Towards Digital Music Performance for Mobile Devices Based on Magnetic Interaction

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Abstract— **Digital music performance require high degree of interaction using natural, intuitive input controllers that provide fast feedback on user's action. One of the primary considerations of professional artists is a powerful and creative tool that minimizes the number of steps required for the speed-demanding processes. Most of the musical performance applications, which are designed for mobile devices, use touch-screen or accelerometer as interaction modalities. In this work, we present a novel interface for musical performance that is based on the magnetic field sensor embedded in recent mobile devices. The proposed method, at this point, promises a new independent ground for inputting momentary data during music composition and manipulation process. Giving the opportunity to freely, fully and quickly utilize the surrounding 3D space, it possesses the potential to bring a wide-spectrum of unique options for production and performance process of music.**

Keywords-digital music performance; electronic instrument; magnetic field sensor; gesture-based interaction; mobile devices

I. Introduction

Along with the ongoing development of innovative technologies, audio production as a concept is in a constant progress, through which artists are given new opportunities and unique methods to compose music and perform their artwork to the masses. Trendsetting functions and capabilities become available with a perpetual motion, inspired from tendency of constructing audio through new and creative approaches. Specifically, diverse methods focused on new input technologies are being introduced that all aim to provide options untried before to artists' process of music creation and performance.

In this work, we propose to use the magnetic field sensor (magnetometer) embedded in new mobile devices, such as Apple's iPhone 3GS and Google's Nexus One, for musical performance on mobile devices. The embedded magnetometer provides a measure of magnetic field strength along X, Y, and Z directions. In this method, the user takes a magnet that can be in shape of a rod, pen or ring; in his hand and draws coarse gestures in 3D space around the device. Several characteristics of a song or an audio (such as frequency, equalization, filtering, etc) can be altered based on the magnetic field caused by the magnetic gestures. Position, movement, shape, and orientation of the magnet can be used as an input modality to alter parameters of music being played or being adjusted. In comparison with touch-screen or keypad input, this technique provides higher degree of flexibility for musical performance because the interaction space extends beyond the physical boundary of the device. Consequently, it is especially suitable for small and tangible devices while it does not require any change in their hardware or physical specifications.

Playing musical instruments such as chordophones, percussions and keyboard types accompany with harmonic interaction of player's hand with the instruments. The proposed method establishes a mapping between the motion of hand (or fingers), and movement of a magnet (taken in fingers) in the space around the device. Moving a tiny magnet around the device can transparently pursue the activity of playing an instrument and the phonation intentions of the user can be simulated on the mobile device by capturing its gestural pattern. Position, movement, shape, and orientation of the magnet can be used as an input modality to alter parameters of music being played or being adjusted. Besides, musical performance requires the manipulation of several interdependent parameters simultaneously; thus, it's gestural interfaces needs to be suitable with motor capabilities of the user. The use of natural, intuitive and touch-less gestures performed around mobile device reduces the motor and cognitive load of the performer. The proposed method enables a more creative, unique and innovative way of audio production and performance that can be utilized for different type of target groups including both professional artists and leisure oriented hobbyists. Furthermore, the use of natural and intuitive gestures is consistent with the mobile music technology challenges regarding the action-sound relationship and music-movement correspondence.

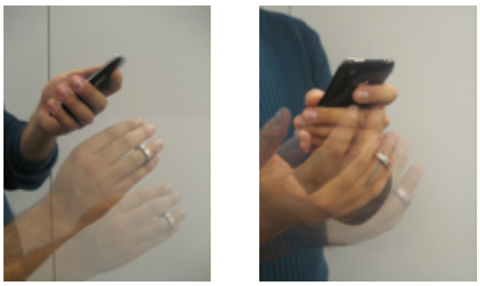

Figure 1. Magnetic interaction with digital music performance proto-types that works on iPhone 3GS

