The Augmented Drumstick

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-
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Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Graz, June 2, 2019

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Kurzfassung

Elektronische Musik und Live-Elektronik haben die Klangmöglichkeiten maßgeblich erweitert, aber auch einige Diskussionen über die musikalische Darbietung ausgelöst. Die vorliegende Masterarbeit befasst sich mit dem Problem, wie akustische Klänge mit Live-Elektronik kombiniert werden können, ohne die musikalische Performance beim Schlagzeugspielen zu beeinträchtigen und bietet einen Überblick über den aktuellen Stand der Forschung zur Frage von Kontrollern für Live-Elektronik mit der Schwerpunkt auf das Schlagzeug. Der Forschungsteil befasst sich mit dem Thema *Augmented Instruments* und der Bedeutung von Performativität und Ausdruckskraft im Bereich der Live-Elektronik. Das Ergebnis dieser Arbeit ist die Entwicklung eines neuen *Augmented Drumsticks*, eines Musik-Kontrollers, mit dem Musiker die Klang- und Leistungsfähigkeiten bei einem Instrument wie etwa dem Schlagzeug ergänzen können, obwohl beim Spielen alle Gliedmaßen im Einsatz sind. Mit dem vorgestellten Ergebnis schränkt der Einsatz der neu entwickelten Technologie die musikalische Schlagzeugleistung nicht ein, sondern bereichert sie.

Abstract

Electronic music and live electronics have definitely expanded the sound possibilities but have also led to several discussions about musical performance. This master thesis focuses on the problem of combining acoustic sound with live electronics when playing an instrument such as the drums without interfering with the musical performance. The present master thesis gives an overview of the context of controllers for live electronics with a focus on drums. The research part explores the topic of augmented instruments and the importance of performativity and expressiveness in the area of live electronics. The result of this work is the development of a new augmented drumstick, a music controller that allows the performer to broaden the sound and performance capabilities when playing an instrument such as the drums, where all limbs are involved. With the presented result, the usage of the newly developed technology does not limit the musical drum performance, but rather augments it.

Chapter 1

The Sound Control

Using live electronics expands sound possibilities, but this does not always mean that the performativity is expanded as well. This thesis focuses on finding a way to combine and especially control electronic and acoustic sounds, naturally during the drumming performance. The theoretical part examines several controllers for electronic music with a particular focus on drums. Another section is dedicated to augmented instruments and how performativity can be enhanced.

1.1 Music Controllers

Different musical interfaces have been developed for controlling or making electronic music. One of the first sensor-based controllers for electronic music is *The Hands*, developed by Michel Waisvisz in 1984, at that time director of the institute STEIM[1], an independent research center for experimental electronic music. Thanks to the emergence of the MIDI, a revolutionary protocol based on messages that enabled communication between synthesisers and sequencers, there was the possibility to create new electronic instruments. After experimenting with the Crackle instruments which are based on analog circuits attached to the human body (*1984 - 1989 The Hands (first version)*), Waisvisz was able to develop new controllers for making electronic music. As the author asserted in an interview (Krefeld, 1990) with Krefeld, the innovative controller (Fig. 1.1) let him translate

> "hand and finger movements into controller information, and most importantly [...] route this information through a pattern of conditions to various sound synthesizers and [...] store sounds, short motifs, all sorts of patterns, names, addresses, letters, etc."

The innovative instrument developed consists of sensors and keys mounted on two keyboard that are placed in the hands of the performer. The combi-

[1] Studio for Electro Instrumental Music, for more information see http://steim.org

Figure 1.1: *The Hands II* (1991), second version of *The Hands* by Michel Waisvisz (*The Hands*)

nation of many different sensors make it possible to capture the movements of the player. These movements are then translated to sound through the SensorLab[2], an analog-to-midi interface developed at STEIM that can convert data into the MIDI protocol. During his first performance with The Hands that took place at the Amsterdam Concertgebouw in June 1984, the controllers were connected via MIDI to three Yamaha DX7, which had been specially programmed for this purpose. Based on this experience, different controllers were developed over the years: the sound artist and composer Laetitia Sonami presented her *Lady's Glove* for the first time at the Art Electronica Festival in Linz in 1991. The first version of this controller consisted of gloves where a magnet was attached to the hand and there were five Hall effect transducers on the fingers. By touching the magnet with the fingers, it was possible to create different voltages. These were then translated

[2] http://steim.org/support/sensor.html

into MIDI signals in order to control different synthesizers and samplers. After this first realization of the *Lady's Glove*, Sonami developed several other versions (see Fig. 1.2) by placing the sensors in a different position, hiding the wires and so on. Both the design and the hardware were changed, heightening the whole performance and controlling not only sound but also lights, motors and video (*lady's glove*). The Sensor Board Trio, which con-

