The Flexophone
A study on controlling sounds with EMG signals

UNIVERSITY OF TURKU
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In this thesis, the author will conduct a user experience research on the possibilities of using electromyographic (EMG) signals to control the sound produced by software oscillator. A simple software oscillator and a rudimentary interface using the EMG signals was implemented for the means of conducting the research, and 5 people with previous musical background were recruited to test the interface. The test subjects were given a questionnaire charting their experience, which was analyzed to answer the question of whether this kind of interface is viable for controlling of sound to be used in music.

Results from this study indicate that there could be interest towards this kind of interface among people who practice music, as the average of overall experience was rated 3.72 in Likert scale between 1 and 5. 4 out of 5 test users also reported interest in to using this kind of interface in actual musical performance. However, results also highlight the technical issues this kind of interface must address for it to be viable for and interesting to musicians. Among the issues identified in this research are problems with keeping the rhythm, having wide enough scale of possible sounds and the discomfort caused by the removal of electrodes from the skin. These negative aspects are a matter of technical implementation and will be solved in future research.

Keywords: EMG, interface design, music, sound control, interaction design, HCI

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1 Introduction

I dream of instruments obedient to my thought and which with their contribution of a whole new world of unsuspected sounds, will lend themselves to the exigencies of my inner rhythm - Edgard Varèse, 1917

Musical history of humanity goes back tens of thousands of years [1], perhaps even predating the modern human species altogether, and throughout this history the haptic paradigm, in other words touch and control by hands, has prevailed as the most viable and popular way of controlling the production of sounds which are considered to be music by the norms of society. Of course, before the advent of electrical age there were very few alternatives, but thus far even the electronic music has mostly consisted of sounds created with instruments that are controlled by touch.

Electric instruments have been used in the production of music for almost as long as mankind has known of the potential to harness electricity. [2] While this has led to, especially after the Second World War, the explosion of styles and techniques which have spawned several new musical genres', the actual usage of the majority of the electronic instruments is based quite much on the same principles which have always been the norm with more traditional, acoustic instruments that preceded them. In other words, majority of the electronic instruments are used by controlling them with hands and in relatively similar ways as their acoustic counterparts, i.e. through haptic interface. The electronic aspect of these instruments has thus remained mostly confined to the realm of the recording, playback and manipulation of the sounds created by them and the potentials which electricity provides for interface purposes have remained mostly untapped.

The best known example to the contrary is the Theremin, invented by the Russian physicist Lev Termen in 1919 [3], as a byproduct of a Soviet government -funded research in to proximity sensor technology. Theremin is an instrument controlled by hands, but not by touch. Instead, the user of the Theremin moves their hands between two antennas, which act as proximity sensors and in relation to the position of the performers hand-motions control the frequency and the amplitude of the sound produced by this device. Other notable challenger for the haptic paradigm were the inventions made by the Finnish engineer, musician and inventor Erkki Kurenniemi, who created several experimental electric instruments during the Cold War era. [4]

The subject of this thesis is two-fold. Other of these is the technical description and presentation of a proof-of-concept for interface that is controlled by the electromyographic signals originating from the user, inputted through sensors connected to the users musculature, and then with the aid of computer software processed in to sounds. In other words, the EMG signals are used to control the sounds produced by a software oscillator. The research is conducted with this instrument is the study on how the end-users experience this kind of interface, in other words, whether it feels intuitive and usable to the musician. This research has been conducted by having 5 test subjects, who used the interface and then answered a questionnaire about how they experienced the usability of the interface, how intuitive it was and whether they as musicians perceive it. The test subjects were recruited from the authors social network with the criterion that they all have some form of previous musical experience, thus giving them some kind of context against which to evaluate the interface under test.

In Chapter 2 of this study the author will take a brief overview on the history of the digital sound production and the previous research done in the subjects central to my research, to give the reader a proper frame of reference. Specific examination will be done on the original research and experimentation done by Manford L. Eaton [5] and Erkki Kureniemi onwards from the 1960s, as it has been instrumental in inspiring the author to pursue this avenue of research, namely the viability of musical instruments that are directly operated by the electric signals originating in human body. Author shall also take a survey on the evolution of Theremin and its offspring instruments, as they are distantly related to their own research. Also, the author will take an overview on the research done on using EMG signals for human-computer-interaction, and whether it is related to my own research. In Chapter 3, the technical details of both the software I have developed for this purpose, and the hardware, the electromylographic sensor, it is connected to will be explained. In the Chapter 4, the author will go through the research arrangements and the questions they are attempting to answer in this study. In Chapter 5, the results of this research will be represented. Chapter 6 is devoted to discussing the implications of this research and what avenues should be pursued in the future. And finally, in Chapter 7, author will provide the definite conclusions that have been arrived to during the course of this investigation.

2 Related work

Due to the subject of this thesis the research and experimentation related to author's own can be broken down to several different areas, which are here represented as their own subsections. Author will first take an overview on the research done on similar interfaces in general, i.e. the use of EMG signals in HCI. Most of these studies have revolved around some dilemma of biomedical engineering, but there is a short subchapter devoted to the use of EMG for musical interface purposes also. Next, the author will take a brief glance at the history of the evolution of electronic instruments, focusing on the more experimental interfaces that have been developed over years. Special attention is given to Theremin and the instruments of Kurenniemi. Lastly, the author will take a third survey, this time on the contemporary studies and innovations in the field of experimental interfaces for musical instruments. This cornucopia of research and innovation in both scientific and artistic realms of human endeavour is seen as sufficient to position the authors work within a correct cultural and technological context.

2.1 EMG HCI research in general

The usage of EMG-signals in human-computer-interaction has been studied widely, although mostly for reasons other than musical interests. The application of EMG -signals for controlling both computer interfaces and peripheral devices such as robotics has been done on multitude of topics, from the attempts at interpreting sign-language [6] to controlling robotic exoskeletons [7] and everything in-between.

Koike and Kawato [8] studied the use of EMG signals, and the neural networks in their interpretation, in the control of the artificial arm in their 1996 paper. They demonstrated that their system was capable of correctly classifying certain fundamental movements of the arm.

Barreto et al. [9] published a paper in 1999 describing a system of HCI which used the combination of cranial muscle EMG biosignals and EEG biosignals from the cerebrum's occipital lobe to coordinate the movements of a computer mouse. The system converted these signals to mouse coordinates and clicks by applying amplitude thresholds and using power spectral density (PSD) estimation on discretely windowed data. Spectral power summations obtained from these estimations are then aggregated over the frequency range of 8-500Hz to obtain the correct classification of the wanted movement.

Alsayegh [10] developed and presented a mechanism for detecting specific arm movements via EMG signals. The observation of the specific gestures was based on statistical pattern recognition and using 12 pre-determined hand positions, and it was reportedly good enough to correctly classify 96% of the gestures.

Itou et al. [11] designed an interface for controlling the mouse coordinates and clicks through the inputted EMG signals, which were analyzed by a neural network. This device was intended for the use by amputees and other people who have difficulties in using the normal input devices of the computer. Their experimental results yielded a 70% accuracy in the correct classification of the mouse coordinates.

Fukuda et al. [12] presented a system which combined the input from the continous EMG signals to a neural network that included Hidden Markov Model to interpret the coordination of the mouse pointer. This system also included a physical model that was deployed to make the user experience of the device to be more intuitive, specifically to simulate the feeling of a mass in viscous space, to better engage the users sense of force. This device was originally intended to be used in wearable computer devices, as an alternative which could be used to bypass the requirement of the keyboard and mouse.

Chan & Englehardt [13] developed a system based on Hidden Markov Model to interpret four channel EMG signal that was used to control a mechanical prosthetic arm. Notable feature of this system was that it worked on continous EMG signal, which was not sampled to discrete (time-constrained) form. The system was capable of relatively high precision in fine motor functions.

Kim et al. [14] invented an armband embedded with EMG sensors and signal amplifiers, which could record the surface EMG from the wrist-movements of the user without the need for any adhesive to attach the electrodes to the skin. This device was intended for the control of mouse movements and clicks. Kim et al. deployed a Fuzzy Min-Max Neural Network (FMMNN) as a classifier, and concluded that the system worked fine once the user had learned the correct movements.

Chu et al. [15] designed a similar system for the control of artificial hands, which was based on the use of Multi-layer Perceptrons (MLP) as the classifying mechanism of the hand gestures, and on the wavelet packet transforms as means to map the EMG signal. Their results indicated that this kind of setting was sufficient to interpret the EMG signal correctly with a latency of less than 125ms, and that the classification of the gestures was ultimately based on the

Mobasser and Hashtrudi-Zaad [16] published a paper on the classification of the hand gestures from the EMG signals recorded from the upper arm musculature, by using the Moving Window Least Squares to perform local identification of the dynamic parameters for a limited quantity of operating points in a space defined by the elbow joint and velocity. This information was then used to train Radial Basis Function Artificial Neural Network (RBFNN).

Chen et al. [17] conducted a study on how to use Linear Bayesian Classifier in recognizing specific hand gestures from the surface EMG signals recorded with a two channel sensor device from the upper forearm. They concluded that this kind of device is suitable for correctly detecting wrist movements and the extension of singular singers.

Jung et al. [18] developed a system of recognizing hand gestures from the EMG -signals with a combination of spectral estimation and the neural network. For the power spectral density(PSD) estimation they used the Yule-Walker algorithm [1] and Learning Vector Quantisization (LVQ).

El-Daydamony et al. [19] presented a system intended for the detection of neuromuscular damage, which used the Hidden Markov Model to classify the surface EMG -signal. According to their results, the system achieved the accuracy rate of 90.91%, and had thus potential to be used as a diagnostic tool by physicians.

Kim et al. [20] developed a system for the recognition of hand gestures from the EMG signal, which was used to steer a remotely controlled toy car. Their design incorporated two different neural networks as classifiers (k-NN and Linear Bayesian Classifier), and achieved a success rate of 94% in correctly classifying the hand gestures from the signal.

Ahsan et al. [21] conducted a wide literature review on the research done on the usage of EMG signals in HCI. According to them, the central problem when utilizing sEMG -sensor technology for tasks that require high precision is the low signal-to-noise -ratio, which makes it in general hard to discern the specific signal from specific muscle, as the signals generated by the musculature around the specific point of interest, the electromagnetic noise from the recording instruments and several other reasons interfere. Especially in recent years, there have been multiple attempts at mitigating this noise factor by employing different kinds of neural networks to interpret the correct signal from amidst the noise, especially when striving for the

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[1] https://www.mathworks.com/help/signal/ref/spectrum.yulear.html

recognition of specific gestures to be used in tasks requiring exact control. [22] [23] [12] [13]

2.2 EMG research specifically for musical purposes

In this section, we will focus specifically on the research done on using EMG signals in relation to music. Both the studies done on the design of interfaces based on EMG signals, as well as a cursory look on the studies where EMG is in other ways used in relation to music somehow, will be made. Usually the studies in the latter category are of such nature that the EMG has been used to measure the effect of music in some way, and as such they are of no great interest for the purposes of this study.

