BioTools: A Biosignal Toolbox for Composers and Performers

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Abstract. In this paper, we present the current state of BioTools, an ongoing project to implement a modular hardware and software toolbox for composers and performers, which allows fast deployment of biosignal monitoring and measuring systems for musical applications. We discuss the motivations for this work and additionally three examples are shown of how this set of tools and the compositional strategies were used in the pieces *Díamair* for choir and physiological sensors, *Out of Time*, a project in which BioTools was used to record and analyse biosignals for their later use to inspire and aid in composition, and *Carne*, an improvisational piece that uses BioTools modules as the control interface.

Keywords: Composition, Biosignals, Integral music controller, performance.

1 Introduction

Currently, there is an extensive and constantly growing body of research and artistic exploration in the use of biosignals for musical applications [16], [21], et al. (See [17] for a description of what physiological signals are and their relationship to human-computer interaction.) However, as of yet, there is no universally available set of hardware and software tools that enable easy access to a wider community of practitioners to start composing and performing using physiologically controlled interfaces. Usually, the hardware tools have to be adapted from the medical field, often requiring custom electronics, expensive or electrically unsafe equipment, and specialised analysis algorithms. Thus, using biosignals to control music generally requires a case-by-case methodology, and often involves either a long development process/period of time by the composer or the participation of a specialised engineer (or group of engineers) in the creative process. With the development of BioTools, we attempt to limit this time/effort in order to enable the composer to focus on designing the interaction model i.e. the actual physical positioning and implementation of the diverse sensors from their desired piece and not the low level electronics required. In providing such a toolkit, we believe other researchers and artists can benefit from our efforts, and the field of

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biosignal interfaces for music can go past implementation issues and work can be done in the aesthetic, idiomatic, and stylistic aspects of musical practice as they relate to these specific technologies.

2 Motivation

As early as the turn of the 16th century, western music production started turning its focus of attention from the singing voice to *"new machines"* which we currently know as musical instruments. The importance of this shift wasn't immediately noticeable, since the first instrumental pieces were still based on choral compositional practice, and could as well have been composed for voices. It wasn't until the 17th century, with the works of composers like Johann Sebastian Bach, Claudio Monteverdi, Antonio Vivaldi and others, that instruments started to develop their own *voice* - their idiomatic language. Soon music which was not be suitable to human voices started to emerge.

Ever since, advances on musical instrument design have had a major role in the development of musical language, to name a few we could consider the following cases:

- The development of the well tempered tuning system, due to constraints in keyboard instruments and it's influence on baroque music.
- The invention of the piano and the establishment of the string quartet as a fixed ensemble in the classical period
- The establishment of the symphony orchestra of the classic period, the advances on solo instrument techniques for the romantic period
- The rediscovery of percussion instruments at the end of the XIV century as solo concert instruments and their leading to pitch-less conception of musical discourse.

In the 20th century the constant developments in electrical engineering and computer science have spawned a wide range of changes in musical composition. To detail the work of such important figures such as Lev Sergeyevitch Termen, Max Mathews, John Chowning. *et al* is outside the reach of this paper, but it is within the tradition of music technology (understood as the current state of instrument design development) that the present research is relevant, specifically on the use of biosignal interfaces for composition; in the hope to find something inherent to the use of physiological data for musical applications that might suggest deeper changes in musical thinking.

In 1965 Alvin Lucier first used brain waves as the main generative source for the composition and performance of his piece *Music for solo performer* [10]. Since then the use of biosignals for musical applications has been of great interest to composers and researchers. In the following years great advances have been made both in the artistic expression related to this medium and the underlying technologies involved. Several composers ranging from pioneers Richard Teitelbaum, David Rosenboom and Jacques Vidal to more recent sound artists as Robert Hamilton, Ken Furudachi and Atau Tanaka have made great advances in this field. The work of these artists is highly personal and appears to be more characteristic of their individual artistic expression rather than a more generalised practice that we could define as biomusic in a broader sense. By developing an accessible toolkit for fast implementation of biointerfaces we intend to enable a wider community of musicians to work at a higher level towards finding or suggesting a style of idiomatic music written for biosignal interfaces.