Figure 1.2: *Lady's Glove* by Laetitia Sonami (*lady's glove*)

sisted of the composers and musicians Edwin van der Heide, Atau Tanaka and Zbigniew Karkowski, also experimented with music controllers based on sensor technology. The trio, which started performing in 1993, used different sensors to transform gestural movements into sound. Edwin van der Heide developed the MIDI conductor, an instrument that obtained data on the relative distance and rotational position of his hands thanks to ultrasound technology. Zbigniew Karkowski was able to link the movement of his arms to sounds by using infrared beams. Atau Tanaka translated neural signals (EGM) into data with his instrument BioMuse (*Atau Tanaka*). The trio also developed the Soundnet (*Soundnet*), a gigantic interactive live performance musical instrument inspired by the *The Web*[3], a project by the pioneer Michel Waisvisz. The structure of this enormous net (11 m x 11 m) was constructed with 16 mm of thick shipping ropes with eleven sensor attached to the extremities. This makes it possible to measure the movements and stretching of these ropes. The data collected were used to control a DSP to process the sound material, composed with digital recordings and natural sounds.

1.1.1 Controllers in everyday life

Other controllers based on sensor technology for making music were developed with everyday objects. The music maker Kaffe Matthews, who focuses her exploration on the physical experience of music, built some music controllers with bikes, beds and armchairs[4]. The *Sonic Bike* is actually a continuously evolving project that is still subject of research and development. Originally it was a bike with a GPS system and loudspeakers. According to the location data given by the GPS, different compositions and sound fragments were playback on the loudspeakers. An interesting evolution of the *Sonic Bike* which is closer to the topic of this research project is the *Sensory Bike*. It is a regular bike equipped with different kinds of sensors as shown in Fig 1.3. The data captured by these sensors are then transformed into sound material (*Sensory Bike*).

1.2 Drum Controllers

Another interesting research area are music controllers related to the drum set. In the 1980s, the *Radiodrum* (also called *radio-baton*),was invented at the Bells Lab in New Jersey. The *Radiodrum* is a musical instrument made of two mallets that made possible their tracking in a three-dimensional space. It was originally designed by Bob Boie with the intention of establishing a three-dimensional mouse. But Max Matthews, who considered this invention as a promising tool in the musical field, developed the controller and made different versions that mostly used it as a conducting tool. It was not until later that this controller was also used as percussive sensor, thanks to Andrew Schloss, who further developed it in the late 1980s at IRCAM[5].

Nowadays, there are several commercial products geared towards drummers. In particular, they provide a solution for virtually playing a drum set or solving the problem or drum's practice. Some of them are based on sensor technology, while others use different detection systems. The following provides an overview of the most popular devices.

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[3] See the *Small Web* or *Belly Web* by Michel Waisvisz http://www.crackle.org/Waisvisz'%20Small%20Web%20(Belly%20Web).htm

[4] https://www.kaffematthews.net/about

[5] Institute for Research and Coordination in Acoustics/Music https://www.ircam.fr/

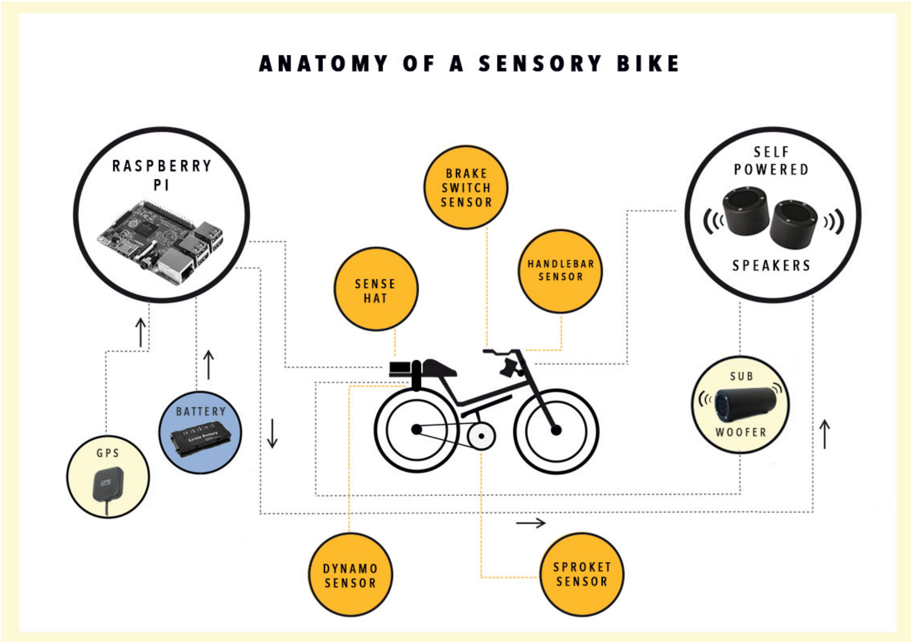

Figure 1.3: Anatomy of a *Sensory Bike*, from the Bicrophonic Research Institute (*Sensory Bike*)