In order to experiment the proposed method, we have implemented several proto-types of digital instruments on iPhone 3GS based on magnetic interaction. They offer music composition options on simple level on mobile devices (Fig. 1) using predefined pitch intervals, instrumentations and presets for various parameters and features popular sound effects to the audio in playback, along with a vinyl-scratching simulation. For that reason, we have ported SuperCollider (SC) server [1], a real-time sound synthesis environment, to the iPhone operating system (iOS). The SC server supports a simple C plugin API making it easy to write efficient sound algorithms that can then be combined into graphs of calculations. Each proto-type consists of a client-side application, which sends the raw XYZ data and recognized gestures through Open Sound Control (OSC) protocol and a server-side SC patch that receives data from one or multiple clients and synthesize parameterized sound. Using client-side application of the digital instruments, the user is able to connect to any SC server using wireless network and output audio from any mobile or desktop device with required patches installed including the iPhone itself.

II. Related Works

Recently, we have proposed Magnetic Interaction Framework (MagiTact) [2], the use of magnetic field sensor for general-purpose interaction with mobile devices and achieved gesture recognition accuracy over 90%. Similar designs of musical instruments based on electric field sensor (cathode relays) [3] and IR proximity sensor [4] are investigated for musical performance on portable devices. However, series of previous work has been established so far regarding possible new methods to provide control on a mobile audio creation environment.

Lots of researchers already attempted to propose different mappings of action to the audio synthesis. The mappings can be explored in two fields in terms of their excitation type: sustained and impulsive. The sustained mappings are based on continuous energy transfer such as the 3D motion data that is captured using different type of sensors; whereas, the impulsive mappings are discontinuous and generally triggered using gestural interfaces. Firstly, Campo et al. [5] proposed a design for generalized sonification environment to deal with experimental data analysis and exploration. Then, Klein et al. [6] described a technique for sonification of 3D vector fields to map vectors in a listener's local neighborhood into aerodynamic sound. Afterwards, Pelletier [7] described another motion-based framework for the generation of large musical control fields from imaging data using granular and micro-sonic algorithms, additive synthesis and micro-polyphonic orchestration. Bevilacqua et al. [8] extended 3D optical motion capture sonification through gestural analysis via segmentation and pattern recognition.

The impulsive mapping has been also widely investigated by designing gesture-based instruments. Wanderley et al. [9, 10, 11, 12] deeply investigated the gestural control of the music and defined different aspects that should be taken into consideration for the gesture-based digital instruments. Fenza et al. [13] presented a multi-layer controller with three stages of mapping that explore the analogies between sound and 3D movement spaces using Laban's theory. Kayali et al. [14] described a number of suitable gestures for musical expression with mobile and tangible devices. Malloch [15] provides the design and construction of a family of novel hardware input devices, a collaborative mapping system and a modal synthesizer software for gesture-based performance. Bencina et al. [16] described a technique for developing gesture-sound mappings using three-axis accelerometer of Wii Remote. Dekel [17] et al. used again accelerometer gestures as input to MIDI instruments and sound generator.

Finally in mobile context, Couturier [18] and Jensenius [19] defined the requirements for using mobile devices as digital instruments. Geiger [20] explains the efficiency of using touch-screen as an input controller. Gillian et al. [21] presented a gesture-based DJ-effecting mobile game having vibro-tactile feedback. There have been also works that show the importance of mobile musical performance via real-time collaborative (orchestral) approaches. For instance, Wang [22, 23] implemented an orchestral ancient flute-like instrument designed for the iPhone using microphone for breath-control and multi-touch for finger holes. Tanaka [24] presented the collaborative composing with mobile devices using MaxMSP music environment and OSC messages. Essl et al. [25, 26] analyzed sensors integrated in mobile devices regarding digital music and they explained the challenges for turning the devices into performance platforms. Most of them experimented the sound generation using striking, shaking and sweeping type of natural gestures using accelerometer. However, playing musical instruments on the surface of the mobile device is not natural enough and usually requires both user hands on a single small surface of the mobile phone [27]. In comparison with touch-screen or keypad input, our technique provides higher degree of flexibility for musical performance because the interaction space extends beyond the physical boundary of the device. When using accelerometer-based interaction, the user has to repeatedly turn the device to launch certain commands and the user loose direct sight to the screen of the device as opposed to our approach.

III. Methodology

In this section, we propose different mappings of sound characteristics for the sonification of the 3D vector data provided by the magnetometer. Besides the mappings, we explain how such a digital instrument can be realized using gesture-based interaction. The magnetic field sensor provides a measure of magnetic filed along X, Y, and Z directions. The mapping of sound characteristics to the 3D vector set provided by the magnetometer can be explored in two fields in terms of their excitation type: sustained and impulsive. The sustained mappings are based on continuous energy transfer such as the 3D motion data that is captured using different type of sensors; whereas, the impulsive mappings are discontinuous and generally triggered using gestural interactions. In other words, there are two distinct methods that one can employ the magnetic field to play a musical instrument. The first way is using the direct sensor values where the projection of sensor value to XYZ-axes provides 3 different modalities, in raw, time derivative or normalized format; which can be directly mapped to various sound generation or modulation parameters. Thus, values and audio output is a function of intensity, position, polarity, orientation of the magnet in the hand of performer. In the second approach, a sequence of sensor values shapes a 3D gesture pattern. This pattern can be matched against a model to realize their corresponding gesture class.

Theremin is a primitive example of sustained electronic instrument that is controlled touch-less by two metal antennae that sense the position of the player's hands and control oscillators for frequency with one hand, and amplitude (volume) with the other. In magnetic sense, the X-axis of the sensor datum may control the frequency of the sound; whereas, the Y-axis can control the amplitude of the sound. Whereas, Metallophone is en example of impulsive instrument where an individual harmonic, which is multiplicand of a base sound frequency, is produced on any consecutive pitch. In order to generate different harmonics, one strike bars with a mallet. The sound harmonic is generated in relation with the properties of the bar and the strength of the performed striking gesture. In magnetic version, the X value of the sensor datum may be dedicated to represent the bars on the instrument by dividing into 24 different intervals, which represents the bar that should be struck on the metallophone. Whereas, the second derivative of Z component of the sensor datum may be used to reveal the strength of struck. When a striking gesture is recognized, a harmonic sound can be generated after knowing which bar is struck by what strength.

The proposed method is examined using a multi-layer model with three independent levels (Fig. 2). Regarding practical options for utilization of the proposed technology in audio production and performance, three incremental levels of application are considered: sound generation, modulation and effecting. Using mobile devices as digital instruments, group of users collaboratively control the event generating musical algorithms that trigger sound generation for sound synthesizers, by providing parameters with the highest level of abstraction. Once these parameters are mapped to the pre-defined synthesizers, subtler parameters of the synthesizers are modulated afterwards by the same group or simultaneously by another group of users. Finally, users can apply different sound effects onto the performance using gestures.

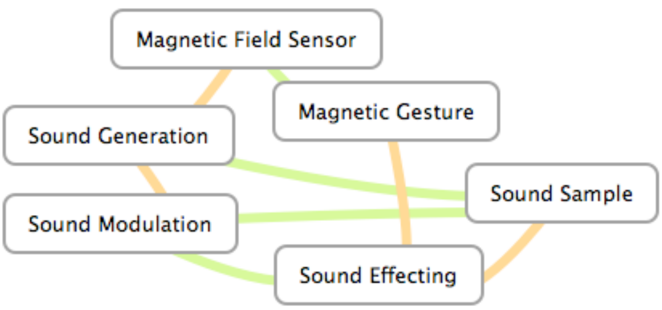

Figure 2. The model for digital music performance that consists of three main levels: sound generation, modulation and effecting

IV. Sound Generation

With its specific meaning for the purpose, generation of sound defines creation of various audio components for composing a certain piece of music. Fundamental elements of music are various and different categorizations can be considered depending on the type of classification. Several examples to primary elements of music can be given as pitch, melody, rhythm, harmony, tempo, timbre, dynamics and texture. Among the given elements, melody and rhythm are the directly audible elements of a music piece, while all of the other parameters determine the values for different qualities of audio.

