# KONTRAKTION

## Sonification of Metagestures with electromyographic Signals

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## ABSTRACT

'Kontraktion' is an embodied musical interface using biosignals to create an immersive sonic performance setup. It explores the energetic coupling between digital synthesis and musical expression by reducing the interface to an embodied instrument and therefore tightening the connection between intention and sound.

By using the setup as a biofeedback system the user explores his own subconscious gestures with a heightened sensitivity. Even subtle, usually unaware neural impulses are brought to conscious awareness by sensing muscle contractions with an armband and projecting them outward into space with sound in realtime. The users gestural expressions are embodied in sound and allow for an expressive energetic coupling between the users body and a virtual agent.

Utilizing the newly adopted awareness of his body the user can take control of the sound and perform with it using the metagestures of his body as an embodied interface. The body itself is transformed into a musical instrument, controlled by neurological impulses and sonified by a virtual interpreter.

**Keywords:**
biofeedback, emg, embodiment, gesture, musical interface, surround sound, sonification

## 1. INTRODUCTION

With todays advanced sensor technologies [1, 2] unprecedented opportunities to pick up on very subtle gestures and energetic traces are opening up, which generally go unnoticed by basic human perception. These gestures can be processed and used to trace our mood, behavior and bodily mechanics. Being able to perceive this abstract information in real time gives us the ability to learn more about our own bodies and minds. This can enhance everyday interactions and expand our perception on the world around and within us.

Exploring these subtle expressions provides us with an intimate and finely grained interface beyond observable movement and therefore gives us more detailed controls for human machine interactions.


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## 2. RELATED WORK

The first gesture based musical interfaces appeared almost a century ago with the creation of the Theremin by Lew Sergejewitsch Termen [3] and the Ondes Martenot by Maurice Martenot [4]. The Theremin allows the user to play notes touch-free in midair by sensing the distance of the musicians hands through changes in an electromagnetic field created by an antenna. These interfaces were the first ones enabling gestural control of musical parameters.

First experiments with biosignals in musical practice came from Alvin Lucier in his piece „Music for Solo Performers" in 1965 [5]. Lucier amplified his brainwaves to control a range of percussive instruments. About a quarter century later Atau Tanaka pioneered in exploring EMG (Electromyography) biosignals for musical performances and laid the ground work for academic research in this field [6, 7]. His work „BioMuse" from 1992 was one of the first to use muscle-sensing for a musical application. Research in brain-computer music is still ongoing has produced interesting publications in recent years [8, 9].

Another form of musical biosignal interaction is used by Marco Donnarumma in his work "Music for Flesh" from 2011. Instead of EMG muscle sensing he uses his self built device called the "Xth Sense" [10]. The principle underpinning the "Xth Sense" is not to interface the human body to an interactive system, but rather to approach the human body as an actual and complete instrument in itself. During a performance muscle movements and blood flow produce subcutaneous mechanical oscillations (Mechanomyographic (MMG)). Two microphone sensors capture the sonic matter created by the performer's limbs and send it to a computer for further processing.

By using EMG signals as the driving force behind the sonification process, the above notions of using the body as an instrument by connecting body and sound intimately resonates strongly with the embodied sonification concept of the Kontraktion performance.

## 3. BACKGROUND

### 3.1 Interfacing with Digital Music Instruments

When interfacing with digital music instruments in general we can differentiate between consumer grade products and idiosyncratic interfaces. Overall we are looking for ways to make digital music instruments as explorable, learnable and expressive as their analog counterparts. To achieve an intimate connection with a digital music instrument multimodal controls and forms of gesture recognition that allow for the same degree of freedom and expressivity as a classical music instrument are required.

Most off-the-shelf musical controllers are not designed for multimodal interaction and consist manly of linear control units, such as knobs, faders and buttons. These discrete forms of input are great for the precise control needed in studio environment. For example: adjusting the parameters of a filter in a mix. But when interfacing with digital music instruments not all parameters benefit from this discrete control. Interfacing with instruments this way generally lacks expressivity, explorability and learnability for the user.