- *Freedrum*[6] is a small device that can be attached directly to the drumstick. The system uses a sensor to detect the angle and the data are then transmitted via Bluetooth to a laptop or a smartphone where is possible to virtually recreate a drum set.
- *Arduino Air Drums*[7]: The technology used in this case is a combination of a three-axis accelerometer with a light sensor that can detect the hit of the drummer on a surface. The data are then processed with the Arduino micro-controller and converted into the MIDI protocol.
- *Hot hand USB*[8] Although it was not developed specifically for drummers, it can be also used to extend the drum performance. An accelerometer sensor that is embedded in this device is connected to a laptop with a proprietary hardware and software that translate the acceleration values into MIDI signals along the axes x, y, z.
- *Aerodrums*[9] is based on a different technology: A camera placed in front of the user tracks reflective material and reflective balls attached to the user's feet and the tip of the sticks.

[6] *Aerodrums* https://www.freedrum.rocks/
[7] *Arduino Air Drums* http://www.instructables.com/id/Arduino-Air-Drums/
[8] *Hot Hand USB* https://www.sourceaudio.net/hot-hand-usb.html/
[9] *Aerodrums* www.aerodrums.com

- *Drums Anywhere*[10] is based on a different system. A microphone is attached to a surface and by hitting this surface in different positions the system can differentiate between different signals.
- *Mogees*[11] works similarly to the previous device. The player is provided with a contact microphone that can be attached to any surface. By hitting this surface in several ways, it is possible to assign different gestures to different sounds or MIDI signals.
- *Cliphit*[12] developed by Korg works with several triggers that the user can attach everywhere. There is no problem with false triggering, which means that other wires need to be added to the system.
- *Senstroke*[13] also makes use of sensors that have to be connected to the drum sticks and feet, and it is possible to virtually recreate a drum kit wireless via Bluetooth.

1.3 Augmented Instruments

The term augmented instruments refers to acoustic or electric instruments that are augmented with sensor technology. The usage of sensor technology makes it possible for musicians and performers to have control over the sound processing or deal with some digital effects (Newton and Marshall, 2011). Impett's *Meta Trumpet* represents definitely a fundament in the history of augmented instruments.

> "This is thus a "meta-" instrument in that it consists not only of the trumpet itself, but also the physical actions performed to and with it, the acoustic output and the musical / logical behaviour of the whole. The sound of the instrument is integrated into the system, being directed to the sound processing elements, which in turn are controlled by the software whose input comprises the physical parameters of performance and of the sound itself. Different views in any number of dimensions can be constructed through the resulting continuous information / sound space, including the possibilities of folding parameters onto or inside each other, and the use of temporal processes." (Impett, 1994)

Impett says about the acoustic-electronic hybrid instrument he developed for the first time in 1993. As the author describes in his article (Impett, 1994), the instrument consisted of a trumpet fitted with different kinds of

10 *Drums Anywhere* www.drumsanywhere.com
11 *Mogees* https://www.mogees.co.uk/
12 *Cliphit* https://www.korg.com/us/products/drums/cliphit/
13 *Senstroke* https://www.senstroke.com/

sensors. The bell of the trumpet was equipped with a cluster of ultrasound transmitters and the receivers were placed at the side of and below the performer. With this configuration, it was possible to track the trumpet's position in a $2\,\mathrm{m}^2$ bi-dimensional space. Some pressure sensors revealed information on the contact of the performer with the instrument. In addition, magnetic field and breath pressure sensors were integrated into the trumpet to extend the number of possible parameters to control with the instrument. These parameters were then converted into MIDI signals with the SensorLab system and transmitted to a two-layer mapping of system and composition. Other interesting extended instruments are The Bahn's *Sensor Bass* (Fig. 1.4) and the *Rbow*[14] built by Trueman and Perry Cook. They are interfaces that

> "extend and abstract traditional approaches to live musical performance, and allow for a direct physicality and musical gesture to be communicated in electronic music" (Bahn and Trueman, 2001)

Figure 1.4: *Sensor Bass* by Curtis Bahn (*Sensor Bass*)

