INTENTION, EFFORT, AND RESTRAINT: THE EMG IN MUSICAL PERFORMANCE

Atau Tanaka, Department of Computing, Goldsmiths, University of London, London SE14 6NW, U.K.
Email: <a.tanaka@gold.ac.uk>.

Abstract

The author presents the challenges and opportunities in the use of the electromyogram (EMG), a signal representing muscle activity, for digital musical instrument applications. The author presents basic mapping paradigms and the place of the EMG in multimodal interaction and describes initial trials in machine learning. It is proposed that nonlinearities in musical instrument response cannot be modelled only by parameter interpolation and require strategies of extrapolation. The author introduces the concepts of intention, effort, and restraint as such strategies, to exploit, as well as confront limitations of, the use of muscle signals in musical performance.

Biosignals have found increasing application in musical performance [1]. The complexity of EMG data poses specific challenges and presents opportunities in live interactive performance applications. A single data stream can embody information about multiple parts of the body. A muscle group controls the movement of limbs below it: One signal from forearm muscles can contain information multiplexing the movement of five fingers. Muscle tension results from physical exertion, but free space gesture takes place in the absence of boundary objects on which force may be exerted. This creates a situation where the performer receives no tactile feedback.

Multimodality and Machine Learning

In order to exploit the unique nature of the EMG signal, and to accommodate its limitations, I used EMG in multimodal interaction with complementary sensing modalities [2,3]. To unwrap the rich, often multiplexed information contained in the EMG, I applied machine learning techniques to classify different gestures and to adapt to variations in their execution. I created an EMG gesture classifier using the K-Nearest Neighbors algorithm to distinguish in real time six different hand gestures using 2 channels of forearm EMG (Fig. 1) [4].

Currently, I am applying recent advances in machine learning to the EMG and other physiological signals. The use of Particle Filtering techniques allows continuous reporting of recognition probability against a training set and real time tracking of gestural variation against the reference template [5]. The temporal sensitivity, however, requires segmentation or some external signal indicating gesture onset.

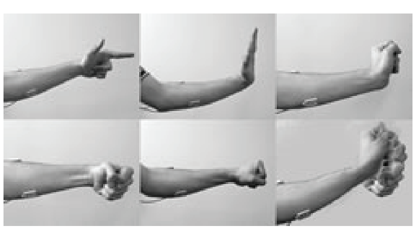

Fig. 1. Six proto-gestures for K-Nearest Neighbors classification. (© Atau Tanaka. Photo: Frank Baldé.)

Mappings Beyond Interpolation

EMG is well suited for the continuous control of sound synthesis parameters. Gesture-parameter mapping strategies, such as "one-to-many" mapping, or "many-to-one" [6], are highly relevant to EMG. Mapping strategies typically involve interpolation [7,8], to imitate the deterministic and linear aspects of instrument response. However, at extremes, acoustic systems become non-linear, for example as a flute goes into multiphonics, or a vibrating string at tensions close to its breaking point. These nonlinearities cannot be modeled by interpolation – indeed, we can think of them as asymptotic behavior outside of the boundaries within which interpolation operates. Could a visceral gesture input such as the EMG be applied in such a context of the parameter "extrapolation"?

In order to harness the richness of EMG signals for such potentially rich forms of musical interaction, I propose three modes of play: *intention, effort,* and *restraint,* as concepts to focus gestural music performance using muscle signals.

Intention

Biosignals can provide low latency information about gesture. The EMG is a neural command that causes muscle tension, resulting in limb movement. In this sense it is situated at the opposite end of movement production than a sensor, such as an accelerometer, that reports on physical artifacts resulting from gesture. A classical sensor, then, is at the "output" of a gesture while the EMG is a signal that is the "input" to a gesture.

I used two EMG channels on the anterior and interior forearm to capture directionality of wrist flexing plus basic recognition techniques to detect wrist rotation. In some ways this is similar to XY rotation reported by a 2D accelerometer. The EMG, however, does not report gross physical displacement, but the muscular exertion that may be performed to achieve movement. In this sense, the EMG does not capture movement nor position, but the corporeal action that may (but may not) result in movement. The EMG is not an external sensor reporting on the results of a gesture, but rather a sensor that reports on the performer's *intention* to make a gesture.

Musical intent is a notion connected to the contested notion of the performer. The primacy of the performer, however, can be problematic. Gritten evokes the notion of the "subject" to criticize research on musical gesture as placing the subject (performer) "ahead" of the performance in a chain of deterministic intent. The performer/performance dynamic is, according to Gritten, more complex. "While the subject certainly experiences performing, the subject is also performed" [9]. This problematizes the notion of sensor systems as deterministic musical controllers and highlights the need for feedback channels that recognize the musician not just as a source of musical intent, but also as a receiver of musical dynamic and context that may alter intent.

Effort

In order to resolve the subject-centric notion of intent, we can look at the performer as situated in the broader performance environment. Hatten, in his treatment of musical gesture, describes effort in relation to the environment:

> *We access the bodily in music through the implied effort required to overcome environmental forces . . . through an analogy with the effort of our own bodies to overcome physical forces . . . to achieve an intention* [10].

Laban Movement Analysis (LMA) theory addresses effort in the context of five components (*Body, Space, Effort, Shape, Relationship*). Effort is typically associated to the shape of a gesture, and the effort/shape combination is used to deduce iconic, emotional content of a gesture [11]. In musical instrument performance, effort is directed through the instrument itself as a physical boundary object. We blow harder into the flute. Callouses on the fingertip result from bending the guitar string. The gesture captured by the EMG, however, can happen in the absence of any boundary object. While muscle exertion

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is produced through bodily effort, where is this effort directed? (Fig. 2)

This situation is symptomatic of virtual reality systems where the lack of resistance in the virtual space can be more disorienting than the accuracy of the display system. In order to re-introduce a kind of resistance in sound and to create a kind of boundary "object" to gesture, we can introduce haptic feedback through the physicalization of sound output. Projecting audio of specific frequencies at amplitudes sufficient to create sympathetic resonance with non-cochlear parts of the body creates a haptic feedback loop through acoustical space of the effort engaged in musical gesture [12].

Restraint

While physicalized sound creates a form of environmental resistance, it does not directly offer a return force that a real boundary object would. Haptic feedback has been demonstrated to facilitate gestural control to, for example, prevent "overshoot" in a tilt sensor based scrolling system [13]. I extend this use of haptic feedback as display to aid the internalization of effort and the exercise of *restraint* in performance. On a traditional instrument, exertion restraint needs to be exercised in order to keep the performance within the physical bounds of the instrument. Restraint in the maximum effort needs to be exercised to avoid breaking the guitar string when bending it, or bottoming out or cracking the clarinet reed when blowing. At the opposite extreme, a minimum exertion needs to be performed in order to produce sound. On the EMG, strategies of restraint allow the execution of fluid movement with little muscle tension and the realization of high EMG levels efficiently without awkward exertion.

Restraint in communicative gesture is also tightly connected to culture. Kendon [14] retraces the evolution of gesture in human communication, noting that restrained gesture was once "considered a virtue." Today, restrained gesture is typically associated with inexpressive or unemotional articulation. As interactive music systems capture gesture to produce sound, rather than consider gesture as a gesticulation side channel to verbal communication, restraint (or lack thereof) goes beyond betraying effusiveness and becomes directly tied to the dynamic range of sound synthesis. In this way, our interest in intention, effort, and restraint is less cultural and semantic, and more directly tied to visceral aspects of interaction.

Conclusion and Extrapolations

Traditional sensor mapping and interpolation are able to model the linear amplitude / timbre response of an instrument within the bounds of its operational design. Near its breaking point, however, an acoustic instrument exhibits nonlinear response: It might require exponentially greater input energy to produce a modest increase in output. Inverse effects occur as in the violin producing a brighter timbre closer to the bridge, but with a fall off in amplitude output that needs to be compensated with greater force. Gestural input enters zones where minute changes in input force create a crossing-the-edge effect from desired tone to noise. A slight shift in an electric guitar player's posture might coax the amplifier into feedback; if the performer moves, control of the feedback may be lost. Plucking and bending a guitar string require simultaneous contact of the plectrum and the meat of the finger in order to generate expressive upper harmonics, at the verge of breaking the string.

This *intent* to push an instrument to its ultimate output dynamic, to keep it just within the bounds of breaking up, requires an *effort* beyond the pure physical resistance of an instrument as boundary object. This needs to be throttled, by *restraint*, in order to keep the instrument from breaking. I propose that through intent, effort and restraint, the performer gauges her relationship to the instrument and the expanded, extrapolated relationships between gesture and resulting sound.

In this paper, I have tried to show that this final zone of expression is well suited for articulation through the EMG. While the EMG may be an apt input signal, a correspondingly rich and nonlinear sound synthesis output technique needs to be found to fully take advantage of its potential. What is needed is a strategy for sound synthesis extrapolation, one where we can plot a physically impossible gestural or sonic point beyond the bounds of system operation (an infinity point), towards which we extrapolate, risking system breakdown.

Fig. 2. The author in performance at STEIM, 2007 [15]. (© Atau Tanaka. Photo: Frank Baldé.)

References and Notes

* Based on a presentation from the first International Conference on Live Interfaces (ICLI), 7–8 September 2012, hosted by the Interdisciplinary Centre for Scientific Research in Music at the University of Leeds, U.K. See <http://icli.lurk.org>.

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