Knapp and Lusted developed a computer system called Biomuse in 1990 [24], which combined the use of EMG, EOG (electrooculogram), EEG signals and microphone inputs to control a synthesizer. The system comprises of two hardware units, the custom-built DSP module and a personal computer, which both run software applications that communicate with each other. The central idea is to map the various signals to MIDI outputs. However, the possible use scenarios of the Biomuse go further than this, and the authors even claim that the interface could be configured so as to be used as general-purpose human-computer-interface, allowing disabled people to use personal computers through biosignals.

Dubost and Tanaka [25] developed an EMG signal interface which was designed to be wireless and network -based to allow for maximum mobility of the user. In essence, the interface consists of wireless EMG electrodes which connect to the wearable device that acts as a basestation, which communicates through Ethernet connection with the synthesizer.

Tanaka et al. [26] studied the use of EMG sensors in combination with gyroscopes to create a multi-modal interface used for human-computer-interaction. In this setup, the EMG was used to record the activity of the muscle and gyroscopes to measure the positioning of the arm to create a system by which the music could be controlled by specific gestures. It should be noted that this kind of setup, where the EMG readings are supplemented by some other kind of sensor data, such as gyroscopes, accelerometers or such can also be used for identifying gestures without the use of neural networks, but it requires some other dimension of measurements besides just EMG signal.

Kara and Özel [27] used EMG readings to study the relaxing effect of music on human muscular system, comparing the effects of ambient reed flute music to that of hard rock. They concluded that the relaxation caused by the music could be studied this way, and that reed flute music was more relaxing than hard rock.

Visentin and Shan [28] conducted a literature review on EMG -research related to music, specifically on how EMG readings can be used to supplement musical learning via biofeedback information, prevention of injuries and in analyzing the musical skills of the practitioner. They concluded that while some studies to this effect exist, the body of literature, and thus evidence of the potentials of EMG for these purposes, is still too small to have meaningful impact as the more widespread adoption of EMG technology for these reasons. As the topics of the studies they reviewed are not exactly in line with the topic of this thesis, the author will refrain from referring them here.

In 2019, Di Donato et al. [29] developed *'EAVI EMG board*, an 8-channel wireless EMG -sensor and accelerometer unit designed specifically for musical input purposes in mind. In a follow-up paper on the subject in 2023 Tanaka [30] presented an improved version of this system which is capable of using EEG -signals as inputs also.

Cui [31] developed a music interface for use with Myo armband[2], which is a com-

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[2] https://wearables.com/products/myo

mercial EMG -based wearable interaction device. In essence, the interface created by Cui controls the sound volume and pitch, and also creates visualizations based on the EMG readings. However, it remains unclear from their paper whether this system is actually meant for sound production, or is it just an interface to control pre-existing sound.

Sarkar et al. [32] conducted a research on the emotional effects of classical hindustani music, in which they used both EMG and EEG sensors to gauge the impact the musical performance had on the listeners. They specifically studied whether joy and sadness could be detected in this way. They concluded that the emotional effects could be gauged to some degree with these measurement techniques, although they also concluded that the development of better algorithms to analyze the data was needed.

As can be seen from this survey on the use of EMG signals in music, it is clear that the concept has not been studied very widely. Some experimental interfaces have been created for research purposes, and some of these have even been used in some projects, such as Knapp [24]. While these interfaces are of much more robust design and implementation than what has been produced for the needs this research, none of these interfaces are available as ready-made solutions, which has been one of the reasons the interface used in this study was developed. It should also be noted that most of this research consists of just technical documentation of these interfaces and their properties, while no studies have been conducted that would focus on the usability and viability of these kinds of interfaces. The field is also very narrow when it comes to the number of people doing this kind of research, with Atau Tanaka and Benjamin Knapp participating in large number of these studies. Rest of the research done on the use of EMG signals in connection to music is mostly interested in the use of EMG to study the effects of music, and while this kind of implementation is interesting in its own right, it is not exactly related to this work.

2.3 Short history of experimental electronic music

In this subsection we will explain the history of experimental electronic instuments, as understanding it is important for putting my research to correct context. Author has here omitted certain better-known electronic instruments such as Moog synthesizers and the evolution of the electric guitar, and focused mainly, in addition to the pre-history of the electronic music, to those instruments which are conceptually or paradigmatically related to my own work.

2.3.1 Pre-history

Figure 2.1: Clavecin Electrique at National Library of France

While the aforementioned Lev Termen was one of the early pioneers to tread the paths of invention in electronic music, he was hardly the first. If we are absolutely precise, the first definitely proven electronic instrument ever produced was the Denis d'or, invented by the Czech theologian Václav Prokop Diviš approximately in the 1730s. Unfortunately it was an unique experimental device which has been lost to the mists of history, but there has remained enough written accounts describing this invention to support its existence. [2] Denis d'or was temporally closely followed by another early invention, the Clavecin Electrique, pictured in Figure 2.1, which was created by a French jesuit priest Jean-Baptiste Delaborde in 1759 [33]. Clavecin Electrique was basically an electronic carillon, which is a pitched percussion instrument consisting of a series of bells, played by a keyboard of sorts. Unlike the Denis d'or, the original Clavecin built by the Delaborde still exists, and is nowadays owned and exhibited by the National Library of France in Paris.

The 19th century saw the true cultural and societal revolution in the use of electricity, and with it the dawn of the second generation of electric instruments. Towards the end of the century, Dr. Thaddeus Cahill invented and patented the Telharmonium, also known as Dynamophone, which was essentially an early form of electric organ and the direct predecessor of the later synthesizers. [33] [34] Shown in Figure 2.2, the original Telharmonium created by the Cahill in 1906 was a gargantuan monstrosity of a machine, weighing roughly 200 metric tons and being of a size of a small building, with its three main components having to be situated in different rooms due to reasons of size, connected to each other through similar technology that was used in the telephone receivers of the time. Cahill also had an idea of marketing the electronic music created with the Telharmonium as live performances on-demand which were to be broadcast over telephone lines, which was nothing short of visionary considering that he conceived this notion in 1901, when neither commercial radio broadcasts nor television existed. However, Cahill's ambitious plans for remotely broadcast music performances were perhaps a bit too much ahead of their time, and the company he founded for selling these services ceased its operations either in 1908 [34] or in 1911 [33], however less than a decade after the first production -quality Telharmonium had been created. Reasons for his failure in turning Telharmonium to profit are often cited to be in the limitations of the transmission technology of the time and that the cultural atmosphere was not yet ready for this kind of innovation. Nonetheless, Cahill is a strong contender for the person who invented content-streaming-on-demand, which took over a century to become mainstream again.

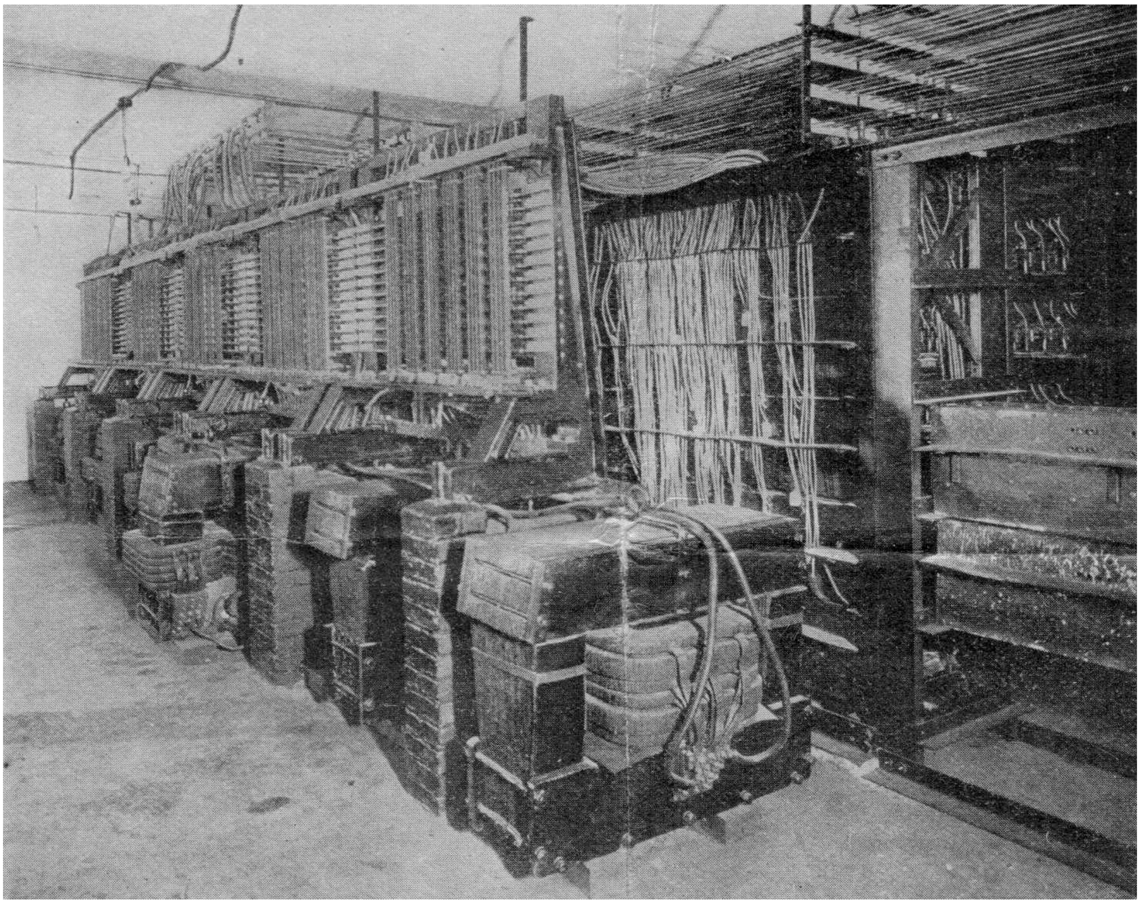

Figure 2.2: Machinery of Telharmonium

Simultaneously with the rise and fall of the Telharmonium, another American inventor by the name of Lee De Forest came up with a device that would permanently change the face of electronics, and with it the production of electronic music. Vacuum tube, invented by the De Forest in 1907, was the first step in the miniaturization of the electronics, as it allowed for an easy way to amplify electronic signals. While De Forest himself created only one electronic instrument with this technology, the Audion Piano, the vacuum tube which made it possible quickly spread across the globe and ushered in to the first true age of consumer electronics with the advent of televisions, radios and microphones. It could be said that the Audion Piano was the precursor of another instrument which would become one of the most famous electronic musical instrument ever made, the Theremin. However, due to the importance of the Theremin for the topic of this research, a separate subsection 2.3.2 has been reserved to discuss it, and we shall here skip it entirely.