The *Sensor Bass* is a five string electric bass that has several sensors (slide, force sensitive, tactile sensors) mounted on it. The data obtained from the sensors are transferred via a micro-controller to the software MAX/MSP,

[14] *Rbow* http://dtrueman.mycpanel.princeton.edu/rbow/

where the parameters of the performance are controlled. A biaxial accelerometer, for example, is used here to control the dynamics with the movement and tilt of the bass. The choice rather to focus on the instrument itself instead of on the bow results from his style of playing, which is pizzicato most of the time. A different approach was used for the *Rbow*, where pressure and motion sensors are attached to the violin bow rather than to the instrument itself, in this case violin. In 2011, research on a tool that enables musicians to explore and experiment in the field of augmented instruments, referred to as *Augmentalism* was presented at NIME[15]. It was developed at the University of Bristol to help musicians extend their instruments and develop new musical performances. The system included both hardware (*Phidgets* sensors were used for this project[16]) and software that could assign the data provided by the chosen sensors to MIDI signals. Although the authors did not conduct experiments with drummers, they discovered that

> "the additional sensors then extend the performance possibilities of the instrument, thus allowing for more potential for creative exploration" (Newton and Marshall, 2011)

One example of live augmented drum kit is the live performance *Trrraction*[17] presented by Christos Michalakos during the *What Is Sound Design?* Symposium at *Inspace*, a festival in Edinburgh that took place in November 2013. Here different microphones are used to translate the movements and gestures from the performer into data that can control both the audio and visual feedback. Michalakos also added loudspeakers close to the drums so that he could play with a controllable feedback. This way, he could physically interact with the instrument, by pushing or muting the drum skins, for example. Another practical example based on augmented instruments was developed for the Synekine Project, a result of performance and scientific research presented by Greg Beller at the IRCAM in 2014. The system is based on a sensor tracking system. Part of this study focused on drums, which is why it is called *Augmented Drums*[18]. The gestures of the performer are recognized and connected to the modulation of effects, sound triggering, expansion and contracting of the time information of the sound material.

1.4 Performativity

> "The Rbow transforms the violinist into a kind of dancer" (Bahn and Trueman, 2001)

[15] New Interfaces for Musical Expression http://www.nime.org/
[16] Phidgets sensors https://www.phidgets.com/
[17] *Trrraction* by Christos Michalakos https://www.youtube.com/watch?v=FyjGaMLtT1Y&t=
[18] *Augmented Drums* by Greg Beller http://www.gregbeller.com/2014/02/augmented-drums/

The authors say about the performative aspect of the augmented violin bow. With acoustic traditional instruments, the performers are strongly in contact with the acoustic sound output of the instruments. The audience does not find it difficult to understand the connection between the gesture and sound that is produced. With new digital music instruments, the issue of the involving technology in a performance and this relation between the gesture and the sound produced has been widely discussed, from the time when realtime performances where possible with computer music (Schloss and Jaffe, 1993). In his article *Something Digital* (Puckette, 1991), Miller Puckette wrote about computer music that

> "there must be a direct and comprehensible relationship between the controls we use and the sounds we hear. (This would not be a bad thing from the audience's point of view either.) A performer who pushes a button to start a sequence is not showing us how the music was really made; all we learn about the music is what our ears can tell us. But if the performer's actions correspond more closely to the sounds themselves, then we can see something about the music's gestural content, and our own music can be better informed by it."

A live musical performance can certainly be extended with augmented or extended instruments. Trueman and Curtis also point to a connection between the interactive musical interfaces and the electronic sound:

> "By itself the Rbow suggests a variety of kinds of physical interaction with electronic sound; moving the frog in various positions, which may require moving the entire body, and simply pressing the bow in various location, all are effective ways of physically playing the Rbow" (Bahn and Trueman, 2001)

An interesting experiment is the tape-bow violin, an instrument developed in 1977 by the artist, composer and musician Laurie Anderson. It is an instrument with a bow that is made of tape instead of horsehair, and a magnetic tape head is placed on the bridge. Anderson used it during a performance film in 1986 to playback the voice of William Burroughs

> "Anderson incorporates the recorded voice of Burroughs in a way that confuses the anticipated relationship between what we see and what we hear. We see a performer playing a violin on a stage, but the sound we hear is different from expectations on the basis of what we see" (Sone, 2005).

Drumming is an Elastic Concept by the musician and media artist Josef Klammer is another example of a harmonious union of technology and performance[19]. By using analog and digital system on drums and percussion, the musician demonstrates how both the instrument and the performativity can be enhanced. The sensor-based instrumental interfaces definitely change the interaction during the musical performance, extending it both at a sonic and physical level (Newton and Marshall, 2011). As Impett states it is in fact important to create a connection between the sound composition, the action of the performers and the space surrounding them through the use of augmented instruments, for instance (Impett, 1994).