One could argue that multiple low-dimensional input units can be summarized into one high-dimensional controller but this is not quite the case, since every control unit requires a discrete input and therefore doesn't really capture the multimodal and finely grained input required to ensure an 'intimate' connection with a virtual agent such as a musical instrument.

The DIY (Do It Yourself), maker and hacking scene has been tinkering with experimental interfaces for years. The availability of fast, reliable and highly diverse types of sensors and rapid prototyping platforms, like the Arduino, enable us to create our own idiosyncratic interfaces and experiment with new ways of interaction. Devices like the Microsoft Kinect enable capturing information optically beyond the two dimensional plane we used to be limited by when using digital cameras. This enables us to capture the depth of an image and gives us information on the proximity of objects. We can tell if objects are near or far away from the camera. The Kinect also allows us to track the human body with a skeleton-wireframe, which makes the tracking and mapping of the hands and gesture recognition possible. Similar depth-sensing technology is used by the Leap Motion[1] (Lyra VR) virtual reality interface and makes it possible to track the individual fingers (skeleton) of the users hands with a higher reliability. Although these interfaces enable wireless interactions, they bind the user to a certain area of effect. All gestures have to take place in front of these sensors and don't allow for the degree in freedom of movement that a musical interface truly requires for a performative setup.

Just now tendencies toward consumer grade embedded multimodal musical interfaces can be observed with promising features, such as the Seaboard by Roli[2] which uses a squishy, touch sensitive fabric for its keyboard layout. This has the added bonus, that it gives the user haptic feedback by smart material choice and allows for multimodal input without leaving the well established layout of a piano in a music production workspace.

The concept of multimodal interaction has been explored with diverse forms of input [11] and resulted in a pilot study on the relevance of biosignals when it comes to analyzing and understanding musical gestures in general. This is a first step to create a gesture vocabulary and establish a taxonomy for multimodal input.

The theory of sonic embodiment, especially when it comes to interaction design is vital. By engaging in tasks through subjective exploration we articulate every nuance of an activity that is necessary for a successful performance [12] and therefore gain greater understanding on the modalities involved in the task at hand.

### 3.2 A View on Classical Music Instruments

When watching a musician on stage the energetic coupling between the instrument and the performer becomes quite obvious: Every gesture of the artist not only modulates the sound of the instrument but also enhances the visual aspect of the performance and illuminates the close relationship between musician, gesture and sound towards the audience. On stage presence and bodily movement play a significant role in the emotional response of the audience when compared to an automated setup [13]. Most musical control interfaces are not designed with this aspect in mind and make it hard for the audience to comprehend what the musician is doing when pressing buttons and twisting knobs on stage. This abstraction not only takes place between the gestures of the artist and the controller but is further obscured by the intransparent connection between the interface, the software parameters and the resulting sound.

*Our observations are consistent with the idea that music performance evokes an emotional response through a form of empathy that is based, at least in part, on the perception of movement and on violations of pulse-based temporal expectancies.*

*–Chapin, H., Jantzen, K., Kelso, J. S., Steinberg, F., & Large, E. (2010)*

Most performative aspects of classical music instruments are due to the physical and physiological aspects found in their form factor [14]. Every part of a violin f.e. combines many sound shaping aspects that can be directly manipulated by the musician: Observing the finger movement of a violinist playing vibrato gives an idea of this sort of interaction and gives a feel for the finely grained coupling we are looking for when interfacing with digital music instruments.

### 3.3 Biofeedback and Medical Application

Biofeedback is a process that provides the user with information about their own physiological functions and therefore enhances the perception towards their own body and its inherent mechanics. The process creates a closed feedback system in which the participant acts as an agent that receives information on their own body and subsequently reacts to these impressions.

By using todays available sensor technology subconscious information on the body can be extracted and fed back to the user by abstracting it through visualization, sonification or haptic sensations [15]. This

[1] https://www.youtube.com/watch?v=wUGMUWDJjn0

[2] https://www.youtube.com/watch?v=8n-bEy9ISpM

enhanced awareness towards the own body by the process of biofeedback enables us to find meta-gestures hidden below the threshold of regular perception and enables us to use this information for a more expressive and multimodal control interface for digital music instruments. This concept allows for the intimate energetic coupling observable when playing classical music instruments (see 3.2) and enables us to transfer it to any digital music instrument or other virtual agent.

