Gesture in performance with traditional musical instruments and electronics

Use of embodied music cognition and multimodal motion capture to design gestural mapping strategies

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ABSTRACT

This paper describes the implementation of gestural mapping strategies for performance with a traditional musical instrument and electronics. The approach adopted is informed by embodied music cognition and functional categories of musical gestures. Within this framework, gestures are not seen as means of control subordinated to the resulting musical sounds but rather as significant elements contributing to the formation of musical meaning similarly to auditory features. Moreover, the ecological knowledge of the gestural repertoire of the instrument is taken into account as it defines the action-sound relationships between the instrument and the performer and contributes to form expectations in the listeners. Subsequently, mapping strategies from a case study of electric guitar performance will be illustrated describing what motivated the choice of a multimodal motion capture system and how different solutions have been adopted considering both gestural meaning formation and technical constraints.

Categories and Subject Descriptors

H.5.5 [**Sound and Music Computing**]: Methodologies and techniques; J.5 [**Arts and Humanities**]: Performing arts (e.g., dance, music).

Keywords

Gesture, multimodal, mapping, embodied music cognition, motion capture, expressiveness, guitar.

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1. INTRODUCTION

In recent years, musical gestures and body motion in music have been subject to extensive interdisciplinary research. Contributions from several fields such as musicology, cognitive psychology, neurology and computer science have brought about new ideas and perspectives, giving rise to new paradigms for the understanding of gesture and music [15, 16, 17]. In particular, new insights from research on embodied music cognition [23] inspired new viewpoints and required a rethink of the relationship between human body and musical experience. Within this theoretic framework, music perception is *embodied* (i.e. closely linked with bodily experience) and *multimodal*, in the sense that music is perceived not only through sound but additionally with the help of both visual cues and sensations of motion, effort and dynamics [13]. Hence, gestures become a core notion as they act as a bridge between bodily movement and meaning formation.

At the same time, motion sensing technologies have become pervasive, many everyday electronic devices use motion data for different purposes and new developments made the recognition of motion features more precise and accessible. In fact, such technologies are being employed in both academic research and artistic practice. In musical contexts, there is a long and prolific tradition of electronic interfaces that exploit gestures and motion as means of control of musical parameters [30]. As Miranda and Wanderley also note, adopting an effective mapping strategy is crucial for the expressiveness of the interface, being the relationship between gestural variables and musical parameters often far from obvious. Mapping has in fact received increasing academic interest and it is recognised as a critical element in instrument and interaction design [19]. Several mapping approaches have been adopted over the years showing new insights from artistic practice, implying that mapping is not solely an issue of interface and control but also part of the compositional process [7, 32].

Within this context, this paper aims at giving an account of approaching gesture mapping in a performance with a traditional musical instrument and live electronics, taking into consideration recent theories of embodied cognition and musical gesture and employing multiple motion-sensing technologies. This interdisciplinary approach not only identifies mapping as part of the compositional process but also supports and explores the idea that gestures and sound act jointly in the formation of musical meaning, therefore gestures are seen as expressive elements rather than as mere means of control. Additionally, we describe the development of specific tools and technical solutions, believing that the study of musical gestures might inform new implementations of motion capture technologies and, at the same time, practice might lead to new contributions to the understanding of musical gestures and their influence on our experience of music.

2. RESEARCH CONTEXT

2.1 Embodied Music Cognition

At the core of the embodied music cognition paradigm there is the assumption that gesture and corporeal imitation are fundamental constituents of musical expressiveness [23]. The body is thereby understood as a mediator between the physical environment (e.g. music as sound waves moving in the air) and the subjective musical experience (e.g. one's feelings in response to that music). In this context, "musical gestures can be described in an objective way as movement of body parts, but they have an important experiential component that is related to intentions, goals, and expressions" [25]. By acting as a mediator, the body will build up a repertoire of gestures and gesture/action consequences, or what Leman calls a *gesture/action-oriented ontology* [25]. This repertoire can be considered as a collection of movements made to achieve a particular goal (actions) linked with the experiences and sensations resulting from such actions. Musical gestures are constitutive of this repertoire. The coupling of actions and perceived sensations forms an engine that guides our understanding of music. Through this mechanism, the listener is able to relate physical aspects of movement in space to expressive qualities, intentions and inner feelings. Conversely, perceived patterns of musical expression recall previously learned knowledge of the corresponding body movement. This continuous two-way mirroring process allows the listener not only to attribute intentions and feelings to music but also to predict the outcomes of actions and project them onto the music [28]. This is what Leman calls *action-perception coupling system*; it forms the basis of musical intentional communication and expressiveness, which then elicits several social phenomena such as empathy and social bonding [23, 24, 25].