Inspired by the Telharmonium, Melvin Severy and George Sinclair created an instrument called Choralcelo in 1909. [34] This instrument was a mixture of a pipe-organ, piano and an ingenious magnetic device which vibrated the piano strings, which reportedly produced a very eerie droning sound. It is also notable that Choralcelo included an inbuilt recording device, which made it possible to record previous performances made with the instrument, making it a strong contender for the first self-recording musical instrument ever made. Like the Telharmonium, Choralcelo never became very popular, and reportedly only six of them were ever sold. However, some of these remained in use for over thirty years.

2.3.2 Theremin

In conclusion, I must express my assurance that electricity, which has had considerable influence on science and engineering, will undoubtedly have a great influence on the precious field of art. - Lev S. Termen, 1922

As was already explained in the introduction, Theremin, created by the Lev Termen in the beginning of the 20th century in Soviet Union, is the most famous of the electronic instruments which operates outside the haptic paradigm. Theremin is controlled by moving the users hands between two antennas, of which another is (in the original configuration) roughly 18 inches tall and upright, while the other is circular in design and oriented horizontally. The first antenna is used to control the frequency of the sound, while the second is used to control the amplitude. [34]The functioning of the Theremin is based on the device known as beat frequency oscillator (BFO)[3], of which there are several at work in producing the sound. [35]

Figure 2.3: Lev Termen performing with the Theremin

Termen stated in the lectures he gave [36] on the design principles of Theremin, that one of the central motivations behind the creation of the instrument was to afford more freedom to the player as it would not require touch. In the lecture he gave, Termen expressed strong belief that this freedom of movement would be an advantage over the more traditional instruments - a vision of the future which thus far has failed to manifest. While Theremin has become very famous instrument, it has never become truly popular among musicians, mainly because it is perceived as being very hard to learn to play. As Clara Rockmore [37], one of the most acclaimed thereminists to have lived has said, using Theremin is akin to “playing the whole

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[3] https://en.wikipedia.org/wiki/Beat_frequency_oscillator

string concerto with a single string". Playing the Theremin has also been compared to "plucking the notes directly out of the empty air", as can be easily imagined from the Figure 2.3.

2.3.3 Experimental 1960s

While the instruments discussed earlier in this chapter have been experimental, mainly due to the virtue of them having been the pioneers and the vanguard of the development of electronic music, it took until the 1960s that the first non-haptic interfaces since the Theremin were again experimented with. In 1965, the first known musical performance where the instrument was controlled by the EEG -signal was created by Alvin Lucier. [38] The EEG -signal was used to control some kind of percussion instruments, and it must be noted that this control was only partial, with a technical assistant working at the same time between Lucier and the instruments. Two years later, in 1967, Richard Teitelbaum performed a piece known as "Spacecraft" while touring in Europe, in which he played a Moog synthesizer which was controlled by a combination of EEG and EKG signals produced from various parts of his body. [38]

2.3.4 Instruments of Kurenniemi

Erkki Kurenniemi was a designer, inventor, musician and a cultural pioneer who lived between 1941 and 2017. During a period between the beginning of 1960s to mid-1970s, Kurenniemi designed and built several experimental electronic instruments. None of these instruments ever entered mass-production, but some of them were individually produced for certain musicians and other customers, most notable among these being the University of Helsinki musicological laboratory, the Finnish broadcasting corporation Yleisradio and the Swedish musician Anders Lundsten. [4]

Majority of these instruments were only used in experimental projects and in live performances by Kurenniemi himself and certain musicians who commissioned them, most famous of them being Mauri Antero Numminen[4], who used the device by Kurenniemi known as "The Electric Quartet" in several concerts. Almost all of these instruments have been either dismantled by now, or have fallen to disrepair. The remaining functional instruments which are located in Finland have been gathered to the University of Helsinki musicological laboratory, and they have been studied by a research team of musicologists and computer scientists. [4]

Figure 2.4: Erkki Kurenniemi and others playing Dimi-S

Ojanen et al. [39] report in their paper that while the schematics and blueprints for the instruments remain, Kurenniemi did not document their usage very clearly or at all, and that practical experimentation was required in figuring out how they should be used. Due to the lack of documentation, some of the instruments were of

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[4] https://fi.wikipedia.org/wiki/M._A._Numminen

such nature that only Kurenniemi himself knew how to operate them, and he was thus periodically employed by his customers as a laboratory technician in projects where these instruments were used. Partially this was due to the reason that Kurenniemi was obviously fascinated by the obscure and experimental ways of controlling these instruments, but also because he hardly cared about any user interface design in the first place. It could be inferred that one of the reasons why none of these instruments gained wider popularity was due to this, and perhaps also because their aesthetics were decidedly alien to the sensibilities of the time. Reportedly Lundsten still has a set of the instruments he commissioned from the Kurenniemi, at his Andromeda -studio, which consists of two functioning units of Dimi-S and the original and only known Dimi-O. In total Kurenniemi designed and completed a total of 9 different instruments between the years 1968 and 1973, and several more in his later years.

From the perspective of my own research, the most interesting of these devices were the Dimi-S, shown in Figure 2.4, colloquially dubbed as the “sexophone”, and Dimi-E (also known as Dimi-T [39]) [4]. Dimi-S registered the changes in electroconductivity of the users, and turned this signal in to sounds. It was designed to be operated by several people in tandem, whom by touching each other created changes in the electroconductivity of their skin, i.e. through sweating, which is why the instrument has gained its nickname. Dimi-E did the same to the electroencelographic signals, i.e. the brain activity of the user, which were harnessed from the electrodes touching the users scalp. Unlike Dimi-S, the Dimi-E was meant to be used only by one person at a time. The inspiration for both of these devices came to Kurenniemi [4], [38] from studying the article “Bio-Music” [40] by an american composer and scientist Manford L. Eaton, of whom we shall take a closer look in the next chapter.

2.3.5 Manford L. Eaton

We know that in the beginning of the 1960s, Eaton was a jazz pianist in Kansas City, playing in a band called The Taijasa Ensemble, and that he had previously studied music at the UMKC Conservatory[5] in the early years of the decade. He was described as being extremely talented as a musician, and extremely eccentric as personality, and several years later moved on to create ORCUS Inc., a company through which he started to design and manufacture experimental electronic instruments. [5] Apart from his musical inventor -career Eaton (or someone with the exactly same name) is credited as one of the authors of a 1969 paper titled *Estimation for a Generalization of the Usual Linear Statistical Model* [41], which being published by the Rand Corporation[6] hints at Eaton's involvement in some kind of military research.

Eaton published several research articles focusing on the subject of using the bio-signals to produce and control music, among them *Bio-Music* [40] that inspired Kurenniemi. Judging by its contents, Eaton was above all interested in the potential of electric instruments controlled by biofeedback-loops not as instruments to create musical art, but rather as tools to more efficiently, compared to chemical methods, to re-program the human mind. In essence, what he sought were controllable and more precise ways of self-hypnosis, to be used in accessing sub-conscious psychological, or as Eaton them described, "psychic" states. Other writings of Eaton, such as *Induce and Control - The biomusic is here today* [42] expanded upon this subject.

In the Bio-Music, Eaton explains various designs for biofeedback -interfaces, both of the kind which had already been realized and ones that were purely hypothetical at the time of his writing. Among these are many designs which would later be realized by, or which would at least come to inspire Kurenniemi. Interestingly, Eaton shortly describes a device very similar in operation to the one that is the subject of this

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[5] https://conservatory.umkc.edu/

[6] https://en.wikipedia.org/wiki/RAND_Corporation

paper, one in which the EMG -electrodes are inserted with needles in to the muscle tissue and the resulting signal directed to loudspeakers, but unfortunately he does not go in to the further details about this device, its exact design nor whether it was ever used beyond singular experiments. However, he does note that in while testing the device, the research team concluded that humans are surprisingly capable and fast in learning to control their muscular expression in ways that are never exhibited under normal circumstances, and thus that the control of the sound is very possible with even minimal contractions of the users musculature. Regardless, this goes to show that similar interfaces have been experimented upon by previous researchers in the past, and that they have borne certain fruits.

2.3.6 Related contemporary work on experimental musical interfaces

In 2008, Geiger et al. [43] designed and developed VRemin I and VRemin II, a VR-technology -based successors for Theremin. The user interface of the VRemin I were implemented by using two Nintendo Wii stick-controllers, through which the user controlled the production of sounds by moving the sticks in the air. VRemin II, on the other hand, was controlled by an experimental glove-like apparatus created by the research team, which combined tracking of the movements with optical sensors deployed around the user, and sensors built in to the glove which registered the position of the fingers. Geiger et al. proceeded to observe how their test subjects learned to play the original Theremin and the two instruments created by the researchers, and what opinions this raised in the test subjects. Their study concluded that for the players new to the idea of theremin-like instruments, learning to use these kinds of interfaces was extremely hard, but pronouncedly more so with the VRemin II. However, at the same time majority of the users were very interested in the unusual nature of the input interface, which contributed to increase in the learning motivation. Majority of the test subjects also were of the opinion that VRemin I was superior to both the original Theremin for having wider scale of possible audio expressions, and to the VRemin II for being more easy to control. Researchers noted, though, that at the time of the experimentation the VRemin II was still in development, and was basically a prototype -version, which might have affected their results.

Ward et al. [44] published a paper in which they studied the movements of two acclaimed thereminists, Clara Rockmore and Lydia Kavina by using the Laban Movement Analysis (LBA). LBA is a method of analysing the bodily movements in qualitative way, originally developed by Rudolf Laban, an Austro-Hungarian dancer and dance theorist. [45] Ward et al. concluded that the central aspect in the movements of these two thereminists, which should be understood when researching new musical interfaces, is the relationship between the Exertion and Recuperation. By this it is meant that in designing new forms of musical interfaces, the flow and the time to rest between the motions controlling the instrument, which are important from the perspective of the musicians, must be kept in mind.

3 Technical description

This part of thesis covers the details of technical implementation of the interface, and the scientific theory relevant to it, mainly in the area of digital signal processing. Both the hardware and software structure of the interface will be covered, as well as the specific used technologies.

3.1 Theoretical aspects

In this section the author will present a brief overview on the theoretical aspects of signal processing regarding the techniques that were used in the implementation. Theory of EMG sensors is also described shortly.

3.1.1 Properties of sound & digital signal processing

Sound, as a physical phenomena, is a series of pressure changes produced by material causes, travelling through air in waves, which are observed by the mechanisms in the inner ear and transformed in to information in the brain of the observer. According to the standards of the Acoustical Society of America, it is defined as:

> *Oscillation in pressure, stress, particle displacement, particle velocity, etc., propagated in a medium with internal forces (e.g., elastic or viscous), or the superposition*

of such propagated oscillation. [1]

Computers do not process or create sound. What they do process is numbers. Thus, to create a sound with computer, we must represent it mathematically and construct a digital audio signal that represents the variations happening in the air pressure in imitation to physical sound. [46] Mathematically the structure of a sound can be represented in various ways, but for the purposes of this study the relevant representation is the sinusoidal wave[2], which is defined as [47]:

$$y(t) = Asin(2\pi ft + \gamma) = Asin(\omega t + \gamma)$$

In the 1924-28 [48] [49], pioneer of signal research Harry Nyquist made certain observations about the effects of the sampling rate, which are nowadays known as the Nyquist theorem. In short, the theorem postulates a Nyquist frequency [50] which is half of the sampling rate, and if the input signal frequency is higher than this, it becomes aliased. Put in other words, this means that the sampling rate must be at least twice the bandwidth of the input signal. The aliasing that happens if this requirement is not met means that the higher frequencies of the input signal become indistinguishable from the lower frequencies. To remedy this, there is often need to use anti-aliasing filters. A very simple kind of anti-aliasing has been implemented in the software.

