EMMA: Enhancing Real-Time Musical Expression through Electromyographic Control

João Coimbra
jpcoimbra@ua.pt
Aveiro University/INET-md
Aveiro, Portugal
jpcoimbra@ua.pt

Luís Aly
ID+, ESMAD, Polytechnic of Porto
rua D.Sancho I, 4480-876, Vila do Conde, Portugal
luisaly@esmad.pt

Henrique Portovedo
Aveiro University/INET-md
Aveiro, Portugal
henriqueportovedo@ua.pt

Sara Carvalho
Aveiro University/INET-md
Aveiro, Portugal
scarvalho@ua.pt

Tiago Almeida Bolaños
Instituto Superior Técnico (IST)/
Instituto de Telecomunicações (IT)
Lisboa, Portugal
tiago.bolanos@lx.it.pt

Abstract

This paper presents the Electromyographic Music Avatar (EMMA), a digital musical instrument (DMI) designed to enhance real-time sound-based composition through gestural control. Developed as part of a doctoral research project, EMMA combines electromyography (EMG) and motion sensors to capture nuanced finger, hand, and arm movements, treating each finger as an independent instrument. This approach bridges embodied performance with computational sound generation, enabling expressive and intuitive interaction. The system features a glove-based design with EMG sensors for each finger and motion detection for the wrist and arm, allowing seamless control of musical parameters. By addressing key challenges in DMI design, such as action-sound immediacy and performer-instrument dynamics, EMMA contributes to developing expressive and adaptable tools for contemporary music-making.

CCS Concepts

• **Applied computing** → **Sound and music computing**; Performing arts; • **Information systems** → *Music retrieval.*

Keywords

Gestural interface, physiological signals, Digital Musical Instrument, Human-Computer Interaction, Composition, Performance.

1 Introduction

EMMA builds upon a rich tradition of research within the New Interfaces for Musical Expression (NIME) community, which has extensively explored the use of electromyography (EMG) in embodied musical interaction [27, 32]. EMMA is deeply influenced by the artistic practice of its first author. As a pianist, finger mapping is central to performance, but EMMA expands traditional pianistic control, allowing each finger to convey unique musical ideas that align with its anatomical characteristics [26].

EMMA aims to leverage the hand as an expressive musical control interface that focuses on precise finger mapping, real-time responsiveness, and nuanced translation of muscular activity into sound generation and spatialization of sound.

NIME '25, June 24–27, 2025, Canberra, Australia

2 Related Work

Since the 1980s, EMG has been used in the musical realm (for a comprehensive review please refer to [1]) with examples such as *BioMuse* [20] [31] and *Body Synth* [32]. More recently, custom interfaces such as Xth Sense [11], MuMYO [25], MicroMyo [17], *EAVI* EMG Board [10] and RAW [13] extend the exploration of EMGs as an expressive musical controller. Among them, RAW, MicroMyo, and MuMYO recur to the commercial wearable Myo Armband [24], which detects hand-muscle and forearm muscle activity. For the purposes of the present study, projects such as Waisvisz's *The Hands*[33], Laetitia Sonami's *Lady's Glove* [5, 14, 30] and the Mi.Mu gloves [22] intensively explored the hand as a gestural controller leveraging its dexterity, expressive potential, and rich biomechanical complexity to create nuanced, dynamic interactions between movement and sound.

3 Methods and Materials

EMMA consists of two main components: a gestural controller and a sound generation unit. The gestural controller is a fingerless glove combined with an elastic wristband, integrating five EMG sensors (see Section 3.5), an Inertial Measurement Unit (IMU) for motion tracking, and a wireless communication module. This preliminary design serves as a test bed for identifying optimal anchor points for EMG sensors. The sound generation unit processes the EMG data in real time and maps data to sound.

3.1 Electromyographic Sensors

Electromyography quantifies the electrical signals produced by muscles during contractions [8]. It is utilized in various fields, including medical research, sports science, and human-machine interfaces. To obtain an EMG signal, two electrodes are placed along the muscle to measure their potential differences. The EMG signal results from the superimposed polarization waves generated by different muscle fibers and is characterized by a stable and relatively noise-free period when the muscle is in a relaxed state [18].