2.2 Musical Gesture

As previously mentioned, in recent years the study of musical gestures shifted from a chiefly philosophical approach to a more systematic, cross-disciplinary method. The concept of *gesture* itself, at the core of these studies, is used across multiple disciplines and contexts. The notion of gesture being quite broad and sometimes vague, Jensenius et al. [20] give a comprehensive look at the term and its uses in music research in order to present a clearer overview. While initially problematic to pinpoint, the notion of gesture has considerable potential in modern music research as it works as a bridge between movement and meaning and, consequently, bypasses the boundary between physical world and mental experiences. Additionally, Jensenius et al. identify four functional categories to better understand the role of different musical gestures in performance; *sound-producing* gestures, *sound-facilitating* gestures, *sound-accompanying* gestures and *communicative* gestures [20]. Overall, being at the core of embodied music cognition, we could say that *gestures are a vehicle for the construction of musical meaning.* This means not only that music perception is embodied, but that it is also *multimodal* in the sense that we perceive it using multiple senses; through sound but also with the help of visual images and feelings of motion, such as kinaesthetic sensations and kinematic images [13].

2.3 Ecological Knowledge and Traditional Musical Instruments

We adopted the term *traditional musical instrument* (henceforth TMI) to define instruments that have a rich idiomatic repertoire that ranges across both popular music and classical music. Examples include electric guitar, violin, electronic keyboards, etc. Such a term is preferred to acoustic instrument because it refers to the use and repertoire rather than to technological aspects. The choice of focusing on TMI performance is motivated by the vast knowledge that listeners have of the gestural and sound aspects of each instrument, which is learnt through experience. For instance, most of us immediately know what sound to expect when we see a drummer hitting a snare drum with a stick. Similarly, if we hear the sound of a violin we can easily associate the gesture of bowing to it. This can be summarised as the *ecological knowledge* [13] of an instrument; listeners have, and in some cases share, *a repertoire of sound-producing gestures.* TMIs also have fairly explicit and known *affordances* [11] that can delineate action relationships between the instrument and the musician, inform expectations in the listeners and be used, along with sound affordances, to devise mapping strategies for controlling electronic aspects of the performance. Using embodied music cognition terminology, instruments have a rich action/gesture repertoire that the listeners can recognise during the performance. In fact, Nijs et al. [33] note that the expert musician has an extensive toolbox of movement schemes that he or she can unconsciously select and perform in response to the challenges provided by the musical environment. Within the paradigm of embodied cognition, the musical instrument is *embodied in the body of the performer* [18] and becomes a natural extension of the musician [33]. It is therefore part of the mediation together with the body, thus allowing a spontaneous corporeal articulation of the music, contributing to the formation and conveyance of embodied musical meaning. In fact, according to Godøy [12], people continuously reenact mental simulations of sound-producing actions when listening attentively to music, adding a motor-mimetic element in music perception and cognition. Additionally, Cox formulates a similar hypothesis: "we normally imagine (most often unconsciously) what it is like to make the sounds we are hearing" [5]. Moreover, there is empirical evidence that the gestures of the instrumentalist can alter the sound perception of the listener [35]. With this in mind, using the instrumentalist's gestures may have a considerable expressive potential in performance as well as in composition as composers would be able to draw from a *gestural palette* of the instrument when writing a piece.

3. THE ELECTRIC GUITAR AS A CASE STUDY

Given this background scenario, it is clear that gestures have a significant influence on how music is experienced and traditional musical instruments are a rich repository of shared gestural information. Therefore, the theoretical apparatus of embodied music cognition (EMC) could be employed to devise effective mapping strategies that may give a substantial contribution to both the expressiveness and the liveness of a performance involving TMIs and live electronics. In recent years, there have been applications of EMC within interactive multimedia environments [2] and singing performance [27].

In this paper, we describe the implementation of some gesture mapping strategies for a performance with electric guitar and electronics. There are other documented approaches to electric guitar augmentation using the performer's gesture [22] and gestural control of digital audio effects [37]. Apart from aspects related to control of musical parameters, our approach emphasises the fact the gestures contribute to the formation of musical meaning, therefore the function of gestures and their relationship with musical features are taken into consideration throughout the implementation process.