Other technique of signal processing which has been used in the implementation of the interface is feed-forward filter [50] in the software that is run in the Arduino,

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[1] https://asastandards.org/working-groups-portal/asa-standard-term-database/

[2] https://mathematicalmysteries.org/sine-wave/

to both cut out the noise from the EMG signal received from the sensor, and to increase the actual signal value. This was done because the signal in itself was very noisy, and it was determined in the development phase of the interface that the actual signal emanating from the muscle was almost impossible to detect beneath the noise. Thus, a filter that cuts out the background noise, and amplifies the remaining actual signal was implemented.

Third signal processing technique that was needed was the use of phase shifting [50], which was also implemented in software that produces the sound.

3.1.2 Electromyographic sensors

EMG is a technology to detect and record bio-signals that happen in the muscle tissue. EMG -electrodes come in two main varieties: surface EMG (sEMG) and Needle EMG electrodes. As their name implies, the surface EMG -electrodes are attached to the skin over the muscle tissue, and non-invasively detect the signals, while needle electrodes are inserted directly to the muscle tissue. [51] The implementation discussed in this paper is based on the use of sEMG -electrodes, and for that reason we will not discuss the invasive forms of electromyography.

In this research, two units of Seeed Studio Grove EMG Detector -brand sensors were used with surface electrodes to record the activation of muscle units. These sensors were chosen because they are in the price range which was affordable at the time, meaning that they are in the low-end of the price range. This decision was mainly informed by the reason that this research has not gained any outside funding, and thus the monetary resources, or rather their lack of, forced this limitation. This probably affected the quality of the sEMG somewhat, as was explained in the previous section, although the EMG signals are known to be very noisy in any situation and with any equipment, due to the nature of musculature that produces them. [52]

Details of how exactly the EMG works in hardware level will not be discussed here, as they have been explained in many of the works cited in this thesis (see [52] and [21] for more details), and would be irrelevant for the topic of this research in general.

3.2 Hardware

The hardware of the device consists of four main parts plus the computer which runs the software:

- *EMG electrodes.* EMG electrodes are used to record the signals from the users muscles. The setup uses common gel electrodes which connect to the skin of the user by sticker like surface.
- *EMG sensor.* The role of the EMG sensor is to capture and process the signal coming from EMG electrodes, and pass it onwards to Arduino MEGA. The setup of the device consists of two such sensors, one for the control of the frequency and other for the control of the amplitude of the resulting sound. The brand of sensors used in this project is the Seeed Studio Grove EMG Detector[3].
- *Base Shield.* The EMG sensor connects to the Arduino MEGA through an intermediary component known as the Base Shield, which has suitable input ports for the sensors. Total of 16 sensors can be connected simultaneously to the Base Shield, although only two will be used in the device described in this study. The brand of the Arduino Base Shield used in the device is the Seeed Studio Base Shield V2[4].

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[3] https://wiki.seeedstudio.com/Grove-EMG_Detector/

[4] https://www.seeedstudio.com/Base-Shield-V2.html

- *Arduino MEGA*[5] The signals are passed on to Arduino MEGA, which connects to the computer and relays the signal to the software the computer is running. The software running in the Arduino MEGA is responsible for filtering the static noise from the signal.

- *Computer*. The software of the instrument is run on the computer. The software performs the operations that calculate the note based on the input signal, based on which the sine wave is formed and placed in the buffer, from which it is played.

The layout of the whole system, including the user and the output devices of the computer, is explained in the Figure 3.1. The user is connected via electrodes to the EMG sensor. EMG sensor is connected via Base Shield to Arduino MEGA. Arduino MEGA is connected to the computer via USB cable. The computer performs the operations of signal processing and sine wave generation, which is played via speakers connected to the computer.

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[5] https://store.arduino.cc/products/arduino-mega-2560-rev3

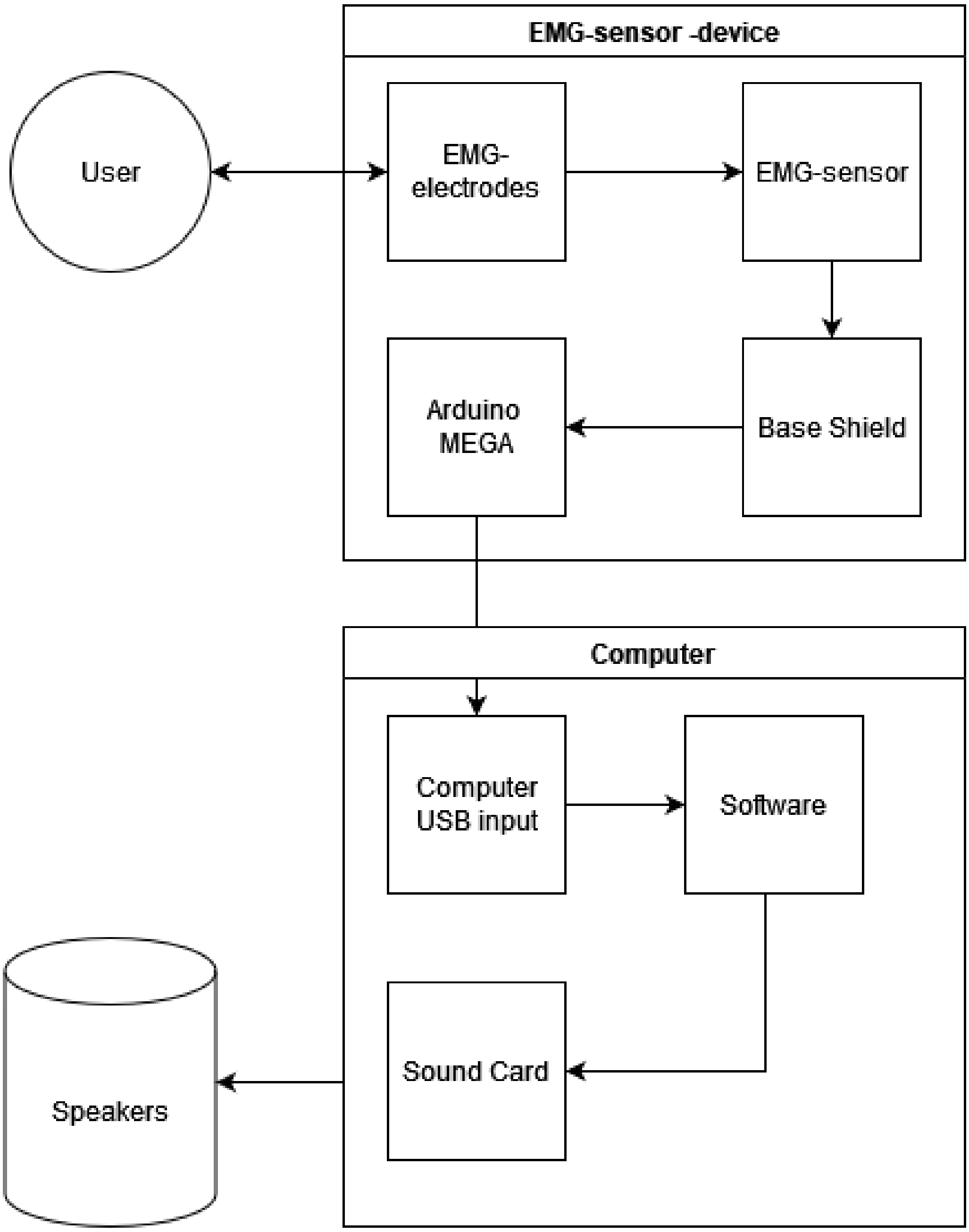

Figure 3.1: Hardware layout

3.3 Software

3.3.1 Algorithm description

In Figure 3.3 we see the control flow of the program running in Arduino. System initializes loop which checks for input signal from the EMG sensor. If signal is received, the signal strength is checked against the static analogue noise value, which is somewhat different for all different users, and must thus be configured separately every time a new person uses the interface. If signal strength is stronger than the static noise, it will be amplified by 1/10 of the value of the previous signal strength, and the input value will be cumulatively added to the previous result value. If the previous signal value is above zero, it will be divided by 4 with each loop iteration. If the value is less than the static analogue value, a decreasing factor will be calculated which is 1/10 of the input value, after which the returned result will be input - decreasing factor. After either of these the returned value is passed as a parameter to a map function which calculates a value between 0 and 99 based on it. This value will then be streamed by the Arduino to the software running on computer.

In Figure 3.2 we see the control flow of the main program run on the computer. On the program initialization, the application will check if the Arduino is connected to the computer. If it is not, the system will inform the user. If the Arduino is connected, the system will initiate a loop where it tries to get signal values coming from the Arduino data stream, and convert them to double values. The value of the signal 2 is subtracted from the value of the signal 1, and the resulting double value is passed as a parameter to the function that creates sine wave. At this point the function will also make the needed signal processing adjustments to the generated sine wave (phase shifting and anti-aliasing) to enhance the output quality. Then the sine waves are added to a buffer, after which the system checks if there is already sound playing, and if not it will play the first sine wave in the buffer. Then the buffer removes the played sound.