Pregelled disposable surface electrodes are the most widely used option for interfacing with muscles due to their affordability and ease of handling. These electrodes have a diameter of ≤ 1 cm and be positioned 2 cm apart (center to center). Proper placement, aligned with the orientation of the muscle fibers and centrally situated over the muscle belly, is essential, especially considering the potential muscle movement beneath the electrodes during the analyzed motion [18]. EMMA uses the Bitalino SnapBIT-DUO;

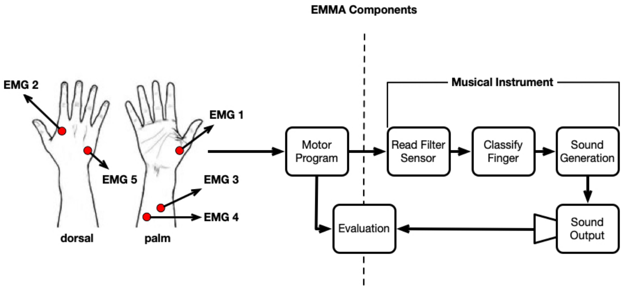

Figure 1: The diagram of the Electromyographic Music Avatar (EMMA) system illustrates the integration of electromyography (EMG) sensors and the signal processing flow. On the left side, the image presents both dorsal and palmar views of a hand, featuring five EMG sensor placements (EMG 1–5) that capture muscle activity from various regions of the hand and forearm. The right side details the functional components of EMMA, beginning with the performer's motor program, which generates movements detected by the sensors. The subsequent signal undergoes processing through filtering, finger classification, and sound generation, resulting in the final sound output. A feedback loop is incorporated through an evaluation stage, enhancing the interaction between the performer and the instrument while refining the expressive control of musical parameters.

however, the standard electrode size presented challenges in identifying optimal anchor points in the hand where spatial constraints and anatomical variations necessitated greater precision (see subsection 3.5).

Figures 2 and 3 depict custom terminals that aim to eliminate plastic casings and minimize the spacing between electrode snaps. Furthermore, the EMG sensor was decoupled from the terminal, contrasting with the integrated design of the Bitalino SnapBIT-Duo. This modification reduces the terminal's weight and enhances flexibility and adaptability during testing, allowing for more precise electrode placement.

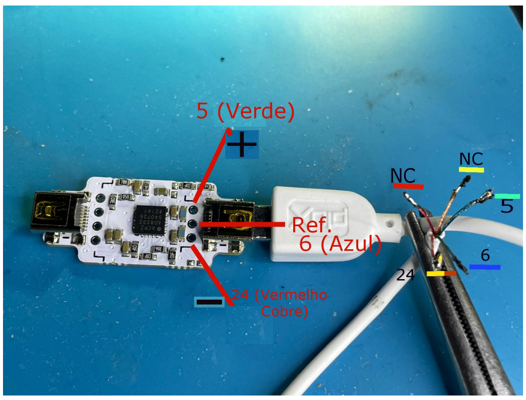

Figure 2: Bitalino EMG sensor with a UC-E6 connector and labeled wiring connections. The annotations indicate the signal channels, including reference (blue), ground (red/copper), and active signals (green). The UC-E6 connector is partially stripped to expose the internal wiring for manual soldering.

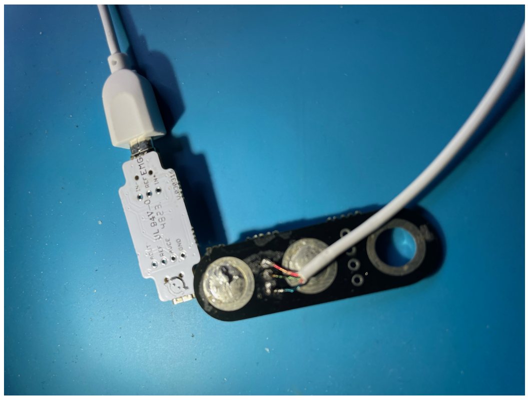

Figure 3: Custom-modified EMG sensor setup featuring a compact electrode terminal. The stripped cable is soldered directly to the electrode terminals. An UC-E6 connector, with an identical cable, links the sensor to the board.