[19] *Drumming is an Elastic Concept* by Josef Klammer http://klammer.mur.at/texte/elastic_term.html

Chapter 2

The Augmented Drumstick

The solution presented consists of a DIY[1] augmented musical controller specifically conceived for drummers who want to combine electronic and acoustic sound without compromising the musical performance. The proposed system is composed both of hardware and software component. This practical part is between the field of sound design and interaction design. The link performativity-sound and musical expression refer to the sound design area, whereas the proposed interface and its relation with the user is connected to interaction design. My personal experience as a drummer experimenting with live electronic music in the past few years led me to find new ways of expression by combining acoustic and electronic music. An instrument like drums certainly enables an accentuated performance. However, it is not easy to create the same musical performance when the acoustic instrument is combined with an electronic setup. This can be achieved by using analog effects for the sound treatment or by digitally using several MIDI controllers connected to a laptop, where the sound is processed. However, this solution does contain problems regarding performativity. In this particular case, the drummer has to interrupt his performance to adjust some parameters, trigger some sounds, control the sound effects, in other words, he has to "break" the expressiveness. This can also move the focus of the audience away from the drumming, which is the main act. Therefore, the use of external controllers for expanding the acoustic setup with electronic sounds or processing live drum sounds becomes difficult and interferes with the performative expression. A new interface integrated in the drumstick it is developed in order to give to the musician the possibility to extend musical sonorities without compromising the musical expression.

2.1 Design Process

The following points were evaluated during the design process:

[1] Do It Yourself https://en.wikipedia.org/wiki/Do_it_yourself

- **Movement tracking:** this means tracking the musician's performance movements and trying to understand which gestures could be used for controlling the live electronics. Adding a device on a drumstick (or mallets or brushes) results in more flexible movements. In contrast, having sensors on the hands or arms could cause a limited degree of moving freely.
- **Independent system:** the idea is to create a device that works on its own for the tracking part avoiding any external reference system. This also helps to solve the following aspect.
- **Portability:** the possibility of having a portable, compact tool.
- **Wireless connectivity:** playing an instrument like the drums means several fast movements along the drum kit. Having different wires connected could interfere with the performance.

2.2 The Technology behind

Different kinds of sensors were considered during the musical controller design process. Some of the controllers discussed in 1.1 solve the problem of playing on a virtual drum set. Even though it is not the intention of this project, it does provide an overview of the technology involved and used to reach this goal. Some of them use a visual tracking system, for example the *Aerodrums* takes advantage of a camera in front of the user. However, this collides with the second aspect discussed in the design process. Other sensors are rather based on sensor technology and seem to be more suitable for this purpose; in fact, they make it possible to not be dependent on an external point of view.

Since the goal is to detect the movements of the drumstick, the sensor taken into consideration is a MEMS'one[2]. This kind of sensor incorporates electrical and mechanical components, for example accelerometer and gyroscope. Controllers that use this kind of sensor are for example the *Freedrum* (gyroscope), *Arduino Air Drums* (accelerometer and light sensor) and *Hot hand USB* (accelerometers). By using a three-axis gyroscope and a three-axis accelerometer, is possible to detect the angular velocity and the acceleration along the tree axes x, y and z. The way to determine the orientation of the drumstick in a 3D space is to combine the MEMS sensors. I chose to opt for the so-called IMU's sensors[3]. These units are a combination of accelerometers, gyroscopes and sometimes of magnetometers, and can measure the acceleration force of a body, its angular rate and the magnetic field around the body. Such technical equipment is mostly used for manoeuvring of aircrafts: the signal of the raw data measured by the sensor is processed and

[2] Micro-Electro-Mechanical Systems https://en.wikipedia.org/wiki/Microelectromechanical_systems

[3] Inertial measurement unit https://en.wikipedia.org/wiki/Inertial_measurement_unit

are reported the values of roll, pitch and yaw. In the case of a body, i.e. an aircraft, the yaw is the rotation around the vertical axis, the pitch represents the rotation around the side-to-side axis and the roll the rotation along the longitudinal axis (front to back axis or noise to tail) (see Fig. 2.1)[4].

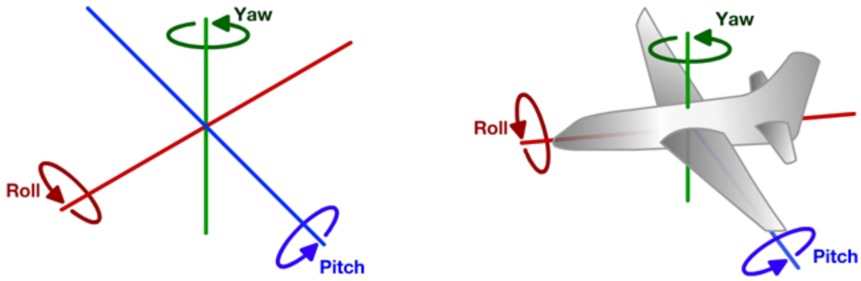

Figure 2.1: Pitch, Roll, and Yaw by Touring Machine Company (*Pitch, Roll, and Yaw*)

2.3 A 9DoF IMU Sensor

An article by Kris Wisner (*Affordable 9 DoF Sensor Fusion*) offers an overview and provides different tests with several 6DoF and 9DoF IMU sensors[5]. Because of the lack of a magnetometer in a 6DOF IMU sensor, the choice of a 9DOF sensor has been preferred. As the author states (*Teardown Compares Combo Sensors*), the range of choice could be limited to the following three chips:

- **BMX055** Bosch Sensortec[6];
- **LSM9DS0** STMicroelectronics[7];
- **MPU-9250** InvenSense[8].

Considering the online documentation available (*MPU9250*), the price and several tests made by Kris Winer, the *MPU-9250* sensor InvenSense was chosen (Fig. 2.2). The next step was to choose a microcontroller that can receive data from the sensor and process it to obtain the values of yaw, pitch and roll. The *MPU-9250* sensor was initially connected to an *Arduino*

[4] Pitch, yaw and roll https://simple.wikipedia.org/wiki/Pitch,_yaw,_and_roll https://emissarydrones.com/what-is-roll-pitch-and-yaw
[5] Six, nine degrees of freedom https://en.wikipedia.org/wiki/Degrees_of_freedom_(mechanics)
[6] Bosch Sensortec https://www.bosch-sensortec.com/
[7] STMicroelectronics https://www.st.com/content/st_com/en.html
[8] InvenSense https://www.invensense.com/

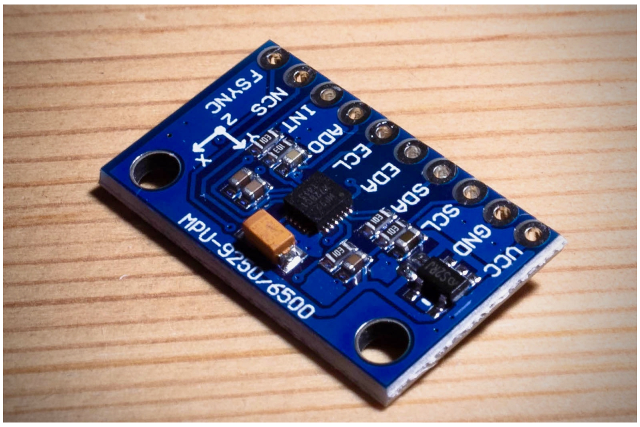

Figure 2.2: MPU9250 by InvenSense

Nano[9], a microcontroller based on a *ATMega328P*[10], through the I2C[11] protocol. Because of the lack of wireless connectivity on the *Arduino Nano*, the microcontroller *Wemos D1 mini* (see Fig. 2.3)[12], powered with a Li-Po rechargeable battery, has been chosen. This microcontroller is a board based

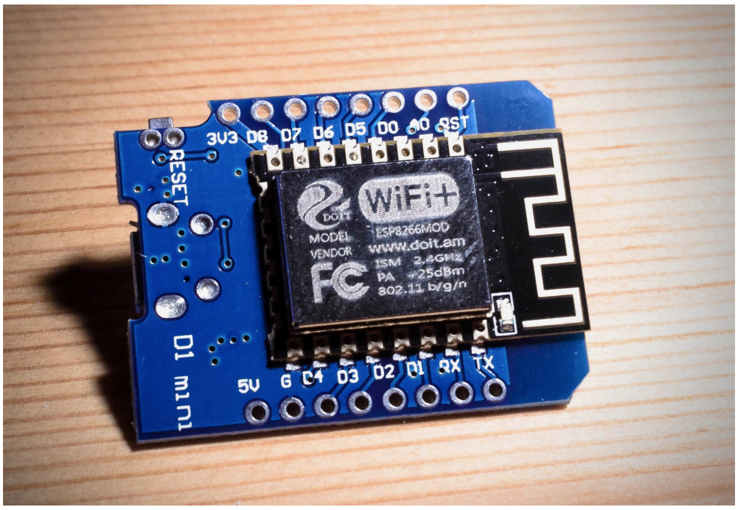

Figure 2.3: Wemos D1 mini

on the *ESP-8266*[13], a low-cost Wi-Fi microchip. The Wi-Fi makes it possi-

[9] Arduino Nano https://store.arduino.cc/arduino-nano
[10] ATMega328P https://en.wikipedia.org/wiki/ATmega328
[11] I2C https://en.wikipedia.org/wiki/I%C2%B2C
[12] Wemos https://www.wemos.cc/
[13] ESP8266 https://en.wikipedia.org/wiki/ESP8266

ble to use the OSC[14] protocol to transmit the data from the microcontroller to the laptop instead of a USB Serial Port. Figure 2.4 depicts a scheme of the hardware chain. The electronics, composed by these three compo-

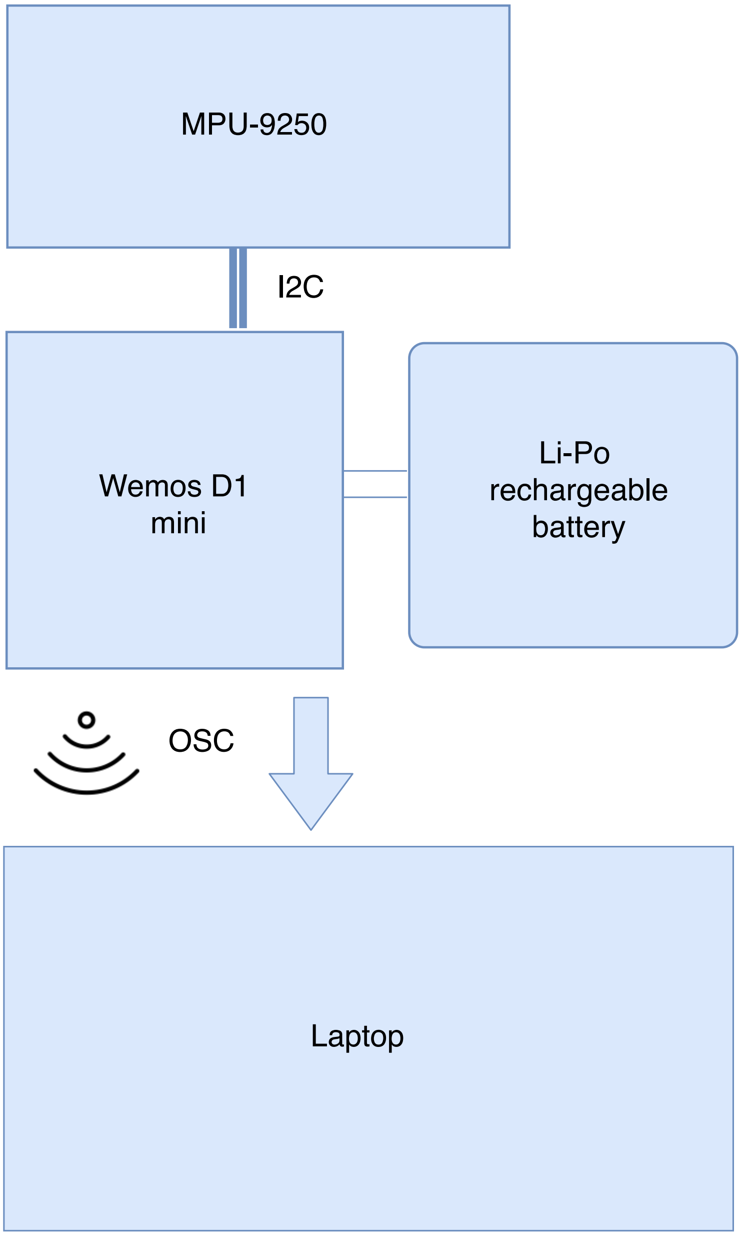

Figure 2.4: The hardware chain for the augmented drumstick

[14] Open Sound Control https://en.wikipedia.org/wiki/Open_Sound_Control

nents (*MPU-9250* sensor, *Wemos D1 mini* and the battery) are placed on a drumstick (Fig. 2.5).

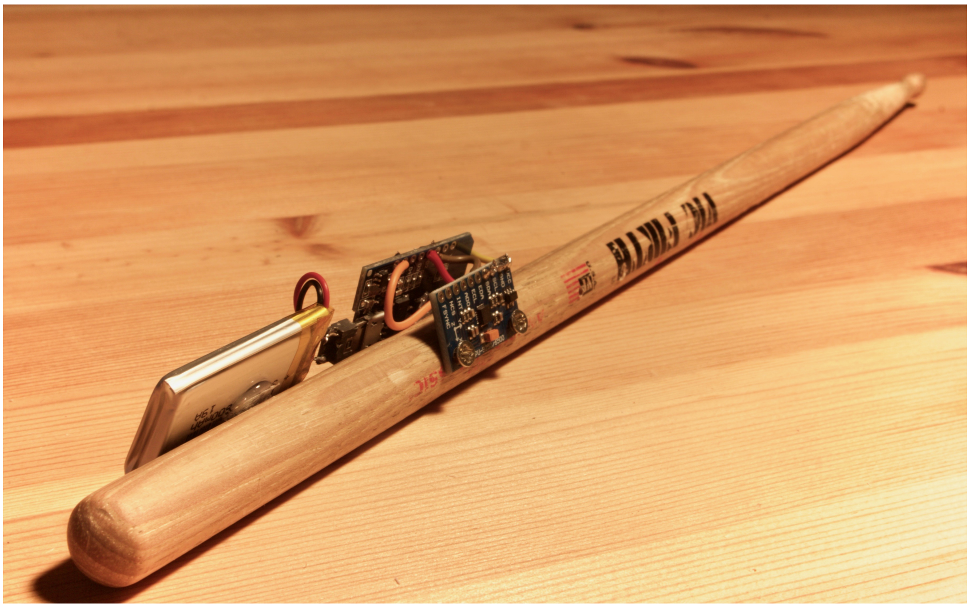

Figure 2.5: The augmented drumstick

2.4 The Software

The software part running on the *Wemos D1 mini* is strongly based on the work of Thomasz Rudkzi. One of the main differences is that in this example, the data obtained are quaternion and these are transmitted via serial to a "bridge" application which calculates the yaw, pitch and roll values. The other difference is the microcontroller that is used for the application "nvsonic 3DOF Head Tracker"[15]: an *Arduino Pro Mini* was selected for this purpose. Instead, based on the work available on https://github.com/rpicopter/ArduinoMotionSensorExample, I directly extracted the parameters of yaw, pitch and roll and adapted the code to make it work on the *ESP8266* board based system. The data are transmitted to Pure Data, a visual programming language for creating music, through the OSC protocol. Here, the different values can be remapped and translated to sound material, used to control the sound processing of the real drums or for the sound spatialisation. When practicing with the augmented drumstick, I could recognize some gestures that can be combined with the drumming and that do not

[15] Thomasz Rudkzi's nvsonic 3DOF Head Tracker project https://github.com/trsonic/nvsonic-head-tracker

alter the expressiveness. One of these is rotating the wrist left or right, or rotating the drumstick. Another one is moving the drumstick horizontally along the plane. A further gesture which is related to the pitch values, is moving the drumstick while keeping its tip fixed on the drumhead.

Chapter 3

Conclusion

This thesis focused on the problem of using live electronics during a musical performance with drums. It introduced an augmented drumstick, a musical controller for performances specially geared towards drummers. In the course of this investigation, different controllers were examined with particular attention to those related to drums. This work constitutes a contribution in the area of augmented instruments, or traditional instruments augmented with sensor technology. It also describes the augmented drumstick from its design process to how it is realized. Thanks to the device connected to a usual drumstick, it is possible to control the sound processing and live electronics while playing the drums in real time. This makes it possible to expand the sound possibilities without losing the natural way of playing an acoustic instrument like the drums.

It would be interesting to let other drummers try this augmented drumstick to understand its possibilities and how this device could enhance the performativity. Working on the recognition of gestures with machine learning algorithms could make it possible to discover more about the relation of gestures and sound. Another field that could be explored is how gestures are connected not only to sound but also to visual environments or an interactive area (for example triggering some engines, working with light). Haptic feedback could make the augmented drumstick more playful and improve its control. Regarding the hardware part, the goal is to make the device smaller by using just the sensor *MPU-9250* attached directly to the *ESP8266* microchip. Another addition is to create a circuit to recharge the battery via USB or wireless. Future research could also be conducted in the field of magnetic-related technologies (*STEVAL-MKI181V1*[1] STMicroelectronics and *TLV493D-A1B6*[2] Infineon) and those that make use of Pulsed Coherent Radar sensors (for example *Acconeer A11* Acconeer[3]). From a

[1] https://www.st.com/en/evaluation-tools/steval-mki181v1.html
[2] https://www.digikey.at/en/product-highlight/i/infineon/3d-magnetic-sensor
[3] https://www.acconeer.com/

software point of view, a machine learning algorithm could be integrated and create plugins for different DAWs, which would create a universal and flexible system.

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