3 BioTools

There are two main tasks we have focused on in the development of BioTools. The first task is recording, assessing, analysing and plotting physiological data obtained from naturally experienced and induced emotional states for its later use on composition. (See [5] for information on this process). This allows for the use of physiological data not only as a control layer at performance time for triggering and controlling sound events or processes, but using this data for biosignal-informed composition, which can be even for acoustic instruments only. Measurements of biosignals through set experiences (performing a particular piece, responding to a questionnaire, watching a succession of images, listening to music, news, etc.) can be used to inform compositional decisions such as: musical structure, polyphony (if we take measurements of different biosensors or different users), rhythm, pitch class sets and others. This approach is very important, as the core characteristics of each type of signal is kept regardless of the diverse stimuli or conditions being measured. Thus, we can start thinking of *biomusic* where certain characteristics are always kept while composers are still free to explore their individual artistic expression.

The other purpose of our toolkit is to allow easy implementation of the required algorithms to use biosignals as part of an Integral Music Controller for musical performances [14] [15].

We attempt to address these two distinct tasks with a set of standardised hardware and software modules which allow for a more widespread use of biosignals for both aims.

Our initial software implementation for BioTools is built upon the Max/MSP platform, due to its widespread use amongst composers and performers. However, we have also begun implementing the data collection and analysis modules in the EyesWeb platform [9] because, as has been pointed out previously [13], Max/MSP still has problems with scheduling and time-stamping synchronised multiple streams of data. EyesWeb is far superior for this precise timing of real-time events and its built-in strengths for image emotive analysis and synthesis capabilities will be beneficial to the composer as well. Different approaches exist for mapping gestures to sound and choosing the appropriate mapping strategy is one of the main artistic decisions composers make on their pieces. We will not attempt to discuss the extensive field of gesture mapping in this paper (please see [4], [19] and [24] for more details). Instead, we focus on the behaviour of biosignals when responding to diverse stimuli to try to create music which is idiomatic to this type of controller. In doing so, we examine two elements:

1. The type of gestures possible for triggering and controlling individual music events on the course of any given composition.
2. The technical, philosophical and aesthetic connotations related to the use of this type of signals for composition, in a similar manner as additive synthesis and FFT analysis techniques have informed the French *musique spectrale* school [23].

4 Hardware Toolkit (The Next BioMuse)

The BioMuse system has evolved over the past 15 years from a high-end research system to a wireless mobile monitoring system [15] [16] [20]. The BioMuse has been redesigned once more to now be a simple toolkit of bands that can be worn on the limbs, chest, or head to measure any of the underlying physiological signals. Fig 1. shows the basic bands which have self-contained dry electrodes with the amplification, adaptation, and protection electronics imbedded within the band.

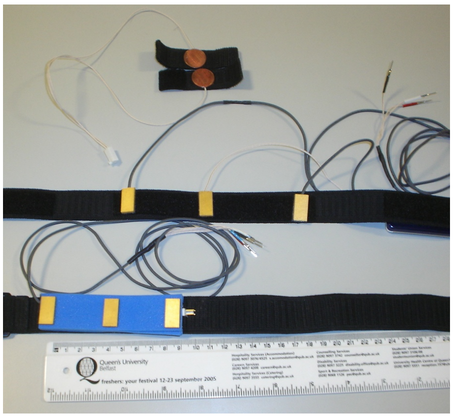

Fig. 1. Headband, Armband, Chest-band and GSR electrodes

Each band has the appropriate signal conditioning and protection circuitry necessary for the type of signal being measured. For example, the headband is specifically designed for measuring EEG and EOG signals. The limb band is designed to measure EMG and GSR signals. The chest band is designed to measure EKG. The output of these bands can then be plugged to any of the standard wireless transmitter systems such as the ICubeX [11] or the Arduino Bluetooth [6]. Fig. 2 shows the diverse bands being used during a rehearsal.

5 Software Modules

The software layer we are currently working on consists of a series of Max/MSP abstractions, GUIs (for fast analysis and visualisation of data) and their related

Fig. 2. Hardware modules during rehearsal

help files. The modules are implemented as a collection of patches instead of external objects to allow for easy modification and improving of these implementations by ourselves as well as others. Upon being captured, all the incoming data from the sensors is converted to the signal domain using the ***sig~*** object, this allows using Max's built in objects for signal processing and analysis, as well as the numerous third party external objects created for this purposes. Fig 3. shows a simple patch to monitor EMG, EKG and GSR from a performer.