3.2 Platform

EMMA incorporates the BITalino CORE platform [7] providing real-time data streaming capabilities along with an integrated 3.7V Li-Po battery charger. The BITalino CORE allows for a maximum selectable sampling rate of 1000 Hz. It features six analog ports (comprising four 10-bit and two 6-bit ports) and four digital ports (including two 1-bit inputs and two 1-bit outputs).

EMMA integrates an Real-time Internet of Things (R-IoT) module directly onto the BITalino enabling wireless sensor digitization. This arrangement ensures reliable performance through a dedicated data transmission router. The R-IoT features a 9-axis digital IMU sensor, which includes a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer allowing on-board computation of the module's orientation in space.

3.3 Implementation

The EMG data is transmitted using custom software developed in Max/MSP [28]. Communication between the hardware and software is facilitated by the BITalino Max object [15], which employs the Open Sound Control protocol [34] to establish a connection between the board and the software. Data is subsequently mapped to sound algorithms fostering sound spatialization through IMU sensing. Data processing and storage were conducted on a MacBook Air equipped with an M3 processor and 16GB of RAM.

The implementation of the EMMA prototype encompasses four stages: **Sensor customization**: Focuses on designing and configuring EMG sensors to effectively capture and transmit data. **Sensor anchorage**: Involves identifying optimal anchorage points on the hand and forearm for sensor positioning. **Signal processing**: Aims to develop effective methodologies for interpreting and transforming incoming sensor data into meaningful control parameters. **Sound mapping**: Involves applying sound synthesis techniques specifically tailored for gestural control in real-time performance environments.

3.4 Sensor customization

Small terminals were designed for the thumb, index, and little finger, while standard-sized terminals accommodate the middle and ring fingers accounting for the deeper muscle configuration in the forearm requiring more spacing between snaps as depicted in Figure 4.

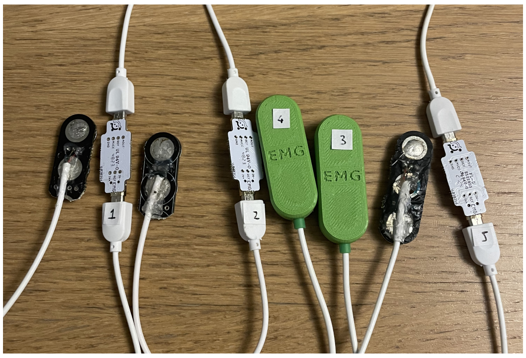

Figure 4: EMMA uses five EMG sensors with UC-E6 connectors linking terminals to sensors. Terminals 1, 2, and 5 on the hand are sized for specific anchoring, while standard Bitalino sensors were used on the forearm.

To assess conductivity, the polymer and the hydrogel layer were removed from the surface of the electrodes. Additional tests were conducted without the electrodes, relying solely on the direct conductivity of the snaps. In-house testing confirmed that snaps alone provided adequate conductivity, which streamlined the design and enhanced sustainability by eliminating the need for frequent electrode replacements due to erosion.

3.5 Sensor Anchorage

In the initial phase, optimal anchor points were identified namely, on the hand and forearm. These anatomical regions are complex, characterized by the close interaction of various muscles, tendons, and tissues, which often leads to signal crosstalk and complicates signal isolation [3, 19, 29]. Through extensive trials, five key points were discerned within the intrinsic muscles of the hand (entirely contained within the hand) and the extrinsic muscles (located in the wrist and forearm) [2, 16].

3.5.1 ***Intrinsic Muscles Anchorage.*** In the intrinsic muscles three anchorage points were identified: (i) *Thenar* Muscles: Located in the palm of the hand, just below the thumb, these muscles form the thenar eminence (the fleshy mound at the base of the thumb). *Thenar* muscles are primarily responsible for the movements of the thumb, including opposition, flexion, and abduction. (ii) *Dorsal Interossei*: Found between the metacarpal bones of the hand, these muscles facilitate the movement of the fingers. Specifically, the index sensor is anchored on the left side of the index finger. And, (iii) *Hypothenar* Muscles: Situated on the ulnar side of the palm. *Hypothenar* muscles create the hypothenar eminence responsible for movements, such as flexion, abduction, and opposition of the little finger.

3.5.2 ***Extrinsic Muscles Anchorage.*** In the case of the extrinsic muscles, two anchorage points were identified for the middle and ring fingers within the *Flexor Digitorum Superficialis* (FDS) muscle. The FDS muscle allows for independent EMG activation in adjacent regions. This anatomical feature supports the differential activation of individual finger compartments, highlighting the specialized function of motor units in fine finger control [21], which is particularly beneficial for tasks requiring precise proximal interphalangeal flexion, such as playing musical instruments [4].

3.6 Fingerless glove

Figure 5 shows terminals anchored with a medical-grade band for stability. A modular fingerless glove enhances support with a wrist strap and fabric extensions securing the thumb, index, and little finger. These ensure stable sensor placement, prevent adjacent triggering, and allow individual adjustments. A wristband holding the circuit board reinforces sensors on the middle and ring fingers, maintaining consistent skin contact while preserving flexibility in finger movement.

Figure 5: EMMA's interface consists of 5 EMG sensors, a modular fingerless glove and a wristband housing the acquisition board. These components serve as mechanical reinforcements for the terminal sensors at the skin surface.

3.7 Signal Processing

EMMA processes signals in real-time, converting sensor data into audio within milliseconds. This allows the use of standard musical signal processing techniques, including gates, filters, and compressors (Figure 6). Transforming EMG signals into audio enables intuitive system calibration with familiar audio processing tools.

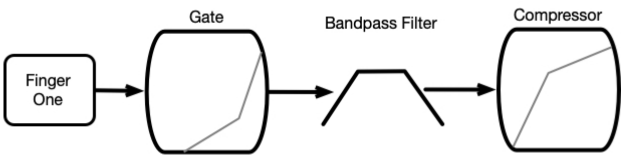

Figure 6: A noise gate filter was utilized to suppress unwanted signals that fall below a specified amplitude threshold, effectively reducing electrical interference and minimizing unintended triggers. The processed signal subsequently passed through a Butterworth bandpass filter (20 Hz–150 Hz), optimizing frequency capture for the selected anchoring points. This filter could be finely adjusted for each input like the noise gate. The signal processing chain concluded with an audio compressor to prevent clipping.

In [9], the authors highlight that effective EMG decomposition requires noise power to be no greater than half of the signal power. Each finger is independently processed through four stages: waveform visualization, noise gating, Butterworth bandpass filtering, and compression. These components can be fine-tuned, calibrated in real-time, and saved for future use.

The noise gate sets high and low thresholds to distinguish EMG spikes from noise, with attack and release times adjusted per finger. A 4th-order Butterworth bandpass filter isolates key frequency ranges, typically 50-150 Hz [32], optimizing distinction between fingers (in our tests, 20-85 Hz for the thumb, 20-110 Hz for the middle finger). Finally, a compressor reduces amplitude ranges for the five signals, improving overall signal amplitude distinction for intrinsic and extrinsic muscle activity.

Each finger is individually calibrated for two hand poses: *pianistic* and *aerial* fingering. The pianistic pose aligns with hand positioning on a horizontal surface, compensating for key press damping. The aerial pose functions without physical contact, triggering audio output when finger movements exceed specific angular thresholds.

Calibration provides two types of gestural control: **Discrete Myoelectric Control**, which treats the entirety of a dynamic gesture as a single input, resulting in one output [12]. In contrast, **Continuous Myoelectric Control** interprets the full progression of a dynamic gesture (for example, the force exerted between opposing fingers) in a manner similar to that of a sustain or expression pedal.