In sound generation stage, users create parameters for controlling sound generators with the highest level of musical abstraction. The X coordinate of the raw data is mapped to a selection of notes defined with their pitch / frequency and the Y and Z coordinates are mapped to Major and Minor chords (Fig. 3). These parameters including pitch, velocity and rhythm (the placement of events over time) are routed to pre-defined synthesizers to create sounds of desired types. Possibilities for creative composition of musical pieces can significantly increase when the second axis is assigned to Major chords and the third axis is assigned to Minor chords.

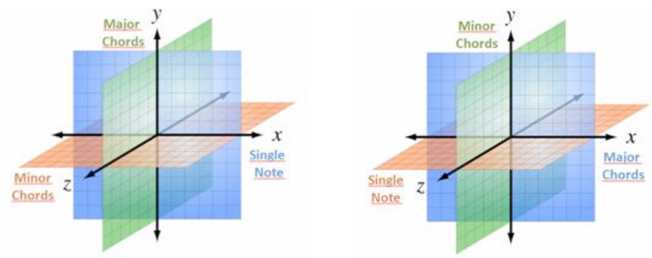

Figure 3. The axes of the magnetic field data are mapped to notes in a subtractive synthesizer defined with their pitch, Major and Minor chords.

V. Sound Modulation

After creation of a certain type of sound, it is possible to modify its characteristics through a high number of parameters with a subtractive sound synthesizer, including but not limited to Amplitude, Filter Frequency / Resonance, Pan / Stereo Spread, Velocity, Envelope (Attack / Decay / Sustain / Release), Motion, Articulation (Legato / Staccato) and Vibrato. The aforementioned sound generation model determines what to be played, and controlling these subtler details of musical expression enables us to play with a wide spectrum of sound qualities. Modifications on characteristics of an already created sound enable different expressions to be obtained from the audio, enabling options for further improvement. In addition to pitch-based sound generation functionalities of a magnetic interaction based input, possible combinations regarding allocation of axes to modifiers of sound characteristics will enlarge the scope of sound production and performance for cross-border capabilities (Fig. 4). For instance, it may be used as music synthesizer keyboard modulation wheel of the proposed subtractive synthesizer. The complexity of the magnetic signal and the cut-off frequency and resonance of the filter can be controlled along with a form of pulse width modulation in order to simulate the natural timbre of a given instrument.

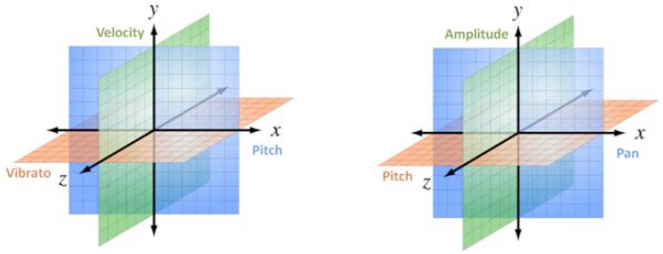

Figure 4. Different combinations of sound characteristics mappings that are considered for the sound modulation

In a strict sense, pitch defines the lowness or highness of a sound on a note-based scale. A note with its direct meaning in music is actually a pitched sound itself. Any note played on a piano keyboard includes a certain pitch value and it gets higher as other keys to the right are played and vice versa. Within the audible range from 20 Hz to 20.000 Hz for the human ear, every key played for a note in a modern piano features an absolute frequency in Hertz. An 88-key piano with a virtual range of 8 octaves (Fig. 6) will feature a note range from A0 (lowest) to C8 (highest), around which the frequency ranges from 27,5 Hz to 4.186,01 Hz.

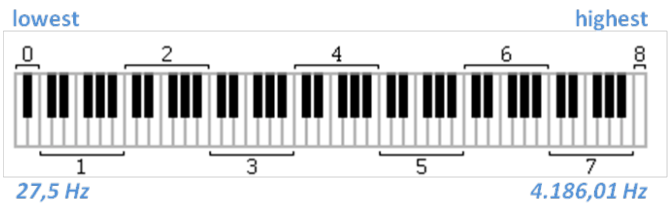

Figure 6. 88-key piano with a virtual range of 8 octaves

The harmonic element of a music piece is usually obtained through a series of chords that accompany a melody and/or rhythm. In a simple sense, a chord is a set of harmonically related notes that are played simultaneously (Fig. 7). While further varying with their characteristics, chords fundamentally represent a certain single-key note on the keyboard. Using the knowledge described above, we have developed a digital piano instrument, which works on the thin air, using the raw data derived from the magnetic field sensor.

Figure 7. Major and minor chords of the note C

VI. Sound Effecting

A sound effect can be shortly defined as an enhancement brought to a certain sound with alterations and diversifications applied on the signals. Sound effects can create dramatic changes on any possible parameter of sound and enable a number of opportunities for shifting musical components to various forms. Hence, it supplies advanced sound processing capabilities to any audio performance software. With the unique freedom given by the proposed method to utilize the three axes for different parameters of sound generation, modification and effecting, various combinations can be considered for desired type of music scoring performance, each with a potential to deliver diverse qualities. While it is possible to reach further results with combinations of parameters, a brief list of possible sound effects follow as Equalizer, Pitch Bend-Pitch-Shift, Reverb, Delay/Multi-tap, Compressor, Chorus, Limiter, Fuzz, Distortion-Overdrive, Flanger, Phaser, De-esser, Noise Gate and Ring Modulation. For that reason, we have proposed several mappings of sound effect to the axes of the magnetic field sensor (Fig. 5). The sound effects can be applied collaboratively or simultaneously to enhance the digital music performance. The passage between different mappings of sound effects can be performed using magnetic gestures, as an alternative to the touch-screen interface.

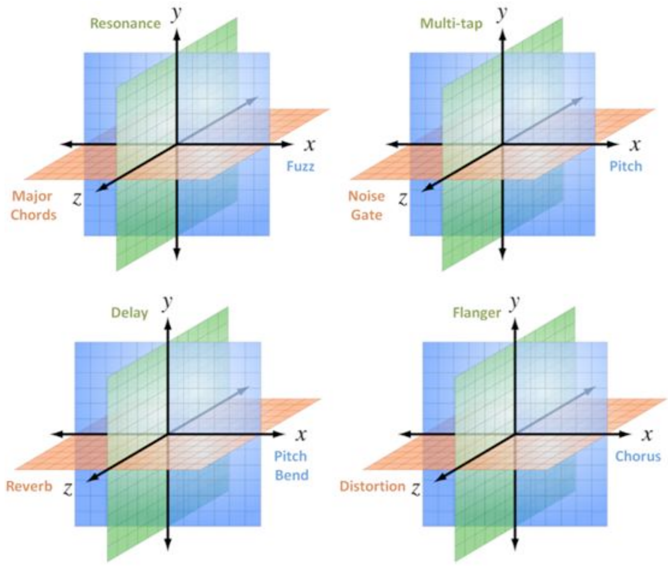

Figure 5. Different mappings of the various combinations of sound effects to the axes of the magnetic field sensor

In order to demonstrate the approach, a simple DJ effecting proto-type is implemented for iPhone 3GS. The proto-type is able to perform two essential DJ effect: Cross-fading and Scratching. Cross-fading is the term for interlacing two playing songs by increasing the volume of one and decreasing the volume of the other simultaneously using a slider (cross-fader) that overlaps one song with another. Scratching is a DJ technique to produce distinctive sounds by moving, stopping, reversing a vinyl record back and forth on a turntable while optionally manipulating the cross-fader on a DJ mixer.

In the DJ proto-type, we have assigned the X-axis values of the magnetometer to the cross-fading action of the DJ, and the Y-axis to the scratching action. Mixing coefficients are calculated based on X component of magnetic sensor output, hence relative position of hand with magnet on the X-axis. In this way, the DJ can obtain different mixtures of two sounds by moving his hand left and right with respect to the device. The tuning data obtained by mobile phone. Thus, the DJ preserves his natural gesture to tune the sound output while he can freely move through the audience. DJ pooling can also be realized when several mobile DJ terminals join to a central SC server.

VII. Collaborative Performance

The SC server can be used with other languages or applications having any number of input/output channels because all external control in the server happens via OSC. Furthermore, it gives access to an ordered tree structure of synthesis nodes, which define the order of execution with a bus system dynamically restructuring the signal flow. Thus, any SC server is able to receive data from multiple clients simultaneously through the wireless network. The SC server does not send or receive sound because it is expected that clients will send all control commands for the synthesis. Patching between modules is done locally through global audio and control buses. In order to perform collaboratively, group of users can simultaneously generate sounds of different types of digital instruments. Then, characteristics of the generated sound are modulated afterwards by the same group or simultaneously by another group of users. For instance, one performer can alter various characteristics of sounds that are generated from the control data of another performer. Finally, users can apply different sound effects onto output of this collaborative performance using gestures.

In case of collaborative performance, the system requires the central server to be the only audio output source due to latency and synchronization issues that might occur. Therefore, it requires all of the users to be in the same place and able to get audio feedback at the same time from the central server. This assumption removes synchronization concerns and ensures suitable latency because it reduces the amount of data that needs to be sent, as it only requires the raw or derivative sensor datum and user interface input specific to the digital instruments. Each user selects the appropriate SC patch, which belongs to the digital instrument that he wants to play. SC patches interpret the received data in real-time to collaboratively produce the sound output using shared buffers for writing and reading.

Accordingly, we have implemented a proto-type similar to the Mobile Electronic Orchestra [23] where multiple mobile devices play the role of various instruments to form a philharmonic orchestra. In a real orchestra, strings, brass and percussion sections are collaborating to compose an intertwining music. This instrumental ensemble can also be leaded by a constructor to keep the overall playing process organized. In order to establish such an orchestra, we have installed each client implementations described above on different mobile devices to perform the music collaboratively. The proto-type is able to perform without any problems while manipulating the same music sample simultaneously.

VIII. Discussion

During user studies, we have learned that magnetic instruments based on the sustained mappings, which generates tones of any pitch throughout its entire range, are very easy to use due to the flexible, natural and intuitive interaction. Directional movements of the magnet allow producing small and reliably reproducible changes in tone quickly and even were able to create tremolo or vibrato effects by their selves. On the other hand, they were difficult to specialize due to control of the instrument's pitch with no guidance, as it does not have physical feedback (except audio feedback), such as string tension or the tactile fingerboard for strings. Furthermore, professional performers with an excellent sense of pitch sometimes experienced a vocal slide between two pitches. Consequently, touch-less sustained instruments are more suitable to perform legato on continuously variable pitch instruments.

More dimensional mappings for digital music performance stages could be developed though the fusion of multi-sensor data. For that reason, we would like to extend the interaction possibilities by combining data from multiple sensors embedded in mobile devices. Furthermore, stand-alone hardware units can be configured besides mobile devices in order to obtain the minimum latency and maximum accuracy for providing more efficient results during professional-level operation with higher process rate. Several opportunities arise from binding any possible sound generator, modifier or effecter device to the axes of magnetic field based interaction Thus, equipping of a multi-purpose software with sound sampling / generation abilities to various professional audio production software appears very suitable. Finally, we should investigate the separation of sources in order to establish a collaborative magnetic field based digital instrument without having the necessity of multiple devices.

IX. Conclusion

In this work, we have proposed a novel interface for musical performance that is based on the magnetic field sensor integrated in new mobile devices. Moreover, we have proposed different mappings of sound characteristics for the sonification of the 3D vector datum of the magnetic field. Besides the mappings, we have explained how such a digital instrument can be realized using gesture-based interaction. The proposed interface allows digital imitation of a broad number of instruments while still being able to sense musical hits and relative plectrum gestures. It provides a framework for extending interaction space with music applications beyond physical boundaries of small mobile devices, and to 3D space around the device, which allows for a more natural, comfortable and flexible interaction. Finally, we have presented several mobile digital instruments developed based on the proposed method on the iPhone operating system. Through trained motions of a professional artist or a leisure-oriented hobbyist, the proposed technology is highly likely to bring a new and effective trend to concept of the digital music performance on the mobile context.

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