5.1 Electromyogram (EMG)

The EMG hardware module measures underlying muscular activity generated by motor neurons. This signal is the most versatile for musical applications because

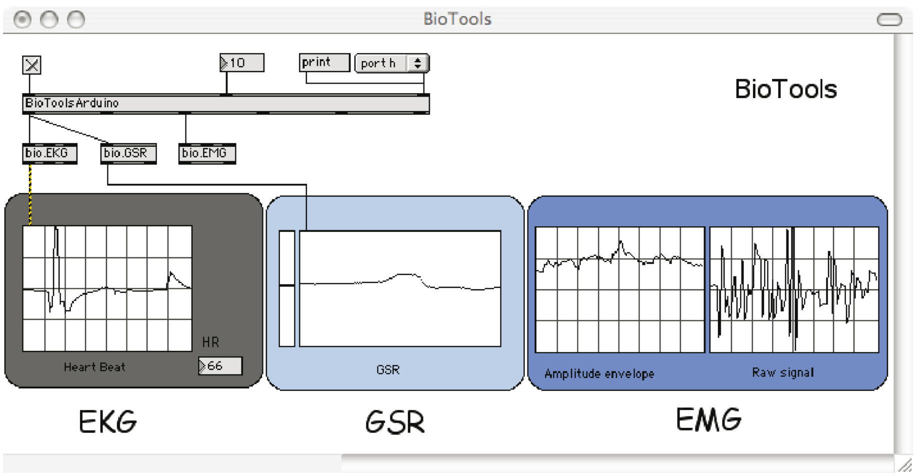

Fig. 3. BioTools' Max/MSP modules

it can be measured above any muscle, including arm (using armband) and face (using headband or glasses) and can be used both for continuous control and state recognition. Thus, it can track not only emotional information, but can be used in conjunction with more traditional non-physiological sensors to measure any of the physical gestures related to playing musical instruments and other performing arts.

As demonstrated by Atau Tanaka [7] and others, the most common placement of EMG sensors for musical practice is in the forearms of the performer. This is a convenient place for the sensors because it allows finger activity to be tracked without an intrusive device such as gloves which can directly affect the performance. The current implementation of the EMG module of BioTools has been developed for this purpose. The abstraction provides simple envelope following of the overall muscular activity tracked by the sensor and incorporates dynamic low-pass/high-pass filters and an adaptive smoothing algorithm to address the trade-off between stability of the signal and accurate response to fast gestures.

As a sub-group of the EMG module, we are currently working on gesture recognition of specific sets of muscles in order to assess information related to the specific performance practice of different musical instruments.

5.2 Electrocardiogram (ECG, EKG)

Created by the electrical impulses of the heart as it progresses through the stages of contraction, the EKG is one of the largest bioelectric signals. **Fig. 4** shows the components of a typical EKG signal. Our abstraction reads this signal and currently measures two key components: the RR and the QRS complex segments. The heart rate is computed directly from the length of the RR interval, The change in the duration of the RR interval measures the overall heart rate variability (HRV) which has been found to be strongly correlated with emotional stress [18].

The QRS complex can give valuable information on the breathing patterns of the performer without requiring an additional breath sensor, thus it makes it possible to voluntary use breath as a direct controller for sound manipulation as well as to use ancillary breath patterns related to specific instrumental practices (wind instruments and voice).

5.3 Galvanic Skin Response

GSR refers to the change in skin conductance caused by changes in stress and/or other emotional states. The GSR is extremely sensitive to emotional changes. Both subtle changes in the tonic level of the GSR and dramatic changes in the phasic level can be tracked with this technique. The GSR signal in its raw format is often confusing for musicians who are not familiar with the way it works, higher arousal levels (stress, increased involvement) cause the skin resistance to drop; reduced arousal (relaxation, withdrawal) levels results in increased resistance. To address this non-intuitive behaviour, our abstraction extracts both tonic and phasic behaviour and inverts the resultant control signals.

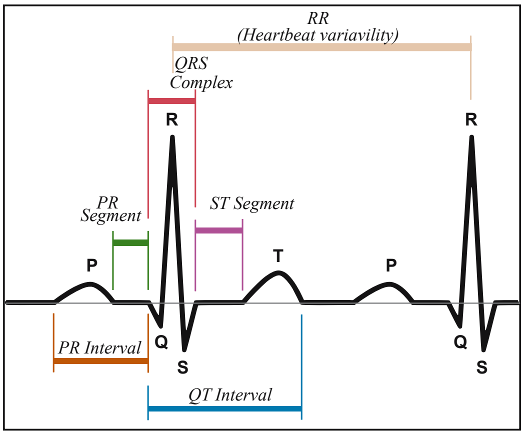

Fig. 4. Ideal EKG signal

6 Examples, Pieces Composed Using BioTools

The presented toolbox has been employed recently for the composition of the pieces *Damair, Out of Time* and *Carne*. For these compositions, BioTools has proved to be extremely helpful - we were able to focus on the physical implementation and the musical contents of the pieces.

6.1 Damair: A Piece for Choir and IMC

Damair [22]is a piece for choir and Integral Music Controller inspired by the poem of the same name, often translated as *A Mystery* or *The Song of Amergin* (after the author to whom it is attributed), this text is contained in the *Lebor Gabla renn* (The Book of Invasions) [1]. For this composition we used the GSR and EMG modules of the IMC in addition to real-time face tracking. The conductor is equipped with EMG sensors on each forearm and the modules are used to gather basic information on his/her muscular tension. We use this data to identify staccato and legato articulations (as well as interpolation between them) on his/her conducting gestures. This information is then used to control spatial spread of the electronic sound sources and to apply amplitude and frequency envelopes. A group of eight soloists are equipped with GSR sensors. These sensors are placed in custom choir folders that the singers hold in their hands as shown in Fig. 5. This implementation succeeds in being non-intrusive for the singers.

The GSR signals from the choir where mapped to a granular synthesis engine to control transposition (specifically levels of dissonance), number of grains (polyphony) and grain size in order to shape the materials through involuntary autonomic physiological reactions, creating a direct interface between emotion and sound manipulation. The choir is laid out in two concentric circles with the

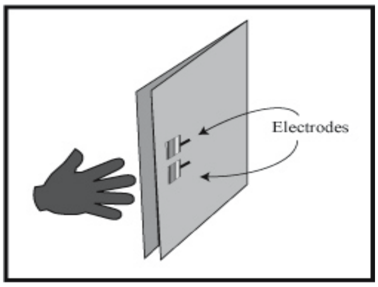

Fig. 5. Hardware implementation of GSR sensors for choir soloists

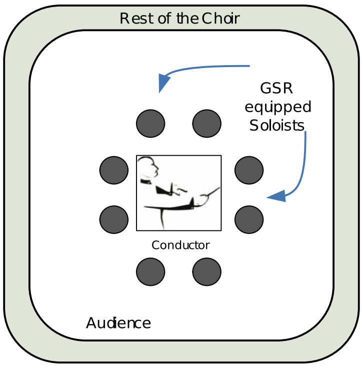

Fig. 6. Spatial choir configuration

conductor at the centre as showed in Fig. 6. The inner circle is formed by the eight soloists. The rest of the choir who are not equipped with sensors are placed surrounding the audience.

An imposed challenge for this project was to keep the hierarchical conductor-soloists-choir relationships in their interaction with the electronic sounds. Using the distributed IMC [14] concept to allow all the possible levels of interaction, we distributed the interface (GSR and EMG sensors) between the conductor and choir. The conductor has the capability of controlling the choir through his physical gestures. His control is augmented by the GSR module so that his gestures also remotely control the live electronics. The soloists do not have direct control over their sound manipulations but rather interact with them through ancillary and induced involuntary autonomic physiological reactions. The remaining choir members who are below the soloists in the hierarchical tree (conductor-soloists-choir), have no direct interaction with the live electronics, but close a feedback loop by their singing which affects the conductors gestures and soloists emotional states. The use of the interface had a major role in the final compositional result. The GSR signals evolve slowly over time which in initial tests proved to lack more dynamic changes. To address these limitations specific fragments of the piece were written to induce different stress levels to the soloists.

6.2 Out of Time: Physiologically Informed Soundtrack to the Film Out of Tune

Out of Tune is a short film by director and writer Fran Apprich. This work depicts women's exploitation in a world in which girls want to be women. The story is set in a strip club in reference to Jean-Luke Goddard's *Vivre sa vie.* The collusion of a girl backstage with a stripper triggers an unexpected clash of personalities and generations. The music for this film explores further this idea of exploitation by measuring the emotional responses of the actress during the main stripping scene and analysing such measurements for their later use as a compositional framework for the whole soundtrack. The EKG and GSR modules of BioTools were used to measure, record and plot the actress' stress levels during rehearsals and shooting. The recorded data from the different takes was averaged to find consistent curves in her emotional state changes during acting. As well as the overall plotted curve, we found spikes at different points actions in her stress levels (i.e. the increase in stress seconds before stripping and slow relaxation afterwards as she managed this stress). As she played the role of the stripper, subtle changes on her emotional states where identified relating to the different elements of the performance (i.e. dancing dressed, stripping, dancing naked afterwards). The soundtrack is composed almost exclusively for an out of tune piano; the overall emotional curve measured by the GSR module is used to dictate the form and structure of the piece. Changes in the heart rate variability were found to be associated to more specific actions and were used to organise dynamics, articulations and harmony. This project was (in a sense) more restricted, as the outcome couldn't be just a personal musical expression or aesthetic statement, but it had to work within the film's context. Another restriction imposed by this fixed medium was the impossibility to use biosignals as a real-time performance tool. The physiological information on this project was used to layout more traditional musical parameters. For the final result, there is no direct sound generation or manipulation by the biosignals, but rather the recorded data serves as a structural framework for the compositional process. This data was averaged between the different takes and then rendered into form, harmony and rhythmic structures for the composition of the piece, some other elements of the composition as melodic outline and style references are not related to the physiological information recorded from the actress, but rather from the specific requirements of the film's narrative.

6.3 Carne

Carne is an interactive piece for two EMG sensors. It was composed as part of the activities carried on by group 8 [2] on the eNTERFACE summer workshops '07. It was premiered at the Boğaziçi University Music Club on August 8 2007. The piece is an audiovisual collaboration between Miguel Angel Ortiz Pérez (interface and sounds) and Hanna Drayson (visuals). Fig. 7. shows the performer at the premiere.

Carne is loosely inspired by Terry Bison's 1991 short story *They're made out of meat*[12]. The concept behind Carne is based on a very simplistic view of

Fig. 7. Premiere performance of *Carne*

muscle activity as the friction between slices of meat. Taking this idea further, we could say that all types of arms movement from minimal arm gestures up to the highly complex synchronised movements of fingers during musical instrument performance, are simple variations of this meat grinding activity.

The sounds in this piece, evolve inside a continuum from imaginary muscle sounds to pre-recorded sounds of western bowed string instruments, while always keeping focus on friction as a unifying metaphor.

The hardware implementation of *Carne* consists of 2 EMG sensor bands from Biocontrol Systems[3] connected to an Arduino BT board. These hardware components interact with a computer running EyesWeb software and a custom built patch for data acquisition. Analysed data is then transferred in real-time through OSC protocol to a second computer running a slightly hacked version of the CataRT[8] application by Diemo Schwartz. Within this patch, a large database of samples are loaded, analysed and organised using psychoacoustic descriptors. The resulting sound units are laid on a two dimensional descriptor space where the X axis represents noissines and the Y axis represents pitch. The EMG signals from each arm controls movement on one of these axes. The values from the EMG are dynamically scaled throughout the duration of the piece, allowing the performer to explore cluster areas of the sound corpus and giving a sense of structure and evolution to the piece.

7 Conclusions

We have described a new set of tools, BioTools, which are currently being created for rapid development of musical applications using physiological sensors. The new hardware sensors enable flexible placement of the sensors anywhere on the body and measurement of any type of physiological signal. The initial software tools are working on the Max/MSP platform because of its widespread use by composers and performers. However, as pointed out previously, time coding different data streams in Max/MSP for analysis purposes is a complex and time consuming process and due to this we have also begun to implement BioTools on the EyesWeb platform, Additionally, we are looking at implementing the modules on other programs such as PD, Anvil, and Chuck to offer more flexibility. The use of BioTools has made the process of creating a piece, Damair, for Integral Music Control as well as a piece, Out of Time using pre-recorded physiological signals an exercise in composition not electrical engineering.

Our current work is increasingly moving towards musical creation and performance and promoting the use of BioTools amongst other artists. We believe the toolkit provides a stable foundation for incorporating biosignals to musical practice for a wider community than previously available.

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