This process generates five distinct signal outputs that are subsequently sonified. While sound mapping is not yet fully implemented, the current emphasis is on system calibration. To achieve this, EMMA utilizes a straightforward one-to-one audio sample mapping (click for video) examining both aerial and pianistic fingering techniques. Furthermore, the IMU unit provides continuous control and sound manipulation. This methodology allows us to investigate and enhance EMMA's multimodal capabilities.

4 Conclusions

Gloves interfere with tactile and proprioceptive feedback, affecting natural movement. A fingerless design maintains the full range of motion and sensory response needed for fine motor control unlocking the hand's expressive potential. EMMA is envisioned both as a timbre enhancer for instruments like the piano and as a standalone timbre generator.

Advancements have been achieved by replacing hydrogel electrodes with custom sensors and optimizing their placement on both extrinsic and intrinsic muscles, focusing on simplicity, signal integrity, and real-time processing. Hand poses, including pianistic and aerial fingering, broaden the expressive range and accommodate a variety of performance contexts.

5 Future Work

Future work will investigate the integration of machine learning for a broad range gesture-based musical instructions. The implementation of machine learning, idiomatic notation of gestures [6, 23] has the potential to enhance artistic possibilities and encourage a wide adoption of EMMA. In addition, further studies will focus on improving the ergonomics of the fingerless glove and wristband, as well as extending the system to the left hand to facilitate complete bilateral finger mapping. A comprehensive sound mapping system will combine granular and frequency modulation synthesis, real-time sound spatialization, and multimodal interaction.

6 Ethics Statement

This research did not involve human participants or animals; all directly involved individuals were members of the research team. All software and tools used in the study were used in accordance with the terms of their respective licenses. The methodologies and processes adhered strictly to ethical guidelines for intellectual property and data management, ensuring transparency, integrity, and reproducibility throughout all phases of the research. This research is supported by Fundação para a Ciência e Tecnologia, I.P (FCT), grant 2022.11160.BD.

References

[1] Luís Aly, Hugo Silva, Gilberto Bernades, and Rui Penha. 2021. Appropriating biosensors as embodied control structures in interactive music systems. *Human Technology* 17, 1 (2021).

[2] R Barański and A Kozupa. 2014. Hand grip-EMG muscle response. *Acta Physica Polonica A* 125, 4A (2014).

[3] Nicolai A Bernstein. 1967. The co-ordination and regulation of movements.

[4] TJ Butler, SL Kilbreath, RB Gorman, and SC Gandevia. 2005. Selective recruitment of single motor units in human flexor digitorum superficialis muscle during flexion of individual fingers. *The Journal of physiology* 567, 1 (2005), 301–309.

[5] Joel Chadabe. [n. d.]. Electric sound: the past and promise of electronic music. *(No Title)* ([n. d.]), 229–230.

[6] João Coimbra, Henrique Portovedo, and Sara Carvalho. 2024. FROM SONIC GESTURE TO COMPOSITION: MAPPING THE PATH FOR THE PHYSICAL COMPUTING INSTRUMENT. *TENOR* (2024), 73.

[7] Hugo Plácido Da Silva, José Guerreiro, André Lourenço, Ana Fred, and Raúl Martins. 2014. BITalino: A novel hardware framework for physiological computing. In *International Conference on Physiological Computing Systems*, Vol. 2. SciTePress, 246–253.

[8] Carlo J De Luca and Egbert J Van Dyk. 1975. Derivation of some parameters of myoelectric signals recorded during sustained constant force isometric contractions. *Biophysical journal* 15, 12 (1975), 1167–1180.

[9] A Del Vecchio, A Holobar, D Falla, F Felici, RM Enoka, and D Farina. 2020. Tutorial: Analysis of motor unit discharge characteristics from high-density surface EMG signals. *Journal of Electromyography and Kinesiology* 53 (2020), 102426.

[10] Balandino Di Donato, Atau Tanaka, Michael Zbyszynski, and Martin Klang. 2019. EAVI EMG board. (2019).

[11] Marco Donnarumma, Baptiste Caramiaux, and Atau Tanaka. 2013. Muscular Interactions Combining EMG and MMG sensing for musical practice. (2013).