It has been shown that EMG biofeedback is useful in both musculoskeletal and neurological rehabilitation practice and was more effective for reestablishing stance stability in hemiplegic patients then conventional physical therapy practice [16, 17]. The use of EEG brain imaging for biofeedback training on children with ADD (Attention Deficit Disorder) also suggested a significant improvement in intellectual functioning and attentive behavior [18]. Using the 'Kontraktion' setup in a clinical environment could help patients with musculoskeletal or neurological handicaps by improving motor skills in rehabilitation scenarios. The added benefit is a system with flexible sonification methods, providing each patient with a uniquely adapted setup. The system can be adjusted to suite the patients specific training needs and provides an aesthetically pleasing and playful sonic environment beyond the clinical, monotonous sounds of regular biofeedback setups.

## 4. TECHNICAL SETUP

The 'Kontraktion' system provides a setup including hardware and software components to analyze and sonify muscle contractions. Data is gathered through an EMG-sensing armband and is processed through the DSP (Digital Signal Processing) environment Max/MSP. After the sonification of the data the audio streams are prepared for a stereo or surround setup and played back to the user. Recording the data makes it possible to review a performance and export a multimodal score.

### 4.1 The Myo Armband

EMG muscle sensing is not a new technique in the field of musical interaction [19, 6, 7] and has been around for decades. Past setups required costly clinical or self made hardware components.

'Kontraktion' uses the Myo armband for data acquisition: Eight EMG sensors help gather information about muscle contractions of the arm in real time and a built in inertial measurement unit (IMU) provides information about the spatial orientation of the arm relative to the body or the absolute position in space by interpolating magnetometer data. The sensor data from the armband gets transmitted via Bluetooth 4.0 LE to a USB Bluetooth adapter and is ready for further processing on the computer (see 3.2).

According to the manufacturer the optimal position of the armband is the thickest part of the forearm just below the elbow. We believe this is recommended because at this position all the muscles of the forearm (Brachioradialis, Flexors and Extensors) are close to the surface and make it easier for the EMG sensors to pick up on the electric potential generated by muscle cells during contraction.

Since the movement of the fingers is also controlled by these muscle groups, analyzing the data of the eight EMG sensors makes it possible to determine the position of the fingers and therefore make estimations about the hands gestures through machine learning (see 4.4). The provided 'Myo Connect' software and the open source SDK (Software Development Kit) come with a predefined gesture recognition algorithm capable of distinguishing between five unique hand gestures[3].

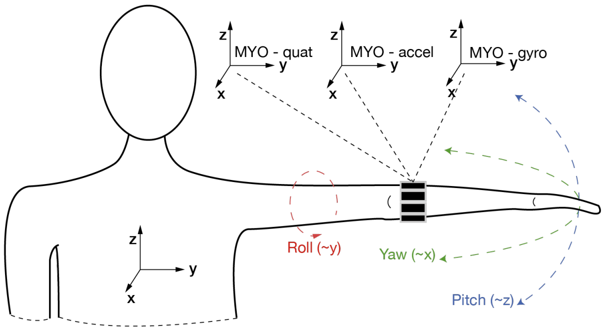


**Figure 3**. Illustration of the wearing position of the Myo armband and available spatial information.

The Myo performed well in an independent evaluation study done by the University of Oslo when compared to state of the art motion capture and medical grade EMG sensing systems [20]. This validates the precision of both the IMU and EMG sensors in the Myo and gives an idea of the potential the armband has for interactive musical applications.

Evaluations of the Myo for clinical use are ongoing at the Johns Hopkins University at the Applied Physics Laboratory (APL) and already provide promising results for controlling prosthetic limbs (MPL)[4]. Touch-free control of medical imaging systems with the Myo are on trail at the medical firm TedCas[5] and show transformative capabilities in the way surgeons work today.

