is utilised for *Trois Machins de la Grâce Aimante* this game server hosts each Coretet client instance (representing each performer) connecting across a local ethernet network. Performers in Coretet see each others' head, bow and instrument in real-time within the virtual concert space, allowing for the use of communicative visual gesture both of the head and of the instrument and bow. In live concert situations, a view into the networked virtual space is presented to audiences from the game server. In a manner similar to e-Sports broadcasts of networked games, a series of virtual cameras on the server are projected in 2D for viewing by audiences seated in traditional concert halls.

3.3 Procedural Audio

The bowed string sounds used in Coretet for *Trois Machins de la Grâce Aimante* are generated in real-time using Pure Data. String length and body scale values of the current instrument configuration are tracked in UE4 and sent to a single running PD server via OSC where they are used to procedurally generate each instrument's sound affecting it's frequency range and timbral identity. Within Coretet, OSC is implemented using a plugin for Unreal's Blueprint workflow programming language. Currently, a single Pure Data instance receives OSC data from all connected Coretet instruments and drives four mono output channels with one speaker assigned to each performer.

Within PD the *bowed~* physical string model from the STK as found in the PD port of the PerCoLate package receives parameters including bow pressure, string position, velocity, and string length. The sound of the physical model is augmented with low-volume sine oscillators, and fed through a series of effects including gain staging, reverberation and a compression/expansion process. Additionally, percussive sounds in Coretet as triggered through virtual hand collisions with the sphere of the Orb configuration are generated using the STK *agogo~* model.

3.4 Parameter Mappings and Modes

To map performative gesture and interactions between bow and instrument to salient parameters of the Coretet audio system, a series of key parameter mappings are used.

Bow velocities. The velocity of the moving bow is tracked at two distinct locations: the frog (near the performer's hand) and the far tip of the bow. At this time only the windowed frog velocity is used to drive each instrument's gain level. Frog velocity is additionally used as a factor in scaling the current detected level of bow pressure.

Bow and bowing bar collision locations. When bow collisions with the bowing bar are detected, the position of bow collision along the curved surface of the bowing bar is used to calculate bow pressure to be applied to the string model. Due to the current practice of attaching the bow to the player's VR hand, a point of collision cannot be tracked in UE4 using standard techniques. Instead, along the bowing bar static mesh are embedded 32 tracking nodes. Similarly 12 nodes are embedded across the length of the bow. The closest distance calculated between bow nodes and bowing bar nodes is used to approximate the point of contact.

String length. When different instruments are selected the scale and length of the instrument neck changes. The string length of any selected string is used alongside the desired tuning of each string to calculate the current sounding note.

Finger Position. Any selected finger position on the neck is used alongside the current string length to calculate the current sounding pitch of the string. When quantized scales or alternate modes are selected on the instrument, the exact finger position is fed into the rounding algorithm for the desired scale or mode.

Neck scale/mode. When selected, finger positions along the neck of the Coretet instrument can be quantized to a variety of modes and scales. To denote each selected mode or scale fret markings similar to those found on a viola da gamba or guitar are made visible along the instrument's neck. These modes and scales include:

- Octave: the neck is divided into two regions.
- Triad: major triad built on a string's root pitch.
- Pentatonic: a five note scale.
- Whole-tone: a six note whole tone scale.
- Chromatic: a single octave chromatic scale.
- Quantized: the full range of the instrument with pitches quantized to a chromatic diatonic scale.
- Free: the full continuous range of the instrument without quantization.

Hand collisions. For the Orb configuration of Coretet, hand collisions with the instrument's body will trigger a pitched percussion note using the agogo model. For *Trois Machins de la Grâce Aimante* triggered notes are selected from a composed set of pitch classes. Hand velocity controls the gain of the signal.

3.5 Notation and Scoring

Within a virtual reality environment where users wear head-mounted displays, performers are unable to view notated scores in a traditional manner. For the first

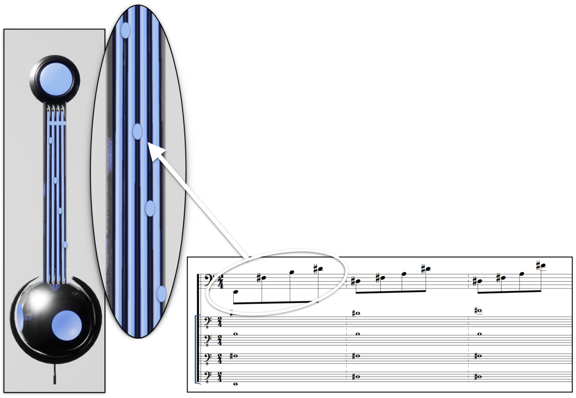

Fig. 4. MIDI score data sets score markers on the neck of the Coretet cello.

two movements of *Trois Machins de la Grâce Aimante* improvisation (Movement I) and a graphic reference score (Movement II) are used to convey individual and ensemble instructions out of real-time. However for Movement III, Coretet displays notes from a composed musical score in real-time as glowing blue pitch location indicators along the instrument's neck (see Figure 4). Scores are synchronized from the server to each of the clients and the system ingests individual MIDI tracks exported from a parent score using music notation software such as Finale.

4 Performance Practices

Coretet was designed primarily as a musical instrument for live concert performance and as such initial validation and testing of the system's technological and functional design decisions has taken place during ensemble rehearsal and live concert performances. The first musical work written for Coretet was *Trois Machins de la Grâce Aimante*, a three-movement string quartet composed to explore the sonic and interactive capabilities of the instruments and the collaborative and communicative aspects of the virtual networked environment. *Trois Machins de la Grâce Aimante* was premiered in Graz, Austria on September 27, 2019 at the Institut für Elektronische Musik und Akustik (IEM) Cube. To date the piece has had additional performances in Mexico City by a second ensemble, and again in Graz at the Mumuth's György-Ligeti-Saal.

4.1 *Trois Machins de la Grâce Aimante*

While *Trois Machins de la Grâce Aimante* is a composition intended to explore Twenty-First century technological and musical paradigms, it is at its heart a string quartet fundamentally descended from a tradition that spans back to the 18th century. As such, the work primarily explores timbral material based around

Fig. 5. Performers for *Trois Machins de la Grâce Aimante* sit in a semi-circle in traditional string quartet order [l to r: violin I, violin II, viola, cello] but face outward towards their tracking towers. In virtual space, each performer retains the same position but is facing inward to see one another's communicative gesture.

the sounds of bowed strings, in this case realized using physically modeled bowed strings, as well as ensemble communication and cooperation between the four performers. The composition takes the form of three distinct movements, each exploring different capabilities of the instrument itself and requiring different forms of communication and collaboration between the four performers [7].

4.2 Ensemble Position and Communications

To date, each performance of *Trois Machins de la Grâce Aimante* has taken place in a venue and in a format in keeping with Western concert music performance. To accommodate four performers with four Oculus Rift head-mounted displays, four laptops and four sets of Oculus Touch controllers and tracking towers, the tightly spaced, inward facing seating arrangements traditionally used in string quartet performance had to be inverted, forcing the ensemble members to physically face away from one another (see Figure 5). In this manner, the Oculus Touch tracking towers could be spaced far enough from each performer to create a sizeable interaction zone within which the motions of their head-mounted displays and hand controllers could be tracked.

Within the shared network space, each performer however is seated in the same relative location but facing inward, allowing the ensemble to see one another's avatar head, bow and instrument. In this manner ensemble members can communicate using gestures traditionally associated with string quartet performance practice, allowing for synchronized timing and visual cues for intensity. In the second movement of *Trois Machins de la Grâce Aimante*, the ensemble is required to conduct the playing of unison chords to one another using their bows, communicating tempo, note duration and intensity visually.

5 Discussion and Evaluation

Musical instruments offer a unique challenge for simulation in virtual reality. Traditional musical instrumental performance practices have been refined over hundreds of years by millions of end-users ranging in skill level from absolute beginner to expert virtuoso. Any attempts to simulate existing musical instruments - or even to create new virtual instruments that essentially inherit performance practice from existing instruments - are instantly and widely critiqued by users who share an intimate and personal connection with the parent model.

The physicality of traditional instruments is an inherent issue with current virtual reality systems. Without haptic feedback, a significant and functional core mechanic of musical instrument performance practice is removed, requiring novel and creative work-arounds to retain the missing functionalities in a manner that is essentially transparent to the end-user. And while today's generation of virtual reality displays and hand-tracking controllers offer an ease of use and widespread availability unprecedented in the history of VR systems, the control systems offered - ranging from bulky baton-controllers and joystick-like grips to infrared tracking of a performers hands - offer a completely different experience from a musician's learned behaviors of hand and finger interaction.

Similarly troubling are the low thresholds for latency required for real-time musical performance. Musicians are notoriously attentive to imposed latencies in musical systems, with thresholds of acceptable real-time latency residing well below 100 ms [1]. The graphics rendering and network requirements of a project like Coretet requires significant computing power across multiple machines, requiring a significant investment in computer and graphics card hardware.

From the time of its inception, Coretet was intended to exist as an instrument firmly descended from traditional ensemble instrumental performance practices with a goal of exploring how virtual implementations of musical instruments could leverage learned expert behaviors of highly skilled musicians. While Coretet's grounding in traditional performance practice has helped focus and constrain potential sonic and gestural exploration, as with any musical work composed for a novel musical interface, instrument or system there was a significant up-front investment of time and resources necessary to both design, create and then explore the physical and virtual affordances made available by Coretet. And as a vehicle for research and further exploration of virtual instrument design and performance, *Trois Machins de la Grâce Aimante* is currently being used to explore issues relating to the role of expert/virtuosic performance in game and instrument design, the perception of mixed and virtual reality performance by audience and performers alike, and the role and successes of communication between performers within rendered and virtual environments.

5.1 Expert Performance

While great success has been had by computer music instruments designed for non-musicians or casual musicians [6], Coretet is inherently designed for trained bowed string musicians, with a goal of leveraging learned performance practices to create a virtual and futuristic version of a traditional instrument. In this context trained musicians share many similarities with expert game-players [12, 20] such as sensitivity to perceived latencies, especially across networks, and an ability and interest in exploring subtle and extended techniques and capabilities of the system. And while each recent performance (and the composition of *Trois Machins de la Grâce Aimante* itself) has stressed ensemble articulation and voicing over individual virtuosic gesture, in post-concert evaluations, within the context of the GAPPP research project, virtuosity in *Trois Machins de la Grâce Aimante* and Coretet was rated significantly higher than in other GAPPP projects evaluated similarly.

5.2 Evaluation by Audience and Performers

In conjunction with the GAPPP project, the premiere performance of *Trois Machins de la Grâce Aimante* featured a post-concert written and oral evaluation of the work by members of the audience, as well as real-time attention tracking during the performance through the use of networked tablets with touch interfaces distributed to individual audience members [17]. While analysis of results from this evaluation are still preliminary, one early reported finding was a significant perception of the virtuosity inherent in performance, a characteristic less commonly associated with other projects as presented and analyzed through the GAPPP metrics. Subjects also reported a desire to view the performance in VR using their own head-mounted displays, a suggestion in keeping with the intent of increasing their own sense of immersion.

5.3 Communication

As elements of musical communication and collaboration are traditional components of ensemble performance and string quartet performance practice in particular, significant consideration went into creating Coretet's network and replication layer to allow performers to see one another. Conversations with performers both during the initial workshop and premiere of the work in Graz, Austria as well as with a second set of performers during the 2019 Ecos Urbanos festival in Mexico City, Mexico showed that performers felt able to see and communicate to a certain extent within the virtual space using methods based in their existent performance practice. Suggestions for greater communication included lessening the perceived distance between virtual performers to make subtle gestures more perceivable as well as rendering more virtual body parts such as arms and hands. During these initial performances a software bug made performers' heads not visible to the rest of the ensemble, which was reported as greatly lessening performers' abilities to non-verbally communicate with one another.

6 Conclusions

The design and development of Coretet was intended as an exploration of VR systems as possible conduits for musical expression. Coretet was envisioned as an instrument directly descended from traditional stringed instrument design as perfected by luthiers throughout the ages. In that light, Coretet was designed first as an instrument for trained musicians, with a future intent of creating levels of abstraction to allow less trained musicians to use the application.

Successful performances using Coretet of *Trois Machins de la Grâce Aimante* suggest that the modes of networked virtual reality instrumental performance afforded by the Coretet instrument are a viable form of musical performance and that the introduction of virtual reality systems within a real-time musical concert situation - while novel - can be perceived as being fundamentally similar to that of traditional musical instrumental performance. Expert users have indicated that performing with the Coretet instrument in *Trois Machins de la Grâce Aimante* has significant commonality with traditional string quartet performance practice and seems to leverage learned skills on stringed instruments. And audience members queried after watching a performance specifically noted the quality, collaboration, virtuosity and creative nature of the project.

Ongoing development of Coretet is currently focused on improving the user experience, bug fixing and implementing interface layers sufficient to submit the application to online software stores available for download by end users.

Acknowledgments. Support for Coretet and the composition of *Trois Machins de la Grâce Aimante* was generously provided by a GAPPP residency and commission from the Institut für Elektronische Musik und Akustik (IEM) in Graz, Austria. Hardware support was provided by an Nvidia hardware grant and additional funding and support was provided by Rensselaer Polytechnic Institute.

References

1. Bartlette, C., Headlam, D., Bocko, M., Velikic, G. Effect of Network Latency on Interactive Musical Performance, Music Perception; Berkeley Vol. 24, Iss. 1, September: 49–62. (2006)
2. Berdahl, E., Backer, S. and Smith, J., III.: If I Had A Hammer: Design and Theory of an Electromagnetically Prepared Piano. In: Proceedings of the International Computer Music Conference, Barcelona, Spain, 59, September (2005)
3. Cook, P. and Scavone, G.: The Synthesis Toolkit (STK). In: Proceedings of the International Computer Music Conference, Beijing, China (1999)
4. Dolby, T.: The Speed of Sound: Breaking the Barriers Between Music and Technology: A Memoir. p. 166, Flat Iron Books, MacMillan, New York (2016)
5. Hamilton, R.: Mediated Musical Interactions in Virtual Environments. In: S. Holland, K. Wilkie, T. Mudd, A. McPhearson, M. Wanderley (Eds.) New Directions in Music and Human-Computer Interaction, Springer, Heidelberg (2019)
6. Hamilton, R., J. Smith, G. Wang.: Social Composition: Musical Data Systems for Expressive Mobile Music. Leonardo Music Journal, Vol. 21, pp. 57–64 (2011)

7. Hamilton, R.: *Trois Machins de la Grâce Aimante*: A Virtual Reality String Quartet. In: Proceedings of the International Computer Music Conference, New York City, USA (2019)
8. Hamilton, R.: Maps and Legends: Designing FPS-based Interfaces for Multi-User Composition, Improvisation and Interactive Performance. In: Computer Music Modeling and Retrieval, LNCS, vol. 4969, pp. 478–486. Springer, Heidelberg (2007)
9. Hamilton, R., Platz, C.: Gesture-based Collaborative Virtual Reality Performance in Carillon, In: Proceedings of the International Computer Music Association Conference, Utrecht, Netherlands (2016)
10. Hemingway, T. Turn It Up to Eleven: A Study of Guitar Hero and Rock Band: Why People Play Them and How Marketers Can Use This Information. Masters Thesis, Brigham Young University (2010)
11. Leonard, J. and Cadoz, C.: Physical Modelling Concepts for a Collection of Multisensory Virtual Musical Instruments. In: Proceedings of the 2015 International Conference on New Interfaces for Musical Expression, Baton Rouge, USA (2015)
12. Lindsted, J., Gray, W.: Distinguishing experts from novices by the Mind's Hand and Mind's Eye. Cognitive Psychology, Vol. 109, March, pp. 1–25 (2019)
13. Lüneburg, B.: Between Art and Game: Performance Practice in the Gamified Audiovisual Artworks of GAPPP. The Computer Games Journal 7:243–260, Springer Science (2018)
14. Mäki-Patola, T., Kanerva, A., Laitinen, T. and Takala, T.: Experiments with Virtual Reality Instruments. In: Proceedings of the 2005 International Conference on New Interfaces for Musical Expression, Vancouver, B.C., Canada (2005)
15. McPherson, A. and Kim, Y.: Augmenting the Acoustic Piano with Electromagnetic String Actuation and Continuous Key Position Sensing. Proceedings of the 2010 International Conference on New Interfaces for Musical Expression, Sydney, Australia (2010)
16. Overholt, D., Berdahl, E., Hamilton, R.: Advancements in Actuated Musical Instruments. Organised Sound, volume 16, issue 02, pp. 154–165. (2011)
17. Pirchner, A.: IRMA (Interactive Real-time Measurement of Attention). A new method investigating performances of audiovisual computer music. In: Proceedings of the International Computer Music Conference, New York City, USA (2019)
18. Puckette, M.: Pure Data. In: Proceedings of the International Computer Music Conference. San Francisco, 1996, pp. 269–27 (1996)
19. Raaen, K., Kjellmo, I.: Measuring Latency in Virtual Reality Systems. 14th International Conference on Entertainment Computing (ICEC), Sep 2015, Trondheim, Norway. Lecture Notes in Computer Science, LNCS, vol. 9353, pp.457–462. Springer, Heidelberg (2015)
20. Salice, A., Høffding, S., Gallagher, S.: Putting Plural Self-Awareness into Practice: The Phenomenology of Expert Musicianship. Topoi (2017)
21. Serafin, S., Erkut, C., Kojs, J., Nilsson, N., and Nordahl, R.: Virtual Reality Musical Instruments: State of the Art, Design Principles, and Future Directions. Computer Music Journal, Vol 40:3, Fall, pp. 22–40, MIT Press, Cambridge, MA (2016)
22. Wang, G., Oh, J., Lieber, T.: Designing for the iPad: Magic Fiddle. In: Proceedings of the 2011 New Interfaces for Musical Expression Conference, Oslo, Norway (2011)
23. Wright, M. and A. Freed.: Open Sound Control: A New Protocol for Communicating with Sound Synthesizers. In: Proceedings of the International Computer Music Conference., Thessaloniki, Greece (1997)