[12] Ethan Eddy, Erik J Scheme, and Scott Bateman. 2023. A framework and call to action for the future development of EMG-based input in HCI. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems.* 1–23.

[13] Çağrı Erdem and Alexander Refsum Jensenius. 2020. RAW: Exploring control structures for muscle-based interaction in collective improvisation. In *Proceedings of the International Conference on New Interfaces for Musical Expression.* 477–482.

[14] Rebecca Fiebrink and Laetitia Sonami. 2020. Reflections on eight years of instrument creation with machine learning. *Proceedings of the International Conference on New Interfaces for Musical Expression* (2020).

[15] github. 2024. thalmiclabs. https://github.com/thalmiclabs

[16] Xuhui Hu, Aiguo Song, Jianzhi Wang, Hong Zeng, and Wentao Wei. 2022. Finger movement recognition via high-density electromyography of intrinsic and extrinsic hand muscles. *Scientific Data* 9, 1 (2022), 373.

[17] Alexander Refsum Jensenius, Victor Evaristo Gonzalez Sanchez, Agata Zelechowska, and Kari Anne Vadstensvik Bjerkestrand. 2017. Exploring the Myo controller for sonic microinteraction. In *Proceedings of the International Conference on New Interfaces for Musical Expression.* Aalborg University Copenhagen, 442–445.

[18] Peter Konrad. 2005. The abc of emg. *A practical introduction to kinesiological electromyography* 1, 2005 (2005), 30–5.

[19] Mark L Latash. 2015. The hand: Shall we ever understand how it works? *Motor control* 19, 2 (2015), 108–126.

[20] Hugh S Lusted and R Benjamin Knapp. 1988. Biomuse: Musical performance generated by human bioelectric signals. *The Journal of the Acoustical Society of America* 84, S1 (1988), S179–S179.

[21] Tara L McIsaac and Andrew J Fuglevand. 2007. Motor-unit synchrony within and across compartments of the human flexor digitorum superficialis. *Journal of neurophysiology* 97, 1 (2007), 550–556.

[22] Thomas Mitchell and Imogen Heap. 2011. Soundgrasp: A gestural interface for the performance of live music. In *Proceedings of the International Conference on New Interfaces for Musical Expression.* 465–468.

[23] Solomiya Moroz. 2020. EXTENDING NOTATION THROUGH EMBODIED RESEARCH. (2020).

[24] Rachel Nuwer. 2013. Armband adds a twitch to gesture control.

[25] Kristian Nymoen, Mari Romarheim Haugen, and Alexander Refsum Jensenius. 2015. Mumyo–evaluating and exploring the myo armband for musical interaction. (2015).

[26] William Ogle et al. 1882. *Aristotle: on the parts of animals.* Kegan Paul, French & Company.
[27] Miguel A Ortiz, Niall Coghlan, Javier Jaimovich, and R Benjamin Knapp. 2011. Biosignal-driven art: beyond biofeedback. (2011).
[28] M. PUCKETTE. 1988. The Patcher. *Proceedings of the 1988 International Computer Music Conference. San Francisco* (1988). https://cir.nii.ac.jp/crid/1573668925314493056
[29] Richard A Schmidt, Timothy D Lee, Carolee Winstein, Gabriele Wulf, and Howard N Zelaznik. 2018. *Motor control and learning: A behavioral emphasis.* Human kinetics.
[30] Laetitia Sonami. 2006. On my work. (2006).
[31] Atau Tanaka. 2009. *Sensor-based musical instruments and interactive music.* na.
[32] Atau Tanaka and Miguel Ortiz. 2017. Gestural musical performance with physiological sensors, focusing on the electromyogram. In *The Routledge companion to embodied music interaction.* Routledge, 420–428.
[33] Michel Waisvisz. 1985. The hands: A set of remote midi controllers. In *Proceedings of the International Computer Music Conference: International Computer Music Association, 1985.*
[34] Matthew Wright, Adrian Freed, et al. 1997. Open SoundControl: A new protocol for communicating with sound synthesizers. In *ICMC.*