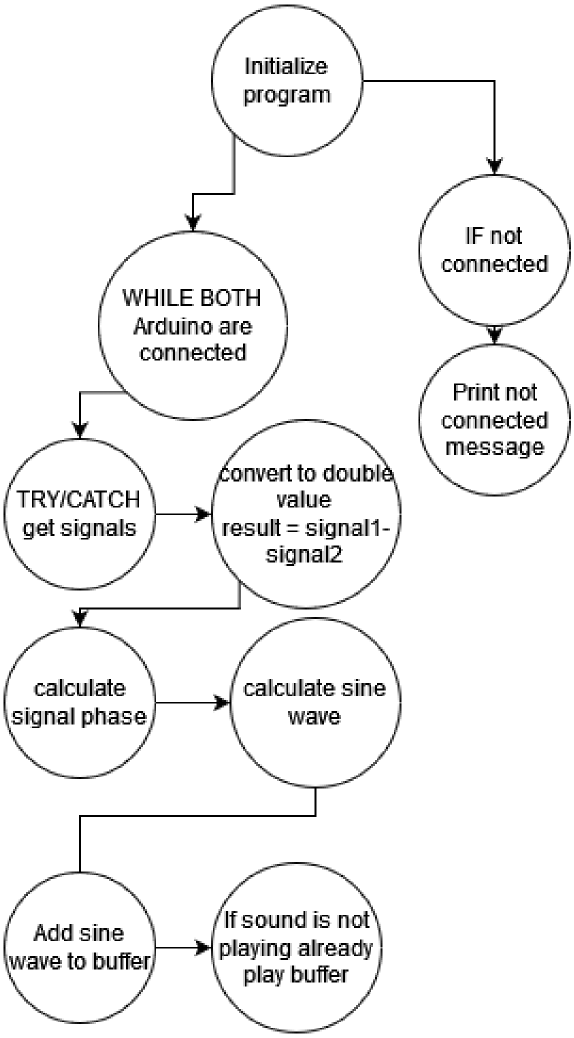

Figure 3.2: Main algorithm layout

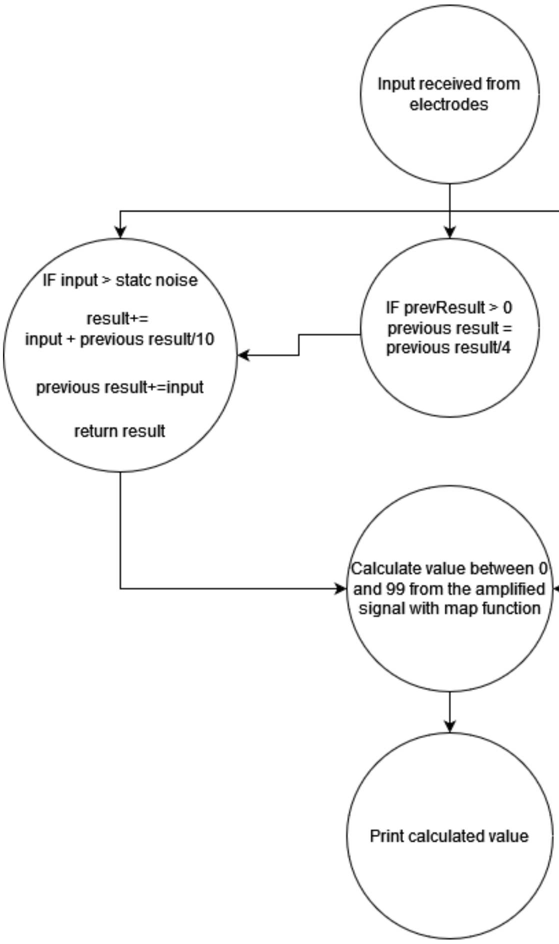

Figure 3.3: Arduino algorithm layout

3.3.2 Implementation

The implementation consists of two different computer programs, which communicate with each other; a script running in the Arduino MEGA, and the one running in the computer. The implementation of these software components is written in C++ for the program that runs on the computer, and with Arduino native language that is based on C++ for the software that runs on Arduino. The choice of the language was informed mainly by the research literature [46] which strongly recommends C++ as the go-to language in these kind of development projects.

The software which produces the sounds has been partially implemented using the SFML library[6], which offers various classes and methods for construction and manipulation of buffers and sound playback. In retrospect, this choice has not been the best possible, as the properties of SFML are not optimally suited for real-time sound generation, but for the purposes of this study they have still been sufficient. Majority of libraries which would have suited the needs of this study better would have been proprietary, with too expensive licenses for me to utilize them for this research.

The software in Arduino MEGA functions in following way:

1. Signal is received from the EMG sensor.
2. Signal is filtered with a feedback filter to reduce the noise.
3. Signal value is printed so that the software running on the computer can read it.

Described in short, the software in the computer functions as follows:

1. Input from both sensors is received from the Arduino MEGA through analog connection.
2. Input is converted to double values A and B.
3. Input value B is subtracted from input value A.
4. End result is given as parameter to function that chooses a frequency of a note based on the value and returns it. If the value is negative, it returns a corresponding note on the low end of the spectrum, if the value is positive, it returns a note from the high end of the spectrum.
5. Returned value is given as a parameter to a function that returns a a sine wave.

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[6] https://www.sfml-dev.org/

6. Returned sine wave is placed in to buffer
7. Buffer is played

The program codes for these implementations can be seen in the GitLab repository.[7].

3.4 Using the interface

To use the interface, the player must first connect the electrodes to their muscles in certain positions. The tests conducted in this paper have all been done with a certain specific positioning of the electrodes, shown in Figure 4.1, which was determined to be most usable by the author of this research, but undoubtedly other configurations for positioning of the electrodes also exist.

After the electrodes have been attached, the sensor cables are attached to them, and the sensor is connected to the Arduino MEGA via Base Shield. Arduino MEGA is connected to the computer via USB cable. The program that generates the sound based on input is started, and if it detects the sensors, it starts creating sound based on input.

The player of the instrument creates the input by flexing the muscles of his arms, in essence by contraction and movement, which is registered by the sensor. In essence the sensor of the other hand creates negative values, and the other positive, which are combined by the software to produce the end result. By combining the movement of both arms the player can produce note in the “middle” range (C4).

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[7] https://gitlab.utu.fi/papuht/gradu_erikoistyo_repo/-/tree/master

4 Study setting & methodology

The electrodes that record the signal that is used to control the sound are placed in the outer forearm, along the outer brachioradialis muscles so that the positive electrode is closest to the elbow, followed by the negative and the ground being placed at the end of the muscle, at the bony protrusion at the wrist area. The exact positioning of the electrodes is shown in Figure 4.1. This positioning has been decided through empirical testing in the software development phase, during which it was determined to allow for the most precise control of the signal, as opposed to other potential muscles. However, as such it is based on anecdotal evidence from one person, the author of this study, and it is possible that better positioning of the electrodes could be determined by conducting tests with larger number of participants. This may merit further research in the future, with larger sample size.

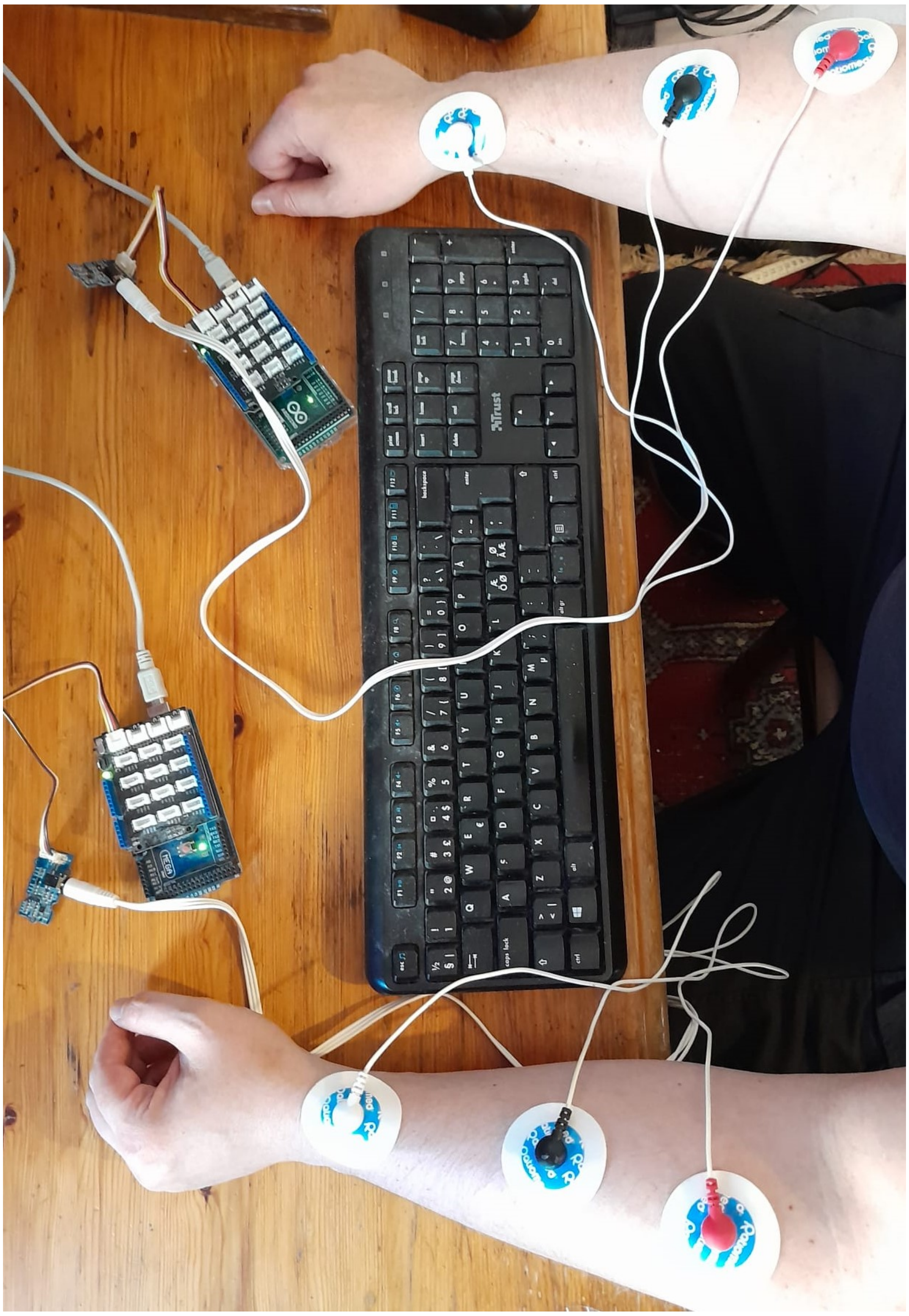

Figure 4.1: The interface device and electrode positioning

A group of five test subjects was chosen, with the deciding factor for the participation being previous experience in knowing how to play any kind of instrument. In other words, all of the participants were more-or-less experienced as musicians, some as hobbyists and some as professionals. Due to temporal constraints the number of test users was limited to 5 and the participants for the research were recruited from the social network of the author. While this may affect the end results to some degree, it must be noted that despite this the profiles of the test users have significant variance, providing perspectives from all ends of the spectrum of the musical proficiency, ranging from very beginner level skill sets to actual musical professionals. The profiles of the test subjects were following:

- **Test subject 1:**
  - Male
  - 10 years old
  - Has recently started to study bass guitar in music school
  - Has learned to rap some years ago
- **Test subject 2:**
  - Male
  - 12 years old
  - Has studied guitar for 4 years in music school
  - Has played in a band
- **Test subject 3:**
  - Female
  - 31 years old
  - Has studied violin for 11 years in the music school, and has completed the 3/3 basic degree on it
  - Has learned to play piano and guitar solo (without instruction)
  - Has sung in a choir for 10 years

  - Has participated in several musical projects, live performances and bands
  - Has released music online
- **Test subject 4:**
  - Male
  - 42 years old
  - Has studied guitar playing solo (without instruction) for more than 15 years
  - Graduated as a music technician from the Ammattiopisto Lappia Tornio unit
  - Bachelor of Arts in Musicology from University of Turku, currently pursuing Masters in Musicology
  - Has produced music
  - Has participated in several musical projects, live performances and bands
  - Has released music online
  - Works as a music technician by profession
- **Test subject 5:**
  - Male
  - 43 years old
  - Has studied bass guitar playing solo (without instruction) for roughly 30 years
  - Has played in various bands and live performances
  - Has released music online and in physical records

The test subjects had first the electrodes attached to their arms by the author of this study, so to ensure that the positioning would be exactly same for all of the participants, after which the sensors were connected to the electrodes. This was followed by calibrating the interface to respond correctly to the unique static analogue values of the specific user, as this value differs somewhat with each participant and thus had to be configured uniquely for each of them to make the interface respond correctly and in uniform fashion. After this the participants were given as much time as each felt necessary to experiment with the interface. Video recording of several minutes was taken of all test sequences for documentation purposes, but the entire played musical sequences were not recorded as to not interfere with the test users willingness to freely experiment with the interface.