The multimodal motion capture system adopted features sensors worn by the performer and a Microsoft Kinect. Flex sensors and accelerometers located on hands and wrists of the guitarist are employed to obtain accurate data of hand movements. In fact, sound-producing gestures of guitar playing as with many other instruments typically involve hands and arms and such gestures are the most readily noticed by an observer [6] therefore more stable and detailed signals allow to capture the subtle movements of hands and wrists. Conjointly the Kinect data, even at relatively low frame rates (30 fps) or with jittery joint tracking, allows for the interpretation of full-body gestures, enabling the recognition of high-level expressive movements.

4. USE OF WEARABLE SENSORS

Flex sensors and 3-axis accelerometers are mounted on custom wristbands together with a custom Arduino-based board equipped with an XBee wireless chip[1]. This sends the sensors signal to a computer for signal processing and parameter mapping. The mapping strategies for these sensors are informed by the functional categories described by Jensenius et al. [20]. For example, the flex sensor on the left wrist is used to monitor the activity of this articulation. In guitar playing, movements of the left wrist act in support of the fingers operating on the fretboard. These movements are therefore defined as *sound-facilitating support gestures*. Stressing the wrist articulation may cause discomfort and alter the tone of the notes being played [4]. To underline this, the flexion sensor is mapped to a bit reduction DSP algorithm that deteriorates the audio signal of the guitar, reflecting the uncomfortable stretching occurring on the left-hand (Figure 1). The analogue signal of the sensor is converted to OSC data, which is then rescaled in software dedicated to mapping[2] according to how the guitarist bends the wrist when playing comfortably or when stressing the joint. The

Figure 1: Use of wearable sensors: flex sensors placed on the wrist activated by a sound-facilitating support gesture.

Figure 2: Use of wearable sensors: 3-axis accelerometer placed on the wrist activated by a communicative expressive gesture.

OSC data is then converted to MIDI and sent to a DAW[3], which hosts several DSP units that process the audio signal of the guitar. In this example the MIDI data obtained from the flexion sensor controls the downsample resolution of a bit reduction DSP unit. (Figure 1).

The accelerometers are instead used to follow the *communicative expressive gestures* [20] of the right arm that immediately follow strumming. These movements can also be considered suffixes of the strumming gesture and are important for its performance and perception [14]. To reinforce the meaning of the gesture, the accelerometer is mapped to a Max[4] patch that affects the timbre and decay of the strummed chord, following the intensity of the movement. The dynamic range of the accelerometer is relatively high, therefore the OSC data obtained from the sensor needs to be compressed and smoothed through the same mapping software used above. (Figure 2).

5. USE OF FULL-BODY MOTION ANALYSIS

Whilst wearable sensors are used to follow subtle gestures of the upper limbs, full-body motion analysis is employed to extract features from complex movements deployed in space over longer time stretches. One measure widely used by

[1] `http://www.sensestage.eu`
[2] `http://steim.org/product/junxion/`
[3] `http://www.ableton.com`
[4] `http://cycling74.com`

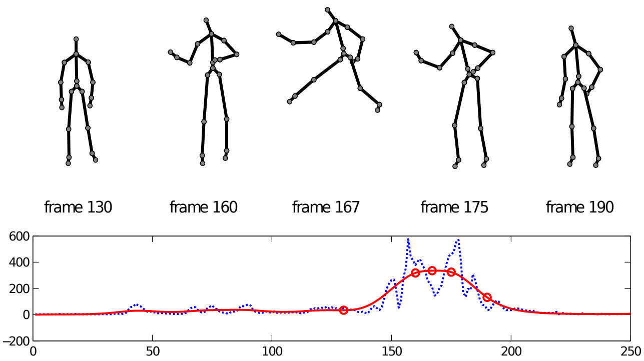

Figure 3: The dashed line shows the QoM on a movement sequence. The solid line is the final measure after low pass filtering. The skeletons (on top) illustrate the skeleton position on each time stamp (marks).

other authors [3, 9] is the Quantity of Motion (QoM). QoM is proportional to the translational movement and it is extracted from a global set of features evaluated over time. It gives high values when the body is moving fast and low values when it is more stationary. Camurri et al, for example, implemented this feature in the EyesWeb processing library [1]. QoM is also useful for extracting contextual syntactic structures from the musical performance [26]. The QoM can be estimated from the skeleton joints tracked by a motion capture system [9]. In this case, the user can measure QoM for specific combinations of skeleton joints.

The QoM allows the movement segmentation by the motion bells [9] patterns. Initially, we used the standard QoM described in others' previous techniques [3, 9]. The motion bells can be estimated in a simple but effective way by applying a low pass filter on the QoM estimates over time. After the filtering process, it is possible to identify the gestures phases by analysing the well defined form of curves on the signal response, as it can be observed in Figure 3. This figure illustrates the motion bell generated by a sudden movement of the performer.

The information obtained throughout this simple procedure is useful to segment the different motion phases, which is an important step of gesture analysis. In fact, the spotting detection [8] (identification of start and end of the gesture) is crucial for classification accuracy of complex gesture recognition algorithms based on Hidden Markov Models [10] or Dynamic Time Warping [31]. Furthermore, each start or end point might be used to control musical events associated with the respective gesture.

The starting point of a gesture is detected when the QoM measure presents an abrupt growing behaviour crossing a pre-established threshold T_1. In other words, when $QoM(n) \geq T_1$ and $QoM(n-1) < T_1$, then the time sample n is marked as a starting point. After the detection of the starting point, it is necessary to identify the duration of the gesture. The same procedure used for identifying the starting point can be used here to detect the end of the gesture. In this case, we evaluate not only the amplitude of the QoM, but also its decay rate. Hence, the parts without movement corresponds to the beginning of the valley regions in the QoM estimate. In this work, the first point n after the beginning of a gesture that satisfies $|QoM(n+1) - QoM(n)| < T_2$ and $QoM(n) < T_3$ is marked as the corresponding end gesture timestamp. T_2 is a slope-related threshold and T_3 is an amplitude related threshold (used to avoid spurious local minima at the peaks).

To find new ways of using QoM in musical contexts, we implemented a measure that describes the quantity of motion in relation to the periodicity of the movement. We named this measure *Periodic Quantity of Motion - PQoM.*

There is often sensorimotor synchronisation between the rhythmic structure of the piece and the periodic motion of the body [34]. The use of PQoM allows to connect these two features.

In our case study on electric guitar, the movement of the strumming hand often plays a periodic rhythm. During a crescendo, the periodic hand movement might be executed with greater amplitude and different body parts might be engaged with this movement, performing a periodic motion with the same frequency. This corporeal resonance with the music might be mapped to musical parameters that follow this increase of energy, such as the gain or other timbral features of the guitar audio signal. This idea can also be used with other instruments, such as bowed strings and percussion instruments.

The PQoM estimate is obtained from the decomposition of the motion capture signal into frequency components by using a filter banks [31]. For each frequency, the process is similar to the computation of QoM, but it uses only the amplitude of that specific component.

For example, the resonance of the body movements with a certain rhythm might be used to add sampled percussive elements to the music, reinforcing the tight relation between auditory and kinematic elements of the performance. The Figure 4 illustrates the extraction of such features from the body motion captured by the Kinect sensor.

In this example the guitarist performs a periodic motion with the strumming hand. The hand oscillates with a frequency equal to multiples or fractions of the music tempo in BPM. On Figure 4a, the lighter regions show where the movement resonates more with the rhythm. In the same figure, the bounding boxes represent the individual movements with distinct frequencies, detected using the threshold scheme described for the QoM approach. The light blue, pink, dark blue, red and green colours indicate movements corresponding to rhythms made of quavers, crotchets, minims, semibreves, and breves respectively. Finally, Figure 4b shows the motions bells for each one of the expected frequencies and the segments delimiting the individual movements.

The system can be further customised to follow other periodic features of the music and to recognise specific motion patterns and it can also be used to attune the music to the gestures of the performer, allowing for a two-way feedback between music and movement. This allows to explore interactions based upon corporeal resonance and entrainment, which are spontaneous phenomena that can be observed in listeners and performers [23, 6].

6. CONCLUSION AND FUTURE WORK

Looking at music and gesture within the framework of embodied music cognition can radically influence the development of new expressive interaction tools. Gestures very often appear both as body movement schemes and mental representations, bridging body and mind [24]. Considering gesture as an active constituent of embodied musical meaning implies that its role in an interactive music performance goes

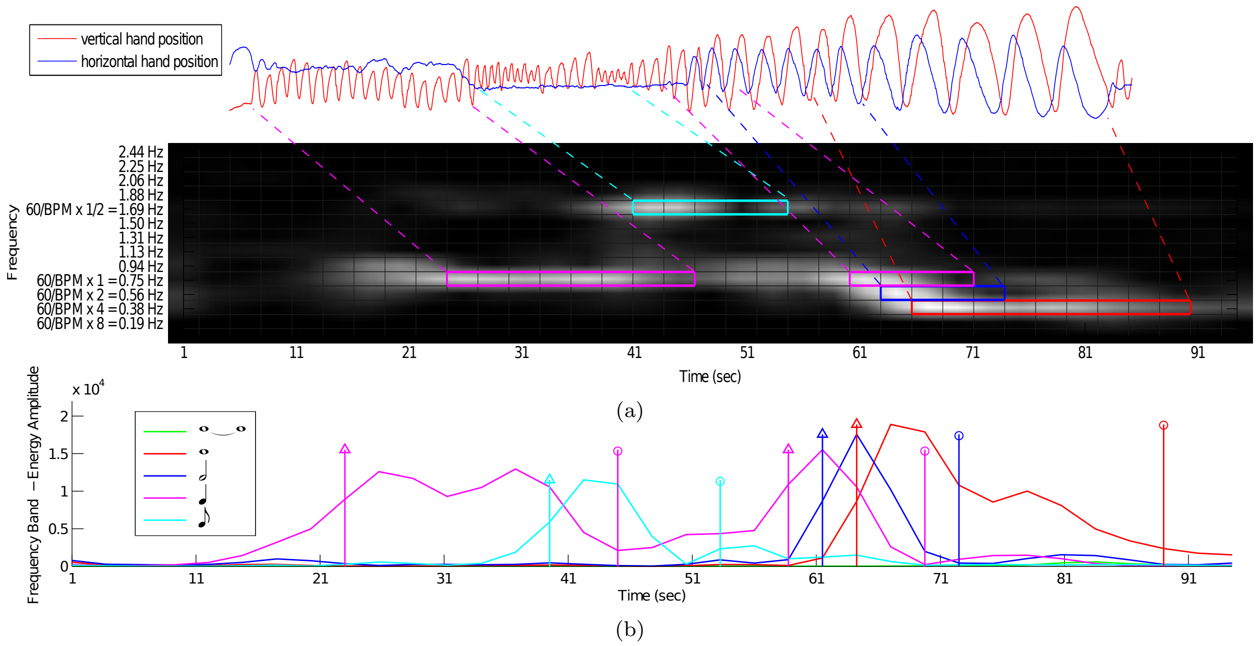

Figure 4: (a) The lighter regions show where the movement resonates more with the rhythm. The light blue, pink, dark blue, red and green bounding boxes indicate movements corresponding to rhythms made of quavers, crotchets, minims, semibreves, and breves respectively. (b) The plotted lines (light blue, pink, dark blue, red and green) show the QoM related to each frequency response. The vertical stems show the starting point (triangle) and the ending point (circle) of each periodic motion.

well beyond being a mere means of control of musical parameters. We have shown how this approach can inform different mapping strategies and technical solutions, first by considering the function of different gestures in a performance to electronically modify the sound of the instrument played using sensors and then by measuring the quantity of body motion of the performer in relation to musical rhythmic features. Working on different layers of gestural complexity not only allows for the development of more advanced systems but also reflects the multi-level nature of gesture within the mechanism of musical meaning formation. Gestures are in fact experienced as elements of a nested hierarchical structure [24] and taking this aspect into consideration can aid the design of expressive musical systems. Achieving the illusion of a total, fully conscious control is not the goal of this approach. Lahdeoja et al. [22] explored non-direct control using semi-conscious gestures showing how these can be used to control subtle aspects of the music performed. Our focus is also directed towards gestural aspects of music and aims nonetheless at exploring the tight relationship between music and body on both a conscious and sub-conscious level. Focusing on a traditional musical instrument allowed us to draw gestures from an existing, well-established gestural vocabulary. However, this does not mean that the approach cannot be extended to new digital instruments or employed to develop new interfaces. From this perspective, acoustic instruments are seen as rich repositories of gesture-sound couplings unmediated by mapping, which may be a useful resource to understand gestural aspects of music and at the same time to find new ways of musical expression. Future work will focus on other instruments and on ensemble playing across different musical styles, trying to combine well-established musical workflows with experimental approaches to implement more complex interactions between the music and the body of the musician. Embodied music cognition is the subject of an ongoing interdisciplinary research and new contributions to the understanding of important elements of its workings have been recently published [28, 29, 21]. Practice may lead to new intuitions, as it did in other contexts [36]. New cross-disciplinary approaches may in fact help to "move beyond designing technical systems" [38] and give rise to new engaging musical experiences that can both raise questions and provide new insights about musical expression and cognition.

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