### 4.2 Data Processing

To transfer the data of the Myo into our workspace in Max/MSP many different approaches and format protocols where tested. The highest flexibility and stability was provided by the Myo-OSC wrapper originally committed by Samy Kamkar [21]. Through the Myo-OSC wrapper the data is prepared in an OSC (Open Sound Control[6]) format and can easily be received and routed in Max/MSP by the UDP (User Datagram Protocol) network protocol. The original Myo-OSC code was slightly modified to automatically send EMG data and to stop vibrating on every "successful" gesture recognition, since the fail rate of the algorithm is obviously quite high when using the Myo in a performative and expressive way, because a performer

[3] https://www.myo.com/techspecs
[4] https://www.youtube.com/watch?v=LSuzMxQDmzg
[5] https://www.youtube.com/watch?v=ngcVtQQ4V2Q
[6] http://opensoundcontrol.org/introduction-osc

doesn't want to pay attention to the predefined gestures most of the time.

Once the data is transferred to Max/MSP it can bes prepared for sonification, machine learning or mapping. To make the data comfortable to work with it is good practice to scale the data uniformly to a range between 0 and 1 and handle them as floating point numbers. To do this the setup contains an automatic scaling abstraction, capable of determining the minimum [through] and maximum [peak] values within the desired movement range [scale]. Alternatively these values can be calibrated manually if needed. This process makes it easy to set up the system and makes it adaptable for different tasks and different users. For some scenarios it makes sense to further smooth the data with a linear function, such as the [line] object. Averaging the data for a defined frame length with the [zl.stream] object can also help smoothing the data stream over time.

To reduce jitter in the fast, high precision dataset it is advised to apply some low pass filtering available in the setup. By adjusting the frequency of this filter the overall sensitivity of the system can be manipulated according to the preferences of the user and the setup requirements. This process is by design not automated and remains the only parameter that is highly subjective to the user next to the scaling, which can be done automatically (see above).

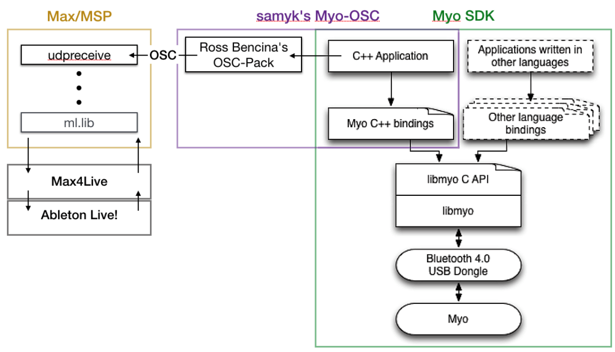


**Figure 4**. Flowchart illustrating the software stack of the system from the Myo to Max/MSP (or M4L).

### 4.3 Data Sonification

After trying different synthesis methods like frequency modulation (FM) and granular-resampling synthesis it became clear that physical modeling (PM) brings the system closest to an explorable and trainable instrument with comprehensive mechanics and a 'realistic' feeling. This is no real surprise since the goal was to achieve a sonification method that reflects similar parameters to a classical music instrument. The correlation between movement, sound and muscle contractions became most apparent with the use of this synthesis method. Different playing surfaces and resonant bodies from beams, strings, membranes, plates, tubes and pipes can be used and shape the fundamental characteristics of the sound. Each resonator allows the manipulation of multiple parameters, such as the geometry of the body and the characteristics of the material. Different resonant models can be configured in series or parallel to emulate realistic models, such as a xylophone, or create configurations beyond physical constraints.

In the default setup the EMG sensor values excite resonant filters and inherent delay lines of the PM-synthesis engine. Flexing the muscles starts the synthesis process by triggering an impact on the resonant bodies. This creates a transient sound in the default arm position (arm relaxed). By mapping the spatial information data to synthesis parameters, such as decay and pitch, the sound can be morphed up to a degree that resembles a tonal drone sound with sustain.

Manipulating the physical characteristics and geometry of the resonant body in realtime by mapping these parameters to interpolated spatial and EMG data blurs the lines between a sound that can be found in nature and a surreal, virtual sounding landscape.