After playing the instrument, the test subjects were given a questionnaire which contained both open-answer questions to gauge their opinions about this kind of interface, and a set of multiple-choice questions through which they graded their experience in the scale from 1 (Extremely Negative) to 5 (Extremely Positive). The open-answer questions were:

1. What is your overall impression about this kind of interface?
2. Compared to other instruments you have played, was this interface intuitive to learn?
3. Would you use this kind of instrument in musical performance?
4. How do you feel, as a musician, that this interface should be further developed?
5. What is the greatest drawback in this kind of interface, if any?
6. Other observations:

The multiple-choice questions given to the test subjects were:

1. How would you rate the overall experience of using this kind of interface, from 1 to 5?
2. How would you rate the usability of this system, from 1 to 5?
3. How would you rate the comfort factor of using the system, from 1 to 5? Explain this answer verbally also. (How comfortable or not comfortable the interface is to use).

5 Results

Presented in this chapter are the results of the research. We will first go over the answers to the open questions, and then take a survey of the Liker scale questions and what key observations arise from both of these question categories. The full answers in their original form can be found from the appendix.

5.1 Answers to open questions

Questions were presented to the users in English, but explained in Finnish if the test user answering the question felt that they needed clarification. Test users (TU from this point onwards) were given the option of answering the questions in either Finnish or English, whichever felt more natural. All of the test users answered in Finnish, which the author of the study has translated to English. Answers to the open questions ranged from one-word responses to sentences and whole paragraphs in length. Perhaps not surprisingly, longest answers were given by the two test users with most musical education, numbers 3 and 4, and these answers also reflected the most on the quality of the experience. In the following we will break up the answers categorized by the questions.

5.1.1 Question 1: What is your overall impression about this kind of interface?

In general, the test users where of the opinion that their overall impression of the interface was positive. These ranged from TU1 only stating that the "experience was good" to TU3 being of the opinion that it was rewarding to learn to produce new sounds from the system. TU4 commented that the most interesting part of the interface was the non-haptic way of using, but also that this made the interface very challenging to understand. TU5 answered that the concept and the functional logic of the interface was interesting, and TU2 that the experience was interesting, and that the idea felt "possibly potential".

5.1.2 Question 2: Compared to other instruments you have played, was this interface intuitive to learn?

Answers to this question, on the other hand, showed that 4 out of the 5 TUs felt learning to use the interface to be non-intuitive and even hard. TU4 reflected upon this by saying that the logic of using this kind of musical interface was so foreign compared to anything he had learned before, that the previous musical experience did not matter very much, if at all. TU2 was of the opinion that trying to learn to use the interface was confusing, while TU1 was of the opinion that it was "semi-reasonable". TU5 was of the opinion that getting the exact signal control was the hardest part, which reflected in difficulty of keeping the rhythm of the sound stable.

Interestingly, only the TU3 reported that she felt successful in learning to control the instrument, although after certain difficulty at first. She was also of the opinion that learning to produce sounds in orderly fashion from the interface was very challenging, due to the fact that it differed so much from what she was used to with other instruments.

5.1.3 Question 3: Would you use this kind of instrument in musical performance?

Answers to this question ranged from ambiguous “Perhaps” from TU1 to strict “No” from TU2 to clear “Yes” from the TU5. TU3 was of the opinion that if the interface could be made to accommodate larger scale of notes it can play, it could be used to make very interesting live performances due to the bodily aspect of playing it. She also reflected that in such a fashion, this kind of interface could be used in creating very interesting video performances incorporating dance. TU4 was of the opinion that he would use this kind of interface in a performance, mainly due to its novelty and innovative nature.

5.1.4 Question 4: How do you feel, as a musician, that this interface should be further developed?

Answers to this question mainly boiled down to technical improvements that could be made to the interface to make it better responsive to the users controls, and there was some form of consensus in their answers. 3 out of 5 TUs (TU2, TU4 and TU5) were of the opinion that the interface responded too slowly to their movements, which made keeping the rhythm hard, or even impossible. 2 out of 5 TUs (TU3 and TU4) suggested improving the note range of the interface to be capable of producing sounds on a larger frequency range than what it was currently capable of. TU2 also commented that the logic of using the system would need improvement. Only the TU1 did not find anything to improve in the interface.

TU4 also offered further development ideas, including creating a viable user interface for the software for controlling the settings of the EMG interface, which would allow for the user to choose which kinds of sounds the interface produces.

5.1.5 Question 5: What are the drawbacks in this kind of interface, if any?

Answers to this question were as varied as the TUs, although one common theme that was present in 2 of the answers was that the use of gel-electrodes was uncomfortable, especially when removing them. TU1 was of the opinion that the interface had no drawbacks. TU2 stated as only drawback the aforementioned discomfort with the electrodes. TU3 said the same, but also that when using the interface for long, it tends to put certain strain on muscles as they are constantly flexed and contorted. However, she also felt that this was kind of natural for an interface that is based on EMG signals. TU4 restated his earlier opinion that keeping up with the rhythm was hard, and that it was hard to find rhythm intuitively. TU5 was of the opinion that if the ideas he represented in answer to question 4 were implemented, the interface would otherwise have no drawbacks.

5.1.6 Question 6: Other observations

Only one of the TUs commented on this question, the TU2. He wanted to emphasize that the interface was hard to use.

5.2 Answers to Likert scale questions

Answers to the three Likert scale questions showed surprisingly little variance. In a nutshell, it can be said that only one of the TUs found only one aspect of the interface, the overall experience to be Extremely Positive (5), while none found it to be extremely negative.

5.2.1 Overall experience

Answers to the “How would you rate the overall experience of using this kind of interface, from 1 to 5?” received the average of 3.72 on the Likert scale, which clearly indicates that the overall experience was considered to be more positive than negative.

As can be seen from the Figure 5.1, the experience was in general well received by the TUs. Both TU1 and TU5 gave it 4 points, and TU4 even 5. TU2 and TU3 were more reserved in their evaluations, finding the overall experience to be not great but not bad either.

The reasons for TU1 and TU5 feeling better about the overall experience might be related to the fact that they are bass players, albeit of very different skill level. As the interface is currently implemented, it perhaps feels more at home to someone used to this kind of instrument, as opposed to violin and guitar instrumentalists.

However, the two guitar players TU2 and TU4, felt very differently about the overall experience. This might be relative to their other musical interests, as especially TU4 has studied music from academical perspective, and has wide interest in all kinds of experimental forms of music, while TU2 is mostly interested in more traditional hard rock music.

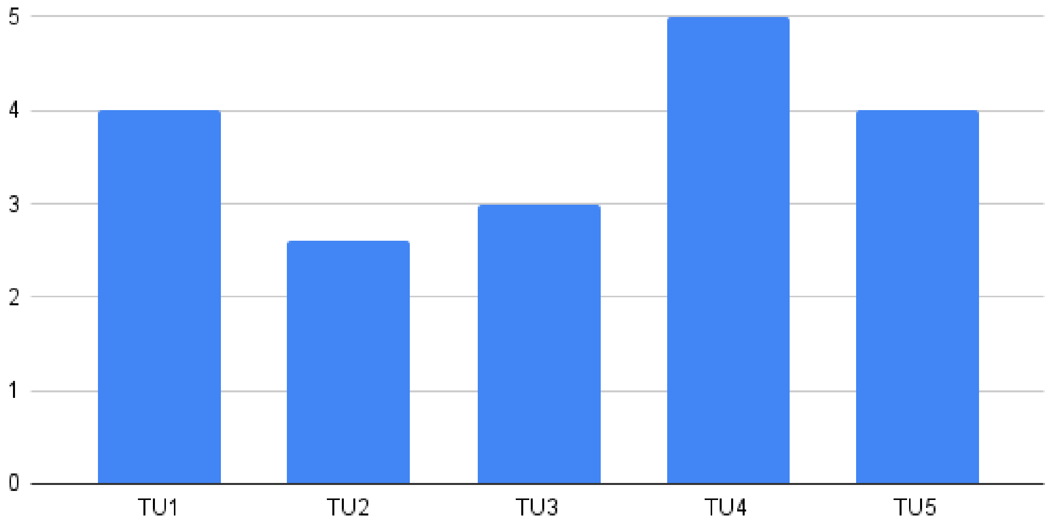

Figure 5.1: How would you rate the overall experience of using this kind of interface, from 1 to 5?

5.2.2 Usability

Average of the answers to the question “How would you rate the usability of this interface, from 1 to 5?” on the Likert scale was 2.9, which shows that the usability of system was considered to be less than optimal, although not definitely negative either.

Answers to this question, shown in Figure 5.2 were quite uniform. 3/5 of the TUs were of the opinion that the usability rated in the middle of the scale, being neither extremely positive nor negative. TU1 scored slightly higher than them, but only marginally so. Interestingly, TU4 who gave 5 points to the previous question, scored the usability as only 2 points, but he wanted to add a comment that this was reflective of the current state of the interface, in other words that it is only proof-of-concept and not a full product.

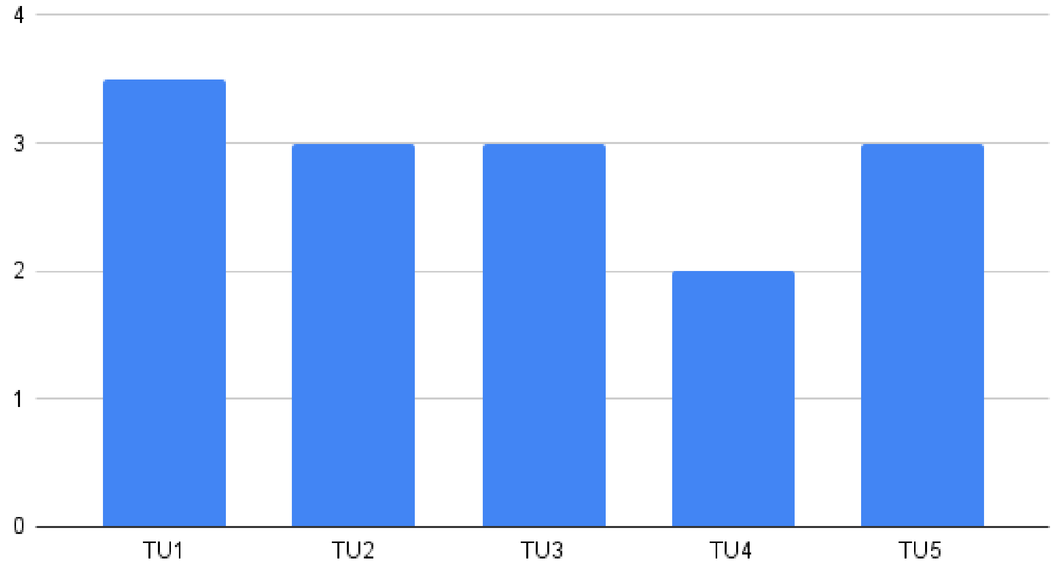

Figure 5.2: How would you rate the usability of this interface, from 1 to 5?