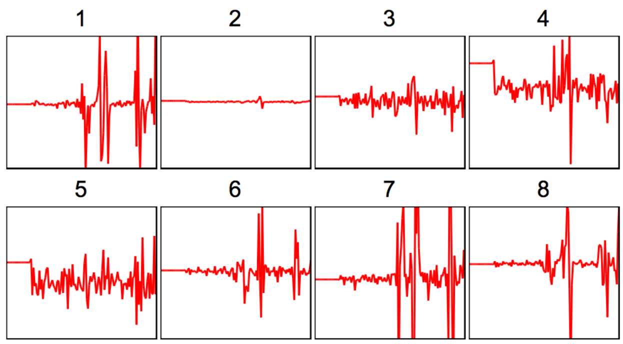


**Figure 5**. Graphing the EMG sensor input (intensity over time) in Max/MSP before smoothing.

The EMG signals are left mostly untouched besides some scaling and optional low-passing before entering the sound synthesis. The eight individual EMG sensor values are processed discrete and make it possible to manipulate all eight resulting audio streams individually. This becomes more important later when dealing with the surround routing but also makes the sound more diverse and the control for each signal more independent in general.

After preparing the data values on spatial orientation of the arm they are easily assigned to the parameters of the physical modeling characteristics and enable shaping the tonality and timbre of the sound in real time. By mapping the X, Y, Z and Quaternion data to the resonant bodies decay rate, pitch, filter characteristics, geometry and pickup position a multimodal instrument is created that changes it's characteristics in a multidimensional fashion. This basis makes the instrument highly dynamic without loosing it's fine precision for small metagestures and creates the explorable and expressive environment that we aim for. While performing the user can find positions that enable him to play drum-like sounds with muscle contraction metagestures and find other spatial configurations where the sound morphs into an ethereal choir or industrial drone sound.

Adding non-linear curves, interpolating and cross-modulating the spatial information, as well as the EMG data gives the instrument a more diverse and abstract feel. This gives the opportunity to find the boundaries of understanding and comprehensibility in regards to the correlation between movement and sound for the user. Using mostly linear mappings makes the whole sonification process more transparent, when on the other hand a more complex assignment takes more effort and makes it more challenging to control the instrument for an inexperienced user. This is also proof for the desired learnability of the instrument: After discovering the initial behavior of the system the user tends to discover detailed aspects of the sound by reacting with his body accordingly.

Adding velocity and inertial data enhances the dynamic characteristic of the dataset. This data is best used when mapped to parameters that create more drastic changes in the sound synthesis, such as filters, reverb and distortion effects. This ensures the audiovisual correlation between fast movements of the performer and reflects these movements acoustically in the soundscape.

For the Kontraktion setup we wanted to be able to create very small, detailed and percussive sounds and morph them into complex and big drones with sustain. The combination of mapping the physical modeling characteristics and the non-linear mapping of effects makes this effect possible. By default having the arm in a low, relaxed position creates percussive, transient heavy chimes with a smooth transition to distorted drone-like pad sounds when the arm is lifted or in motion. This correlates with the visual aspect of the performance: a relaxed arm creates subtle sounds and a raised arm creates a larger and more abstracted sound.

### 4.4 Machine Learning

Beyond the five pre-determined gestures recognized by the 'Myo Connect' software it is possible to train the system with your own gestures by using the 'ml.lib' machine learning library from CMU Artfab [22]. The library is based on the Gesture Recognition Toolkit (GRT) by Nick Gillian [23] and makes it possible to train unique gestures on the fly. The abstracted gestural information by this process can enhance the possibilities of the system greatly. Gestures can trigger events in the system or be used in combination with the data streams to create more complex sonification or mapping scenarios. To provide some examples for musical applications this method can be used to switch between presets, trigger samples, create loops, activate effects or control transport functions.

With the use of classification algorithms (defined below) the system can be trained to detect stationary arm and finger positions by using spatial orientation or EMG data. The range of different classification algorithms provided by the library is great to experiment with. Most reliable results for training orientational gestures were achieved with the Support Vector Machine (ml.swm) classifier. Temporal based classifiers, like Dynamic Time Warping (ml.dtw) make it possible to recognize moving gestures, like drawing a circle in mid air. These methods were only tested and didn't quite work for the 'Kontraktion' setup, since the gestures must be done at the same pace every time to deliver consistent results. This proved to be unpractical in a highly dynamic performance setup.

Machine learning is therefore only used to switch between different mappings and physical modeling bodies during the performance. The gesture used for this is freely defined before the performance. It shouldn't be too simple, because one would tend to accidentally trigger the mechanism which leads to a frustrating experience, because the correlation between movement and sound tends to become incomprehensible. This is also why the default setup of Kontraktion reduces the use of machine learning to a minimum and tries to preserve the pure information presented by the data for direct sonification without further abstracting it.

More sophisticated experiments reflected positively on the usability of the Myo armband as a gestural controller and were documented at the Integra Lab at Birmingham University [24].

In general using machine learning on gestures abstracts the finely grained data to a more 'low dimensional' trigger signal and therefore should only be used for very specific tasks. The abstraction obviously takes away from the high expressivity of multimodal input if used for sonification purposes.

### 4.5 Surround Setup with Ambisonics

Having prepared eight discrete channels (see 4.3) makes it possible to extrapolate the muscle movement captured by the EMG sensors into space, creating a virtual listening position 'inside the arm'. Interlocking the position of the eight virtual channels makes it possible to move the sound sources according to the spatial position of the performers arm in real time. By using the ICST Ambisonics library [25] in Max/MSP it was possible to route the sonified EMG data discretely and move the virtual speakers by mapping spatial information to the virtual speaker positions.

This sonic projection makes sense for artistic, as well as diagnostic purposes since the panoramic arrangement of the sound correlates with the spatial position of the EMG sensors and gives us a more realistic impression on the arms muscle contractions and the relative position of the muscles in space.

'Kontraktion' can also be used to perform on a stereo setup, which makes the space required for a performance smaller and greatly reduces the computational power needed to manipulate each individual audio stream. Due to the flexibility of the Ambisonics tool the performance can always be scaled up to a setup with more then eight speakers. The more speakers available, the higher is the resolution in the acoustic image until a setup similar to a wave field synthesis (WFS) is reached.

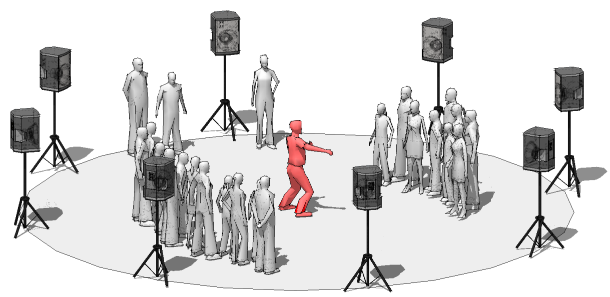

**Figure 6**. Illustration of an example surround setup with eight speakers.

## 5. CONCLUSION

The consumer grade muscle sensing technology is capable of presenting a precise and useable dataset for complex mapping scenarios. By engaging in design tasks through subjective exploration with the interface a digital music instrument that is comprehensive, explorable and learnable can be designed.

Using comprehensive, physical sonic properties the correlation between gestures and sound becomes intuitive once the properties of the instrument are subjectively explored. The interface tends to becomes invisible to the user and makes the body, motion and sound the main components of the instruments control surface. This intimate energetic coupling between body, motion and sound is a key aspect to create an embodied musical instrument.

The concept behind Biofeedback projects the idea of a reactive environment that is closely linked to the subjects body, intention and movements. By adjusting the correlation between the sonic image and the subjects behavior through different predefined mappings, individual movement patterns can be encouraged and therefore create a conceptual prototype of a clinical rehabilitation scenario.

## 6. FINAL THOUGHTS

Adding effort to musical interfaces and making them more explorable and trainable gives them more depth and character. This enables musicians to create electronic music with the same stage presence and expressivity as there analog counterparts. Hopefully more interfaces 'hidden within our bodies' will be discovered through technology and enable us to create more diverse and interesting ways for human machine interaction.

Advances in brain imaging technology will probably enable us to measure brain activity with a higher resolution and by biofeedback training enable us to create an interface that exists purely in the brains synapses. If we are able to identify and sonify neurological patterns by interpreting them with machine learning algorithms a controller within our mind can be created that is manipulated by pure thought. This process would enable us to interface with any virtual agent, like a digital musical instruments, a desktop environment or image processing software hands-free with machine aided telekinesis.

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