5.2.3 The comfort factor of using the system

Anwers to the question “How would you rate the comfort factor of using the system, from 1 to 5?” had the average of 2.8 on Likert scale, which implies that the comfortability of using the interface leaves much to be desired, although not being completely without merit.

Anwers about the comfort factor, shown in Figure 5.3, was considered to be quite consistent across the TUs, with all except TU2 rating it at 3 points. TU1, TU3 and TU4 were of the opinion that removing the electrodes was somewhat painful, although TU4 also noted that apart from this aspect the comfort factor of using the interface was pleasant and even therapeutic. TU3 was of the opinion that in addition to the removal of electrodes, the strain put on the muscles was slightly discomforting, as she had noted already in the previous answers. TU5 mainly felt that the difficulties in keeping the rhythm, which he had explained in many other answers also, decreased the comfort of using the interface.

TU2 commented that the interface using wired connection to electrodes created a feeling of impeding the movement and thus affected his evaluation. This is interesting result, as none of the other test users reported feeling like this, but it might be the result of the TU2 preferring wide horizontal hand movements when controlling the interface, while others focused, perhaps instinctively, to use less spatially requiring movements. TU2 was also of the opinion that the interface responded too slowly to his movements, which further decreased his opinion of the comfortability of the interface.

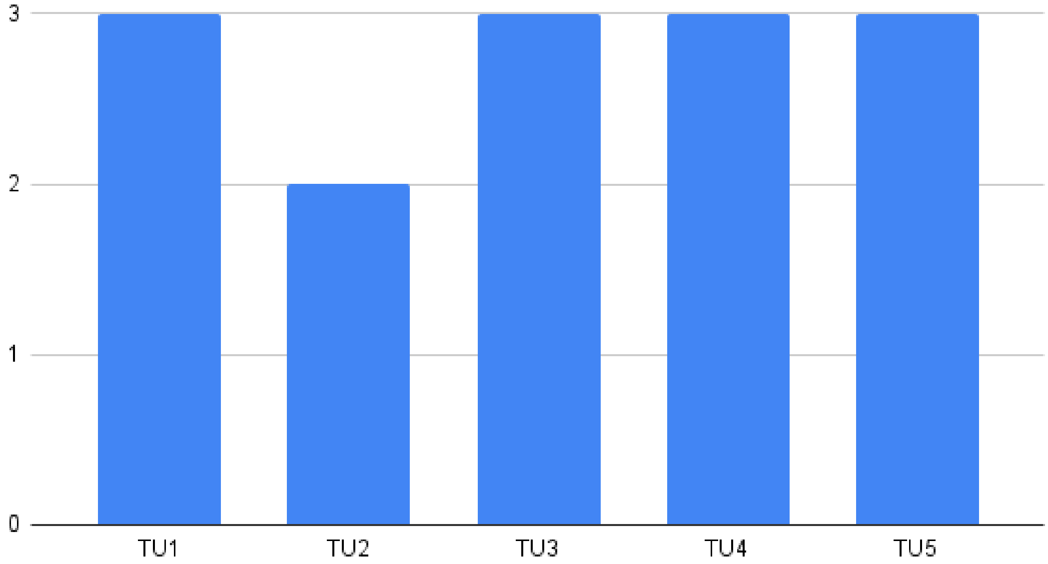

Figure 5.3: How would you rate the comfort factor of using the system, from 1 to 5?

5.3 Key Observations

Based on these results, certain patterns emerged:

- It is obvious that TUs with wider musical experience, and especially those who had studied music more extensively, perceived the interface in more positive light.

- However, TUs with more experience were also more critical of the technical faults of the interface. The only person with very little musical experience, TU1, was the least critical of the functioning of the interface in general.
- In many ways, the answers to the questions overlapped. This might be partially the fault of the author of this study in forming the correct questions or framing them in the right way, but it also highlights that the usability of this kind of interface, or any interface in general, is hard to decouple from the actual implementation. It should be borne in mind that the TUs were explicitly told to think only about the experience of using the interface when answering the questions, not the actual implementation, yet many of their answers reflected on various technical aspects of the system.
- In general, the experience of using EMG -based interface was positive, based on the overall experience valuating at 3.72 in Likert scale and many of the answers in other questions.

6 Discussion

In this chapter the author will reflect upon the results gained during the research and what can be learned from them. Retrospect on what might have effected results, and what should have been done differently for this to be more comprehensive take on the viability of EMG interfaces in general is also offered.

6.1 User Experience and Usability Testing

The answers that TUs provided after using the interface imply that there could be potential in developing these kind of interfaces further in future research, and that people interested in musical expression both as hobbyists and as professionals might be interested in them. This finding is quite important, as thus far the research and development of these kinds of interfaces has been mainly the area of either medical technology, with the musical implementations being a niche explored only by few dedicated researchers. Very few commercial products meant for consumer use even exist, and most of the technology available which utilizes EMG signals is hard to procure or made purely for some kind of research purpose. However, the results obtained by this quite limited scale survey nonetheless point towards the direction of this kind of musical interface having potential user base among musicians.

Only negative feedback not connected to the specific implementation of the interface, that was found from the answers, was the observation by TU3 that the constant flexing and contorting of the muscles can become fatiguing if done for prolonged periods of time. This is probably true, although it must be noted that there hardly is any other instrument or interface either that would not put some kind of strain on the user if used for longer time periods in a row.

6.2 Interface Implementation

Most of the negative aspects recorded during the questionnaire related to the actual implementation of this particular interface, which is after all a proof-of-concept and not a refined end product. It is obvious that things like gel-electrodes, which are attached to the skin with glued stickers, are prone to invoking negative responses from the users, and should not be used in a more professional project. Some other aspects which came up in the questionnaire, such as the limitations of the sound scale the software is currently capable of producing, or the response time of the interface to users muscular activity which affects keeping the rhythm, are things which could have been ironed out or improved upon if the author of this study would have had more time or resources.

This, combined with the results regarding the usability and user impression of the interface implies that if an interface for musical expression based on EMG signals is to gain any wider interest and acceptance amongst people doing and practicing music, it must have certain attributes:

- *Easy-to-remove and equip wireless electrodes*
- *Wide enough scale of control over the properties of sound*
- *Responsive enough to the users motions*

All of these features are essentially solvable with enough experimentation and with the use of correct technologies. EMG electrodes that are attached to the skin with less discomforting techniques, such as armbands or gloves with in-built electrodes exist, although mostly as prototypes for research purposes. Cui [31] deployed the Myo armband in their research, which was a commercially available product in this category. However, Myo has not been produced for some time now, and similar products have not entered the market in recent years. Absence of such refined devices means that the only option is to build such a device from the scratch, but this would require procuring the aid of researchers with more expertise in electronics.

The scale of sounds the current interface can play is limited to five different notes. The decision to limit the output to these five was based mainly on the observation made during the development that larger number of potential sounds would make the control of the specific sounds nigh impossible considering the basic structure of the interface in its current form. In other words, as the current implementation uses only linear input from the EMG sensors to determine the notes to play, it is quite impossible to control such a system with even the less than optimal precision the interface currently exhibits, if the possible outputs would be more numerous. To achieve better control over the properties of the sound, the method in which the signals are processed would have to be much more complex, most likely featuring the use of neural network that is trained to recognize specific hand gestures or other forms of muscular movements from the EMG signals, as has already been described in the Chapter 2. Other option would be to incorporate some other type of signal or measurement to add a dimension that would allow for more detailed recognition of muscle postures, such as the designs of Tanaka et al. [26].

Third key problem identified in the interface implementation was the perceived slowness of response to the movements. TU2, TU4 and TU5 were of the opinion that this made using the interface in orderly fashion and especially keeping the rhythm hard or even impossible. The reason for this slight lag in the current form of the interface is again in decisions made during the development, which were in this particular case forced by the choice of software libraries used to construct the buffer in which the generated sine waves are stored. The thing is, that without implementing two very minor wait times, one in the software run on Arduino (10ms) and other in the software run on the computer (1ms), the precision of control and quality of sound output would seemingly deteriorate to the point that would have made the interface unusable for any kind of testing purpose. With the use of libraries better equipped for handling continuous real-time signal input this could have been mitigated, but such libraries were either unavailable due to being licensed software or if free versions of such exist, they were unknown to the author of this study at the time of development. Other way in which this last point could be sidestepped is by removing the sound generation logic from the software completely, and instead using a hardware oscillator connected to the computer to generate the sound, using the software only to process the input signals from the EMG signals and converting it to control commands for the hardware. However, this option was not available for the time being, as procuring hardware oscillator was beyond the monetary resources of the author of this study.

6.3 Retrospect

Looking back now, reflecting on the choices I made during this project and their consequences, the author must conclude that many things should have been done differently. Foremost among these is the actual implementation of the interface, in which should have been used more external libraries, and on the other hand libraries better suited for the task at hand.

First of these points is mainly concerned with the signal processing part of the software; while the author managed to implement the techniques needed for this in rudimentary fashion, the outcome leaves much to be desired. The technical quality of the output would undoubtedly be better if different choices had been made, and instead some professional-quality library such as KFR[1] had been used. Second part has more to do with the part of the application that plays the sounds from the buffer. SFML library which was used to implement this part of the software is probably not the best option for this kind of work, and should be replaced with something more suitable for this type of sound generation.

In their defence the author would say that external circumstances, in many ways, forced their hand in these decisions. Not only are the high-quality signal processing libraries like KFR de facto proprietary, which put them out of the authors reach due to monetary reasons, but on the other hand the author also assumed that he would have had more time to complete the task at hand. They originally planned to have this whole year to complete this thesis, but due to changing circumstances and opportunities present at the academic world, development and research processes had to be severely hastened for the author to graduate now, and at certain point the author just had to declare that the interface is adequate for the research purposes. Which it is, thankfully, although not being the refined software application the author originally intended to produce.

6.3.1 Reflections on the Research

The lack of time also forced the authors hand in the recruitment of TUs, as the potential testers had to be sourced from people immediately available to the author of the study through personal connections. Original idea was to have much more TUs, preferrably 10 or even 20, and have more variance in their musical background and age than is currently present.

This poses certain problems for the validity of my test results, as it can not be absolutely ruled out that the TUs would not be biased to give too favorable evaluations about the interface due to their social proximity to the author of the

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[1] https://www.kfrlib.com/

study. However, as they were quite critical of the faults they perceived in the interface and in its usability, it perhaps at least proves that the bias was not too strong.

Other aspect of validity that should be considered is whether the musical background of the TUs, which in this study was quite narrow (2 guitarists, 2 bassists, 1 violinist), affects their evaluations to some degree, a factor which could be amplified proportionately by the small quantity of the sample size. What if the sample size would have been 10 musicians, with 2 musicians representing each main instrument?

From this we get to the third point, the disproportion in age and musical experience which absolutely was present in the sample size. Two of the TUs are children, with relatively little musical experience, while three of the TUs are adults with relatively long musical experience. Furthermore, only one of the TUs was woman, while others are men. In ideal situation the gender, age and experience distribution should have been harmonized in some way, preferably by having a group of TUs who are approximately of same age, experience level and either of the same gender or with the gender ratio being even.

In the future research all of these aspects have to be taken in to consideration when recruiting the test users, to ensure that such potential pitfalls for the validity of the research results would not arise.

7 Conclusions

In this thesis the author of this study has both documented the development of a proof-of-concept interface based on EMG signals and conducted a user experience research on how viable such a design is from the end-user, in this case musicians, viewpoint. While neither the interface nor the group of test subjects was optimal due to external factors, the study nonetheless produced interesting insights in to how this kind of interface should be developed and what considerations should be taken in to account.

The results point towards this kind of interface having potential interest for people studying and creating music, but they also highlight that for this kind of interface to be really viable from the perspective of musicians, it must fulfill certain requirements in usability and comfort factors. These requirements could be met with enough expenditure of time and resources in the implementation of the interface, which will be pursued in future research.

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Appendix A Answers to the questions given to the test users

A.1 Test User 1

What is your overall impression about this kind of interface?

KOKEMUS OLI HYVÄ

Compared to other instruments you have played, was this interface intuitive to learn?

SEMI JÄRKEVÄ

Would you use this kind of instrument in musical performance?

EHKÄ

How do you feel, as a musician, that this interface should be further developed?

Ei oikein oo tarvett parantaa

What are the drawbacks in this kind of interface, if any?

Ei

How would you rate the overall experience of using this kind of interface, from 1 to 5?

4

How would you rate the usability of this system, from 1 to 5?

3,5

How would you rate the comfort factor of using the system, from 1 to 5?

And explain this answer also verbally.

(How comfortable or not comfortable the interface is to use)

3 koska elektrodien irti otto sattuu vähän

Other:ei oikee oo mitää muuta

A.2 Test User 2

What is your overall impression about this kind of interface?

Kokemus on ok, mutta ideassa on mielestäni potentiaalia (ehkä)

Compared to other instruments you have played,

was this interface intuitive to learn?

Soitin oli kohtuullisen sekava oppia

Would you use this kind of instrument in musical performance?

en

How do you feel, as a musician, that this interface

should be further developed?

Soitin ei totellut komentoja loogisella tavalla, reaktioaika on hidas

What are the drawbacks in this kind of interface, if any?

Elektrodien kiinnittäminen ja irroittaminen on epämukavaa/ sattuu

How would you rate the overall experience of using this
kind of interface, from 1 to 5?

2.6

How would you rate the usability of this system, from 1 to 5?

3

How would you rate the comfort factor of using the system, from 1 to 5?
And explain this answer also verbally.
(How comfortable or not comfortable the interface is to use)

2 reaktioaika on hidas ja elektrodit rajoittavat käsien liikettä

Other: laite on vaikea käyttää

A.3 Test User 3

What is your overall impression about this kind of interface?

Mielenkiintoinen kokemus. Aluksi koin, että laite toisti suunnilleen samanlaista ääntä, mutta jonkin aikaa lihaksia liikuteltuani ja kuunneltuani laitteesta tulevia ääniä aloin huomata vaihteluita. Vaihteluiden hakemisesta tuli keskeinen osa testiä ja niiden löytämisestä palkitsevin osuus.

Compared to other instruments you have played, was this interface intuitive to learn?

Opettelu oli hyvin erilaista kuin muiden soittimien, sillä äänen korkeutta ja vahvuutta ohjattiin kokonaan lihaksilla. En voinut etukäteen tietää, millainen lihasten jännittäminen tai liikuttaminen tuottaisi tiettyä ääntä. Jonkin aikaa laitetta käytettyäni pystyin kyllä jo toistamaan tiettyjä ääniä, kun toistin tiettyjä liikkeitä ja jännitin lihaksia samaan aikaan suunnilleen samalla tavalla. Tämä oli laitteen käytössä palkitsevinta, kun sitä pystyi jollain lailla hallitsemaan.

Would you use this kind of instrument in musical performance?

Jos laitteen sävelkorkeuksiin saisi lisää vaihtelua
niin, että sitä pystyisi monipuolisemmin soittamaan,
voisin kuvitella että laitteen käytöstä saisi hienoja
esityksiä. Lihasten liikuttaminen tuo siihen lähes väistämättä
tanssillisen elementin, jota olisi varmasti katsojankin mielenkiintoista
seurata. Tämä oli itselleni yllättävän mielenkiintoinen osa koetta:
äänen tuottamisen lisäksi laitteen käytössä oli
visuaalinen elementti, jota teki mieli videoida.

How do you feel, as a musician, that this interface should be
further developed?

Toivoisin sävelkorkeuksiin suurempaa vaihtelua, esimerkiksi jo yhden
asteikon verran. Sitten laitteella voisi soittaa jonkinlaisia melodioita.
Olisin hyvin kiinnostunut kokeilemaan, miltä laite silloin kuulostaisi.
Tämä on itselleni tärkein asia ja oikeastaan kynnyskysymys, jos haluaisin
tehdä musiikkia tällä laitteella.

What are the drawbacks in this kind of interface, if any?

Kuten jo edellä mainitsin, äänenkorkeuksia saisi olla enemmän. Laitteen käyttö voi myös olla pidemmän päälle aika raskasta lihaksille, jos niitä oikein jännittelee. Toisaalta sen voi ajatella kuuluvan asiaan, kun kerran käytetään laitetta, joka perustuu lihaksesta saatavaan signaaliin. Pieni negatiivinen puoli on myös elektrodien irrottaminen iholta, joka voi laastarin repäisyn tapaa hieman kirpaista ja jättää ihoon punoittavia jälkiä.

How would you rate the overall experience of using this kind of interface, from 1 to 5?

3

How would you rate the usability of this system, from 1 to 5?

3

How would you rate the comfort factor of using the system, from 1 to 5? And explain this verbally. (How comfortable or not comfortable the interface is to use)

3

Laitteen kytkemisessä kiinni ei ollut mitään epämukavaa. Laitteen käyttäminenkin oli muuten mukavaa, mutta pidemmän päälle lihasten jännitteleminen teki siitä hivenen raskaan. Ei kuitenkaan niin raskaan, ettei laitetta olisi jaksanut käyttää tai että käsiä olisi tarvinnut lepuuttaa.

Laitteen irrottaminen oli hieman epämukavaa, sillä elektrodien repäiseminen irti ihosta kirpaisee. Iholle jää myös joksikin aikaa punoittavat jäljet elektroditarroista.

A.4 Test User 4

What is your overall impression about this kind of interface?

Mielenkiintoinen laite, johtuen erityisesti käyttöliittymän erilaisuudesta niin sanottuihin ''perinteisiin'' soittimiin verrattuna. Itselläni ei ole kovinkaan paljoa kokemusta vartalon impulssieihin reagoivien soittimien soittamisesta, minkä vuoksi soittimella soittamisen opettelu on varsin haastavaa.

Compared to other instruments you have played, was this interface intuitive to learn?

Ei. Aikaisempien perinteisten länsimaisten soittimien soittaminen eroaa niin perustavanlaatuisesti tämän soittimen soittamisesta, että aiemmalla soittotaidolla ei tätä soittaessa ole juurikaan merkitystä.

Would you use this kind of instrument in musical performance?

Kyllä, ehdottomasti, johtuen sen erilaisuudesta ja innovatiivisesta käyttöliittymästä.

How do you feel, as a musician, that this interface should be further developed?

Soitin olisi hyvä saada reagoimaan nopeammin kehon liikkeisiin. Liikkeiden ja äänentuoton välinen viive tekee esimerkiksi ryhtmisten kuvioiden soittamisen mahdottomaksi. Lisätoiveena olisi myös vaikutusmahdollisuus soittimen tuottamaan äänenkorkeuteen. Laitteen tuottamia ääniä olisi hyvä päästä myös muokkaamaan. Eli toisin sanoen laajempaan sample-kirjastoon olisi hyvä panostaa. Käyttöliittymää olisi myös hyvä viedä käyttäjäystävällisempään suuntaan, joka mahdollistaisi soittimen itsenäisen käytön myös ohjelmoinnista vähemmän tietäville soittajille.

What are the drawbacks in this kind of interface, if any?

Jos soitin kehittyy edellämainittujen seikkojen suhteen soitettavammaksi, on vaikeaa nähdä soittimessa mitään varsinaisia huonoja puolia.

How would you rate the overall experience of using this kind of interface, from 1 to 5?

5

How would you rate the usability of this system, from 1 to 5?

2, soittimen ollessa vielä tässä kehitysvaiheessa.

How would you rate the comfort factor of using the system, from 1 to 5?
And explain this answer also verbally.
(How comfortable or not comfortable the interface is to use)

3. Soittimen soittaminen on miellyttävää ja terapeuttista. Miinuspisteet tulevat elektronien kiinnittämiseen käytettyjen tarrojen kiinnittämisestä

ihoon, jotka poisvedettäessä vievät soittajan ihokarvat mennessään.

Other:

A.5 Test User 5

What is your overall impression about this kind of interface?

Kiinnostava konsepti ja toimintalogiikka

Compared to other instruments you have played, was this interface intuitive to learn?

Hiukan hankala saada signaalikontrolli ja sitä kautta rytminen ulottuvuus

Would you use this kind of instrument in musical performance?

Kyllä

How do you feel, as a musician, that this interface should be further developed?

Parantaa signaalikontrollia tasaisemman rytmin tavoittamiseksi

What are the drawbacks in this kind of interface, if any?

Rytmisyyttä hankala tavoittaa intuitiivisesti, rytminvaihdoissa haastetta

How would you rate the overall experience of using this kind of interface, fro

4

How would you rate the usability of this system, from 1 to 5?

3

How would you rate the comfort factor of using the system, from 1 to 5?
And explain this answer also verbally.
(How comfortable or not comfortable the interface is to use)

3

signaalikontrollin hakeminen ei helpointa. Rytmin ylläpito haastavaa.

Other: