MITACS GLOBALINK RESEARCH INTERNSHIP

REPORT

A SYSTEM FOR RECOGNIZING THE POSITION OF FINGERS OF AMPUTATED LIMBS BASED ON EMG SIGNAL AND MACHINE LEARNING

IHOR SHYBKA

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1. INTRODUCTION

1.1. MITACS GLOBALINK

The MITACS Globalink Research Internship is a competitive initiative aimed at attracting international students from different countries and regions to participate in the program. As part of this internship, students from countries such as Australia, Brazil, Chile, China, Colombia, France, Germany, Hong Kong, India, Mexico, Pakistan, South Korea, Taiwan, Tunisia, Ukraine, the United Kingdom, and the United States have the opportunity to spend 12 weeks of research under the guidance of Canadian university professors.

The main goal of this initiative is to promote academic knowledge exchange and research in various fields, from natural and engineering sciences to humanities and social sciences. As part of the fellowship, participants have the opportunity to work with experts in their fields and deal with topical issues.

MITACS Globalink research internships are held at more than 70 universities in Canada. One of these universities is the University of Quebec at Chicoutimi (Université du Québec à Chicoutimi), located in the province of Quebec, Canada. The university has about 6500 students and 209 faculty members. It is a branch of the University of Quebec and is engaged in research and education in various fields of knowledge. This is the university where I am doing my internship.

1.2. 1.2 UNIVERSITÉ DU QUÉBEC À CHICOUTIMI

Founded in 1969, the Université du Québec à Chicoutimi is part of the largest university network in Canada, the Université du Québec. It is located in the heart of Saguenay-Lac-Saint-Jean, a French-speaking region known for the beauty of its fjord, and has four study centers as well as a digital school. Building on the success of its 60,000 alumni, UQAC welcomes more than 6,500 students each year, including more than 1,500 from about fifty countries.

Figure 1.1 Exterior of the Université du Québec à Chicoutimi

Known for the close relationship that exists between students and faculty, UQAC offers a unique experience and more than 200 degree programs. Through its faculties, continuing education center, Nicanit First Nations Center, and School of French Language and Quebec Culture, it also offers customized learning both on campus and abroad.

UQAC stands out globally for the expertise of its research professors, the excellence of its students, and the innovation it demonstrates in both teaching and research. The university contributes to the development of research and creativity, as well as to the reputation of its community, especially through its areas of excellence. In a knowledge-based society that is committed to creativity and innovation, UQAC is more than ever an important tool for the transfer and dissemination of knowledge regionally, nationally and internationally. I am doing an internship at the Department of Applied Sciences with Prof. Alexandre Robichaud. My lab has about 10 students who are developing their projects. I work from Monday to Friday for 8 hours.

It is a modern and well-equipped laboratory. Among the devices in the laboratory are: a laboratory 4-channel oscilloscope (RIGOL DS1054), a laboratory 2-channel frequency generator (RIGOL DG1022), a laboratory multimeter (RIGOL DM3058E), a laboratory power supply (GW INSTEK GPS-3303), a soldering iron and a ventilation system. There are also several 3D printers and a personal computer.

2. PRODUCTION AND LABORATORY FACILITIES

2.1 LABORATORIES

I have experience in several laboratories of this type. Among them are the Noosphere laboratory at Oles Honchar Dnipro National University, the City Station of Young Technicians in Dnipro, the office for the development of high-voltage equipment circuits at EDS Power, and the laboratory of the WARR student association at the Technical University of Munich in Germany.

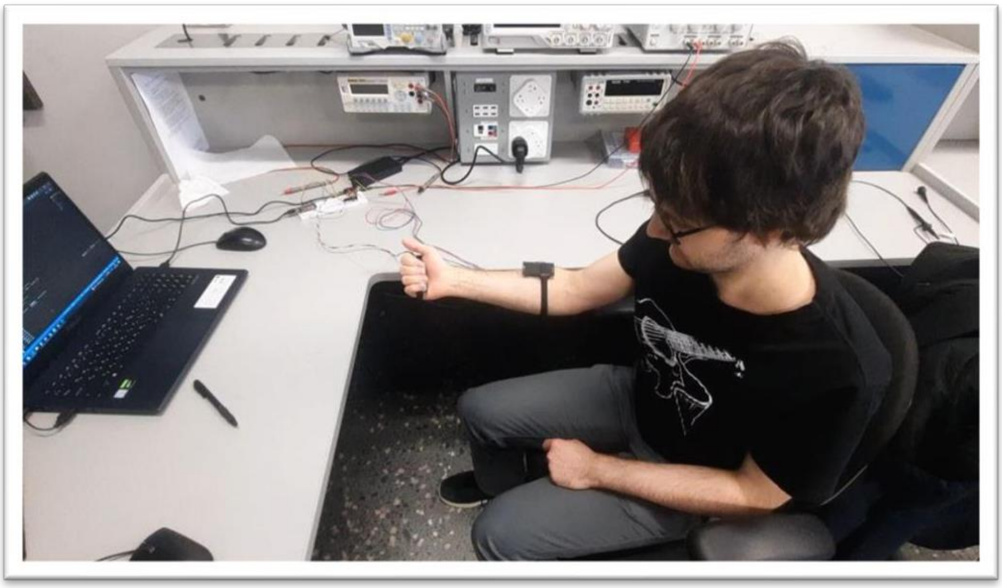


Fig. 2.1 Photo of the workplace

Compared to other laboratories, this one, where I am currently doing my internship, resembles an educational complex the most. It is very similar to the City Station of Young Technicians in Dnipro, but it is aimed specifically at students and graduate students. There are many training stands and desks, each with its own set of equipment. There is a blackboard and a teacher's desk. In addition to the City SUT, here I will receive the most mentoring from my supervisor. Equally important for me is the cleanliness of this place. Compared to the other student laboratories (Noosphere and WARR), it is very clean, everything is laid out in its place, and there is a lot of free space for work and testing.

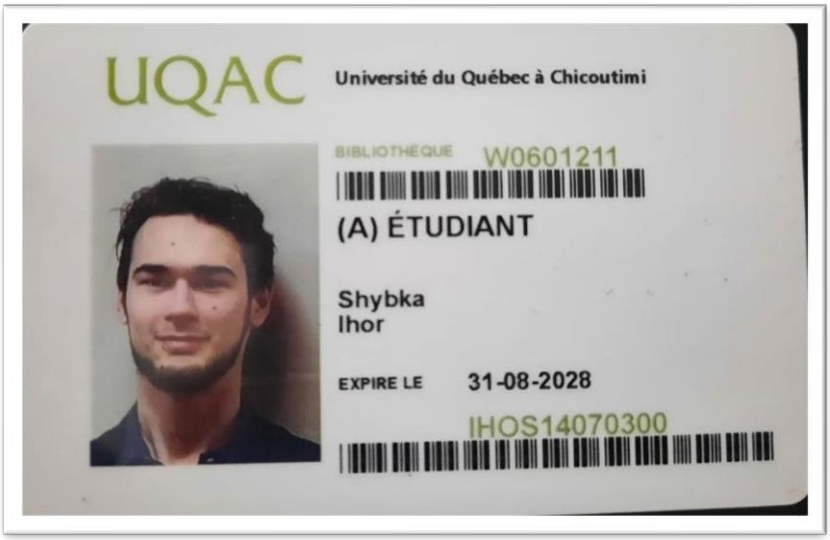


Fig. 3.2 Student card/lab pass

3. PROJECT

"A SYSTEM FOR RECOGNIZING THE POSITION OF FINGERS OF AMPUTATED LIMBS BASED ON EMG SIGNAL AND MACHINE LEARNING"

3.1. INTRODUCTION

Today, a significant number of people around the world face the problem of amputation. Amputation can be the result of injury, illness, or congenital disability, and for many people it is a serious physical and emotional challenge. This problem has become especially relevant for Ukraine today, as many war veterans have amputated limbs.

In order to facilitate the daily life of people with amputated limbs and enable them to return to active life and independence, there is a need to develop effective technologies and systems for controlling artificial hands. One of the promising areas in this field is the use of electromyographic (EMG) sensors and machine learning algorithms.

This project aims to develop a system that, using EMG sensors and machine learning methods, will be able to recognize the position of the fingers in an amputated hand. The use of such a system will allow people with amputations to control prostheses using the muscles that used to control movements.

of the lost limb. This will improve their quality of life, restore some of the functions they have lost, and provide them with greater independence and comfort.

The project will explore the possibilities of obtaining sufficient information using EMG sensors, as well as processing this data using machine learning algorithms.

3.2. EXISTING ANALOGUES

Today, there are several off-the-shelf solutions in the field of limb prosthetics on the market that use electromyography (EMG) and machine learning technologies to recognize the position of fingers. Here are some of them:

- Myo Armband: Myo Armband by Thalmic Labs (now known as North) is one of the popular devices designed to control prosthetic limbs using muscle signals recorded via EMG. It can be used to control fingers and other movements.
- BeBionic: Open Bionics' BeBionic is an EMG-based prosthetic hand with intelligent control that allows users to control the position of their fingers and hand using muscle signals.
- DEKA Arm: DEKA Arm, also known as Luke Arm, was developed by DARPA and DEKA Research. It is an advanced prosthetic arm that provides more natural control and includes muscle signal recognition features for finger control.
- i-Limb: Touch Bionics' i-Limb is a series of prosthetic hands that use EMG to control the fingers and arm. They offer a wide range of functions and customizable control options.
- Michelangelo Hand: The Michelangelo Hand from Ottobock is a prosthetic hand with advanced control capabilities, including muscle signal recognition. It allows the user to control the fingers and hand through muscle movements.

These off-the-shelf solutions offer a variety of functions and options for controlling prostheses using EMG signals. Each solution has its own features and benefits, and the choice of a particular prosthesis depends on the individual needs and preferences of the user.

As for the approximate price of the devices, it should be borne in mind that it may vary depending on the model, functionality, and supplier. Typically, the cost of such systems ranges from several hundred to several thousand US dollars. However, the exact price can only be determined after consultation with the supplier or manufacturer of the prosthesis.

Today, the development of affordable financial and budgetary systems that can be purchased at a low price and assembled by the user is gaining importance. The high relevance of this task stems from the need to provide access to such systems for a wide range of users, regardless of their financial status and capabilities.

3.3. TECHNOLOGY OF EMF SIGNAL MEASUREMENT

An electromyographic (EMG) sensor is a device that measures the electrical activity of muscles by recording electromyographic signals. The principle of EMG sensor operation is based on the observation of electrical potentials that occur during muscle contraction. These electrical signals are the result of electrical impulses from motor neurons to skeletal muscles.

An EMG sensor consists of electrodes that are placed on the surface of the skin next to the muscles whose activity is to be measured. The electrodes record electrical signals generated by muscle activity during contraction. The signals received from the electrodes are transmitted to an electronic device that amplifies and filters these signals for further analysis.

The number of electrodes required for EMG sensor operation depends on the specific system and application. Typically, 2 to 8 electrodes are used. The minimum number of electrodes required for EMG sensor operation is two.

One electrode is used as an active electrode that records signals from the muscles, and the other is used as a ground electrode that serves to compensate for noise and create a closed circuit. This configuration allows you to receive basic EMG signals.

However, additional electrodes can be used to more accurately determine muscle activity and obtain more detailed information. Increasing the number of electrodes allows you to obtain more accurate data on the functioning of individual muscles and display their activity in the form of signal distribution on different electrodes.

The choice of the number of electrodes depends on the specific needs and goals of the study or application. When designing an EMG system, it is recommended to consider the balance between accuracy, ease of use, and complexity of system setup.

3.4. SELECTED TYPE OF SENSOR EMF

For my project, I chose a 3-electrode EMG sensor.

Such sensors include an active electrode, a reference electrode, and a ground electrode.

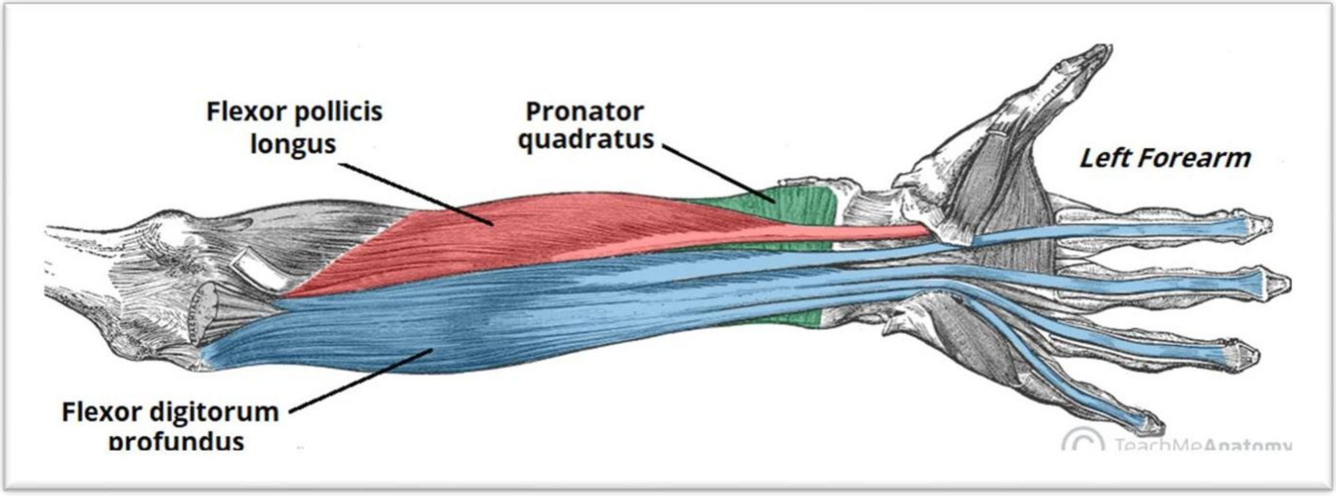
- Active electrode: This electrode is placed over the muscle or group of muscles to be studied. It records the electrical signals that result from muscle activity. The active electrode is connected to an amplifier input to amplify weak signals.
- Reference electrode: This electrode is placed at a location where there is no muscle activity, usually at a remote site from the active electrode. The reference electrode is used to measure the potential arising from the muscles and allows this signal to be separated from noise and interference.
- Grounding electrode: This electrode is used to create a closed loop and provide noise and interference compensation. It is connected to a grounding point or earth to stabilize the electrical potential of the system and ensure proper functioning of the sensor.

This three-electrode configuration allows for a display of muscle activity measured relative to a reference electrode and takes into account grounding to compensate for noise and interference.

3.5. SELECTION OF MUSCLES FOR MEASURING EMG ON THE ARM

Different muscles that continue to function after amputation are suitable for determining the position of the fingers of the amputated hand below the elbow. It is important to note that the available muscles may vary depending on the level of amputation. Some of the key muscles that can be used for this purpose include:

Fig. 3.1 Diagram of the muscles below the elbow



- Forearm muscles: These include the flexor and extensor muscles of the wrist and fingers. These muscles can be used to control the flexion and extension of the prosthetic fingers.
- Palm muscles: Muscles located in the palm of the hand, such as the interosseous muscles, that control the movement of the hand and fingers.
- Muscles of the shoulder girdle: Some muscles in the shoulder, such as the deltoid muscle, can also be used to determine certain movements of the prosthesis.
- Shoulder muscles: Some people after amputation are able to use their shoulder muscles for certain prosthetic functions.

Determining the most appropriate muscles for prosthesis control depends on the individual characteristics of each person and the level of amputation. In order to develop an effective prosthesis control system using EMG sensors, it is necessary to conduct a thorough research and analysis of possible muscles that can be used to determine the position of the fingers and the hand as a whole.

3.6. DEVICE DEVELOPMENT

3.6.1. DEVICE STRUCTURE

A single sensor may not be enough to determine the position of the fingers of an amputee. Therefore, for my project, I decided to create a system of sensors around the hand. This system uses 5 sensors, and the device itself is made in the form of a bracelet. This design will provide sufficient information about the position of the hand and ensure that the position of the fingers is determined. Thanks to this, the user will be able to control the prosthesis with greater convenience. To prevent noise in the EMG signal measurement, it was decided to make each of the 5 sensors a separate device. With its own microcontroller and battery. The communication channel between them and the host computer is made using the ESP-NOW protocol.

ESP-NOW is a wireless communication protocol used on the ESP8266 and ESP32 devices to communicate directly between them. This protocol allows data to be transferred between two or more ESP devices without the need for a router or Wi-Fi access point. ESP-NOW works on the basis of peer-to-peer technology, which means that one ESP device can act as a transmitter and the other as a receiver. The devices can exchange data in real time with low latency and minimal power consumption. This protocol is very popular in the Internet of Things (IoT), especially in the development of networked sensors, remote control, monitoring, and other applications that require direct communication between ESP devices without the use of complex network infrastructures.

Thanks to the use of this protocol, the device will gain IoT capabilities, which allows, among other things, to integrate my project into smart home systems and smart gadgets.

This also allows each individual sensor to be an independent device, and if necessary, it can be installed on any human muscle (during the tests, it was found that it is possible to record heartbeat).

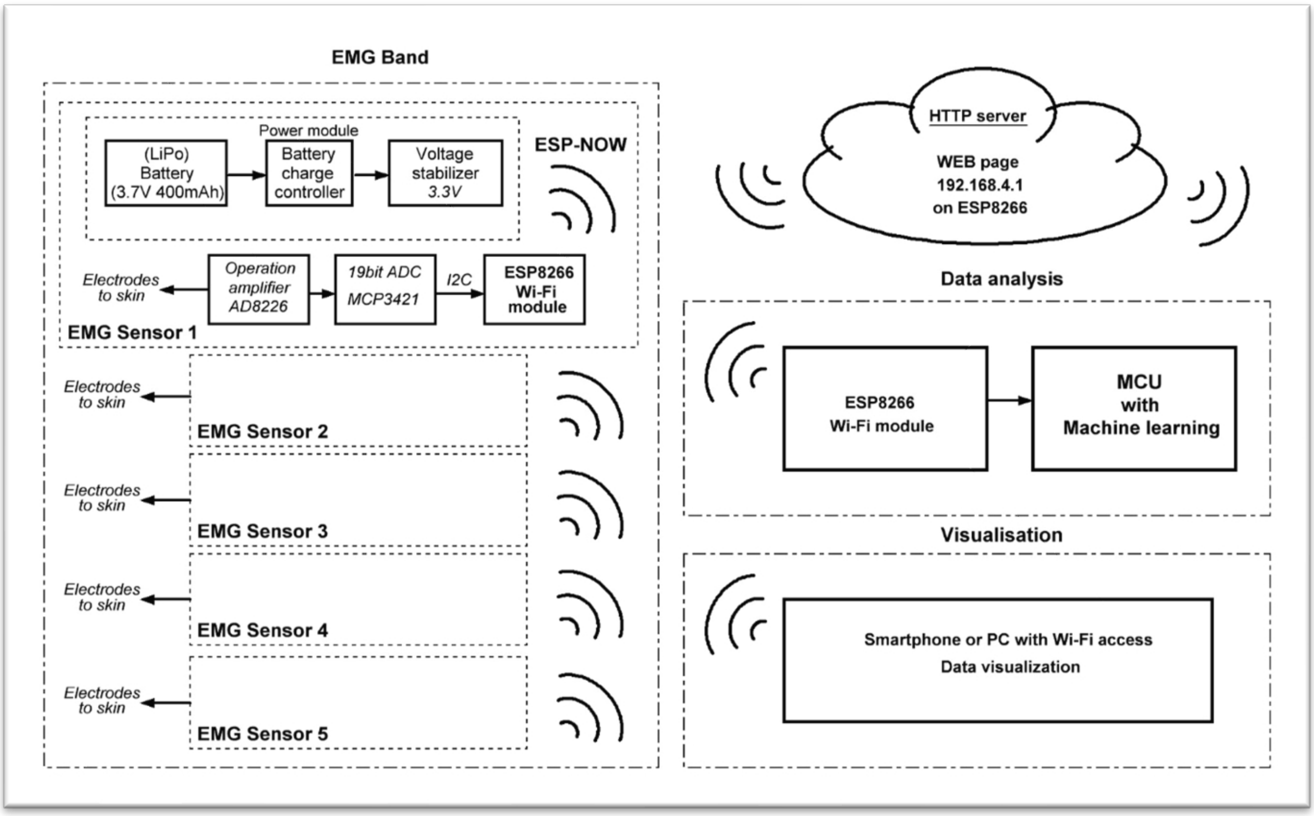


Fig. 3.2 Block diagram of the device

3.6.2. EXISTING EMF SENSORS

There are several EMG sensors on the market that can be purchased for my project. Here are some popular options:

- MyoWare EMG Sensor: This is one of the well-known EMG sensors that is offered by Advancer Technologies. The cost of this sensor is usually around 50-100 USD.
- Olimex EMG/EEG Shield: This is an Arduino shield that can be used for EMG and EEG applications. The cost of this shield is usually around 30-50 USD.
- OpenBCI Ganglion Board: This is a high quality EMG collection platform offered by OpenBCI. The cost of this board is usually around 200-300 USD.
- SparkFun Muscle Sensor v3: This is an affordable and easy-to-use EMG sensor from SparkFun. The cost of this sensor is usually around 50-70 USD.

3.6.3. DEVELOPMENT OF OWN EMF SENSOR

However, all of them are separate, rather large devices that would be difficult to place together with a microcontroller and battery on the arm. So I had to develop my own EMG sensor. At the time of development, I had a MyoWare EMG Sensor, and so I tried to make the signal from my own sensor similar to this example. The development of the sensor circuit was carried out in the LTSpice17 program. Using the program's capabilities, I modeled the circuit and the input signal. The program calculated the output signal after the amplifier, which allowed me to quickly and accurately select the parameters of the passive components.

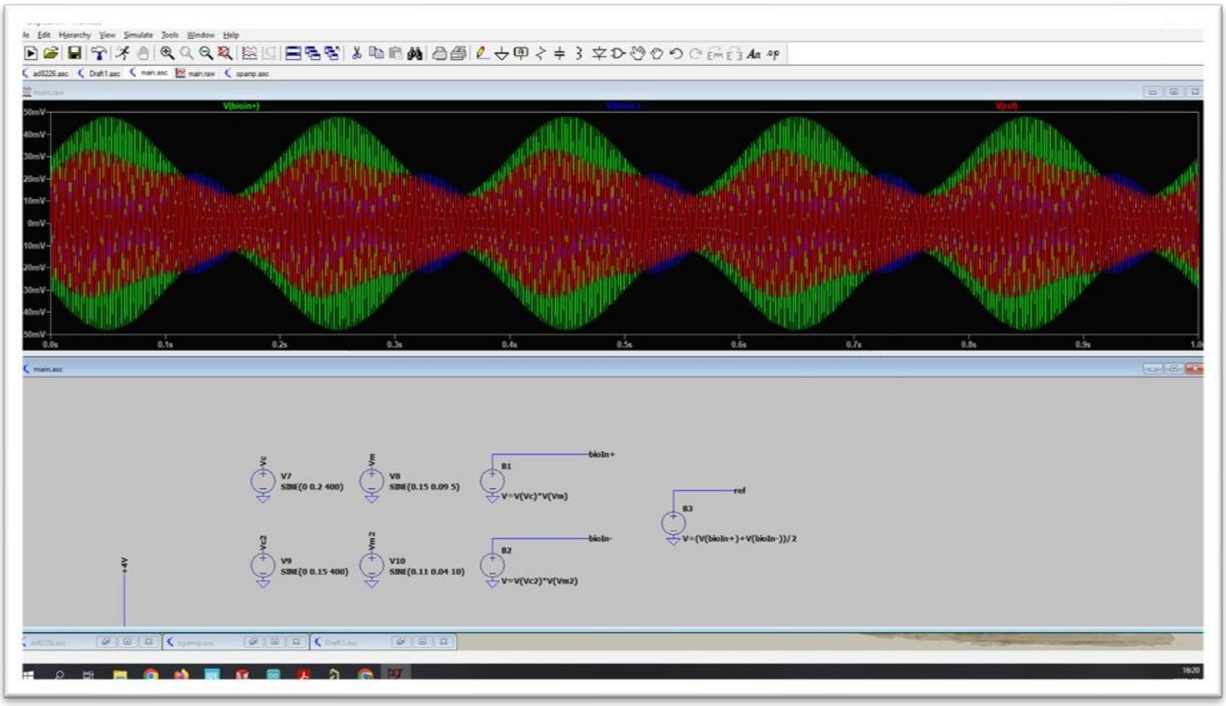


Fig. 3.3.1 Simulation of the EMG signal from the skin. The amplitude is 100mV

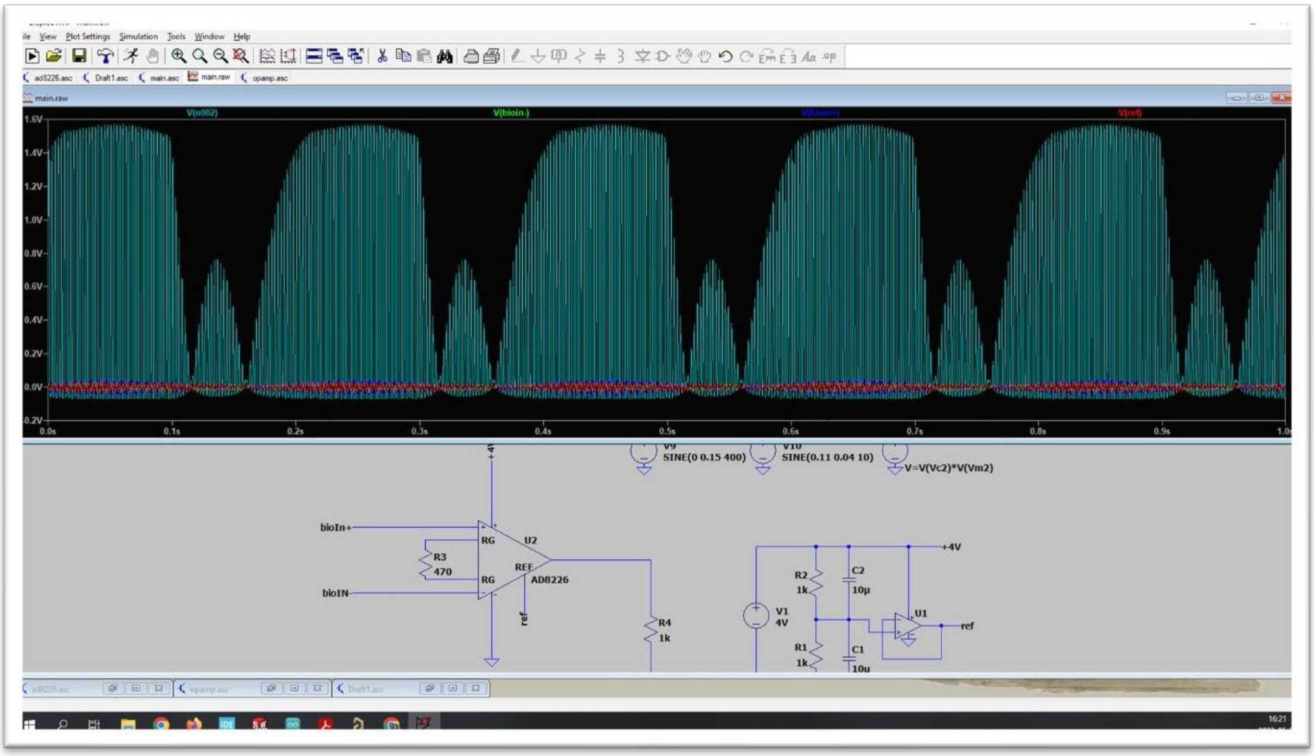


Fig. 3.3.1 AD8226 connection diagram for signal amplification and output signal with amplitude from 0 to 1.6V

3.6.4. MANUFACTURING AND TESTING OF OWN EMF SENSOR

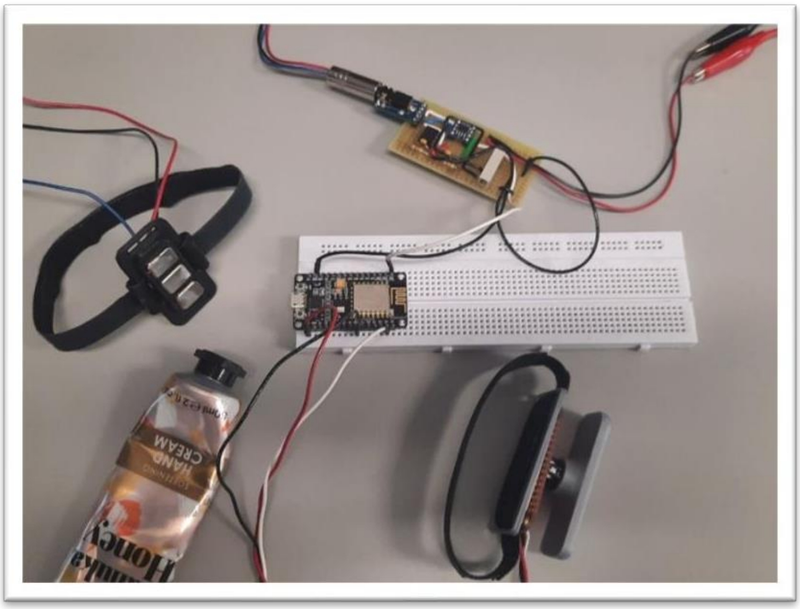


Fig. 3.4 Test layout of the own EMG sensor

The developed EMG sensor was manufactured on a breadboard and tested.

Before testing the sensor using a microcontroller, it was tested using an oscilloscope.

Together with the sensor, they were manufactured and printed on a 3D printer:

- Electrode mounts and electrodes made of stainless steel

steel

- Hand position tracking system (closed/open)

The model was assembled on the basis of a NodeMCU board with an ESP8266 microcontroller. For better contact of the electrodes with the skin, a moisturizer was used at the beginning.

Fig. 3.5 Mounting the test bench on the arm

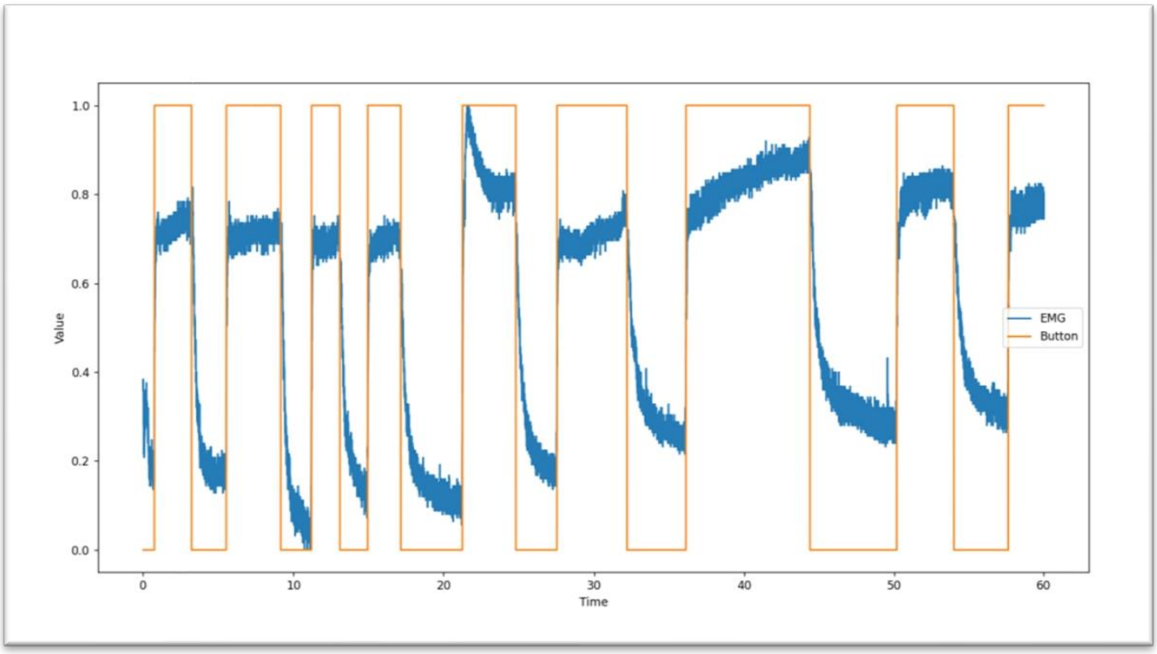
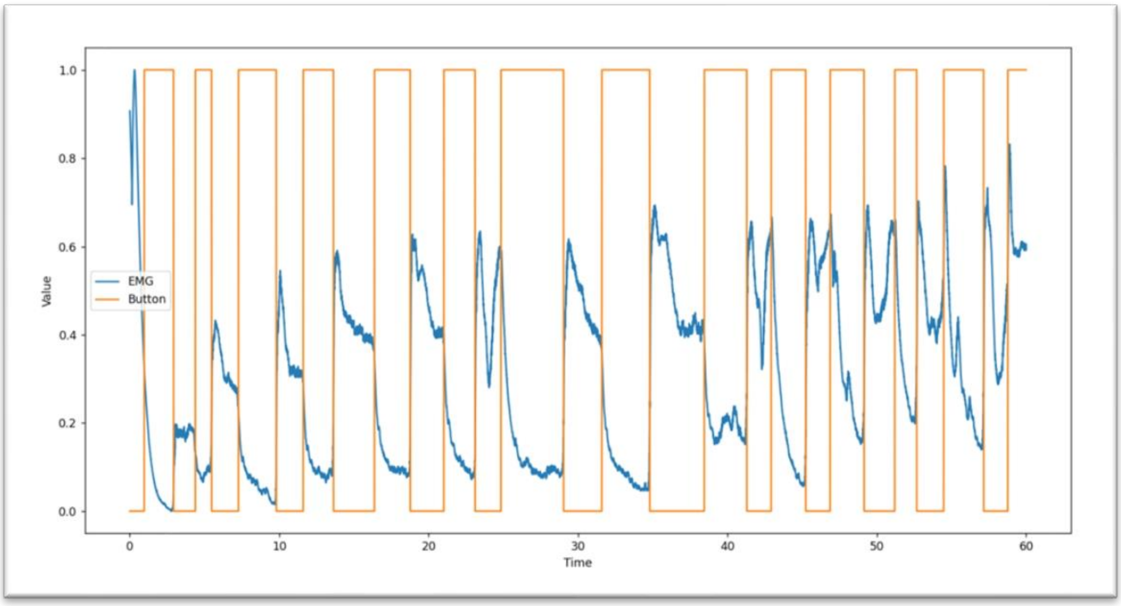


Fig. 3.5.1 Test results of the own EMG sensor. The Y-axis (Value) corresponds to the signal voltage, dividing from 0 to 1, which corresponds to 0 - 3.3 V. The X-axis (Time) corresponds to the time in seconds. Each test was performed for 1 x. Blue graph - EMG

With the help of this stand, it was possible to visualize and save sensor measurements for further processing of information by ML algorithms.

signal, yellow - hand state (closed - 1, open - 0)

Fig. 3.5.2 Test results of the MyoWare EMG Sensor



To keep the sensor compact, it was decided not to install filter chips on the sensor, as was done on the MyoWare EMG Sensor. This can be seen when comparing the signal from both sensors. However, the result was still satisfactory, provided that there were external noises on the stand due to the less than ideal design of the stand, compared to soldering a bifurcated board, and the lack of a sufficient number of capacitors.

Paying attention to the signal from Fig. 5.1, we can conclude that the use of the ML model is inappropriate, since the usual condition (if else) can be

to do everything. However. The tests in Figures 3.5.1 and 3.5.2 were performed in a sitting position and without moving other parts of the body. When other muscles in the body contract, noise or trends appear on the graphs of the sensors on the arm.

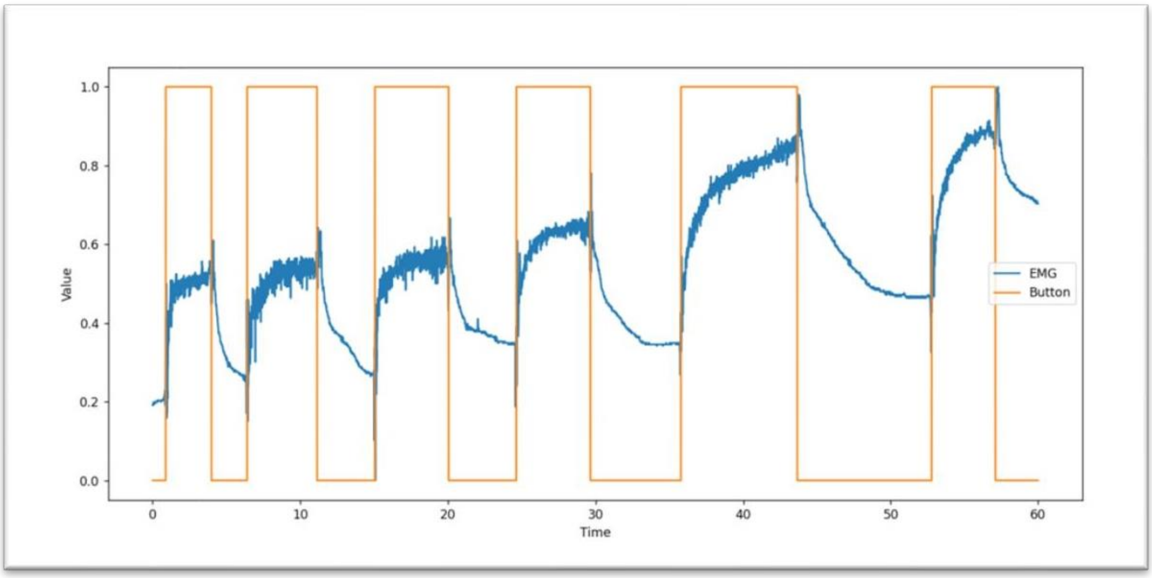


Fig. 3.5.3 Test results of the own EMG sensor at gradual raising the arm with the shoulder.

3.7. TESTING THE POSSIBILITY OF USING THE ML MODEL

Since I already had a data table where the EMG signal was correlated to the hand position within a minute, I tested the possibility of processing the signal using an ML model before developing the device circuit. For quick experiments, real-time hand position prediction was not implemented, but only on the data that was available, but it was enough to confirm the possibility of using the ML model for my project. I used the Sequential algorithm from the tensorflow library. The results were 86% accurate.

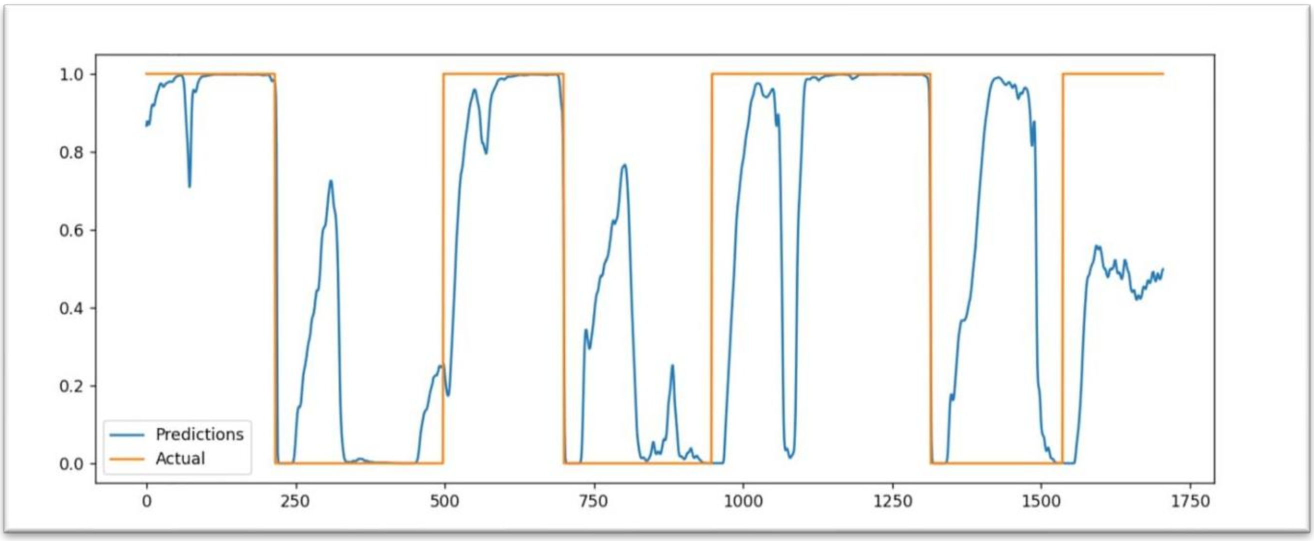


Fig. 3.6 Results of the ML algorithm. I used my sensor for testing. The yellow graph shows the state of the hand (closed - 1, open - 0), and the blue graph shows the ML algorithm's predictions.

3.8. ADDITIONAL FEATURES OF THE DEVELOPED EMF SENSOR

Fig. 3.7 Test results of the sensor when it is pressed to the chest. The measurements were taken using an oscilloscope. The signal amplitude was about 40mV.

When using an 18-bit ADC with a measurement amplitude of ±2.048V, the approximate resolution will be 0.0153mV. This will allow me to use my device as an electrocardiograph if necessary.

3.9. DEVELOPMENT OF AN ELECTRICAL CIRCUIT DIAGRAM

The development of the electrical circuit was carried out in the Altium Designer 19.1.6 environment. When developing the circuit, all components were selected only in SMD packages. The type of passive component enclosures is 0805.

Elements of the device:

1) The power supply is based on a 3.7V LiPo battery with a capacity of 400mAh. To charge the battery, the MCP73831 charge control chip (AD1) and a common USB-Micro port are provided. To power the ESP8266 microcontroller (DD1), a 3.3V LM1117 voltage regulator (AD4) was installed in the circuit. There is a battery charge indicator with LED (D1) and the ability to determine the battery charge by the microcontroller. For this purpose, one of the 2 amplifiers in the MCP6002 chip (AD2B) is used, which is connected with feedback and a voltage divider for 2

resistors R17 and R18. The battery voltage divided by 4 is fed to the built-in ADC of the microcontroller, which operates only in the range from 0 to 1V.

2) The EMG sensor is based on the AD8226A operational amplifier (AD3). The resistor R8 sets the gain of AD3. The higher the resistance, the lower the gain. It is used to adjust the device to different parts of the body. As a reference voltage of the amplifier AD3 can be selected by soldering the jumper on the board (Jmpr2) GND or VCC/2 (1.8V). This is done to conduct some experiments and adjust the AD8226A to different parts of the body. Capacitor C10 is a stabilizing capacitor for AD3. When developing the PCB, it had to be installed as close as possible to the VCC of the chip. To set the reference voltage to 1.8V (VCC/2), one of the 2 amplifiers in the MCP6002 chip (AD2A) is used, which is connected with feedback and a voltage divider on 2 resistors R9 and R10. The capacitor C9 is a stabilizing capacitor for AD2, so like C10, it should be installed as close as possible to the VCC pin of the chip.

3) An MCP3421 ADC (AD6) was installed to convert the analog EMG signal after the amplifier to digital. Data is transferred to the microcontroller via the I2C protocol. C6 is a stabilizing capacitor for this chip. The MCP3421 is an 18-bit ADC with a measurement amplitude of ±2.048V.

4) ESP8266 (DD1) is a microcontroller with the ability to receive and transmit information via Wi-Fi. This microcontroller has 4 MB of Flesh, which allows you to deploy a file structure on it. Thus, you can make one of the network

5) ESP8266 server and deploy a web page for data visualization.

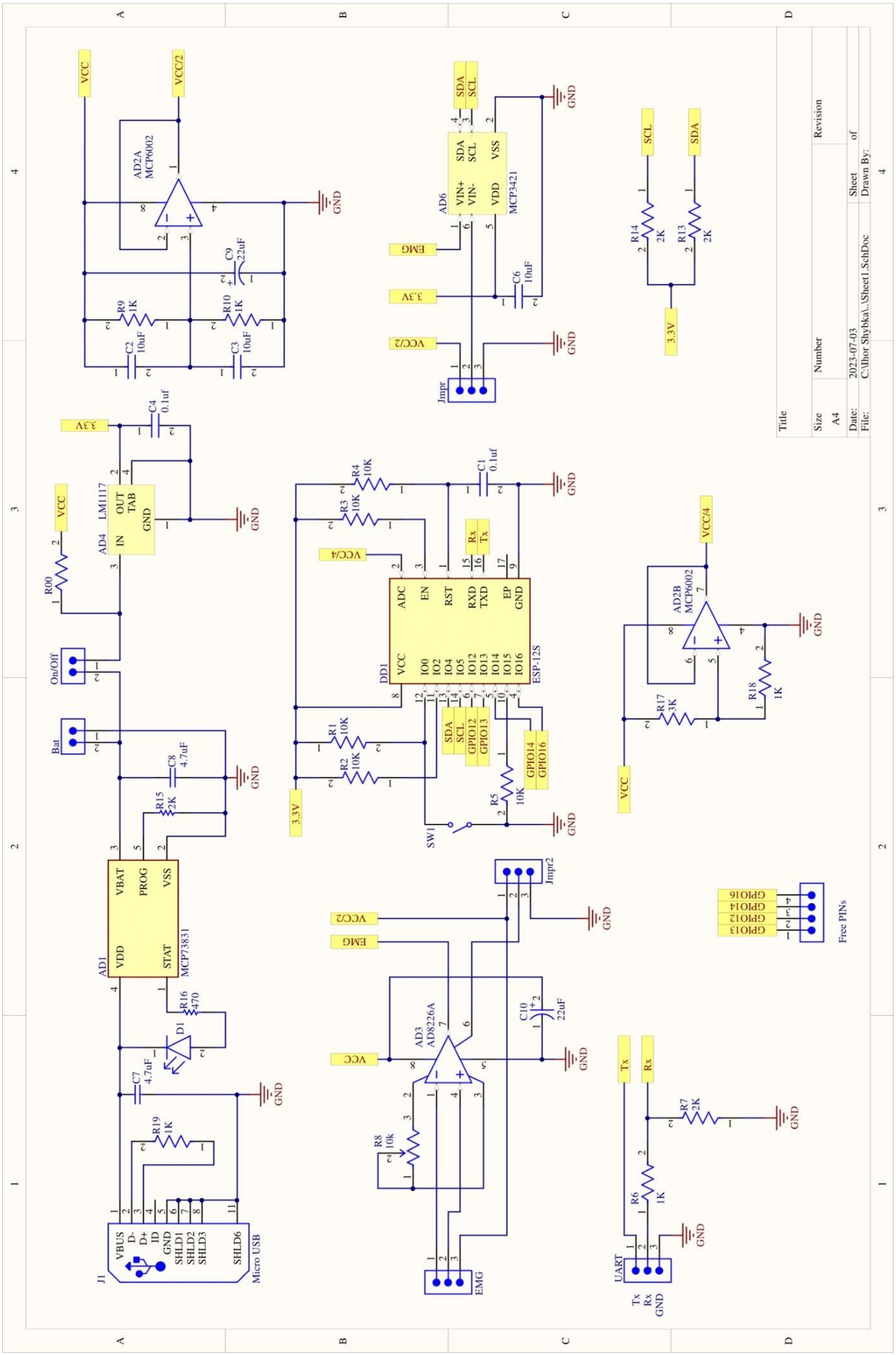


Fig. 3.8 Electrical schematic diagram of the device

6) The UART protocol is used to program the microcontroller. Resistors R6 and R7 are installed on the Rx line. They divide the voltage of the signals from the USB/UART converter by 2/3. This is necessary so that the 5V signals do not burn the ESP8266, whose supply voltage is 3.3V. R14 and R13 are pull-up resistors for the I2C protocol lines.

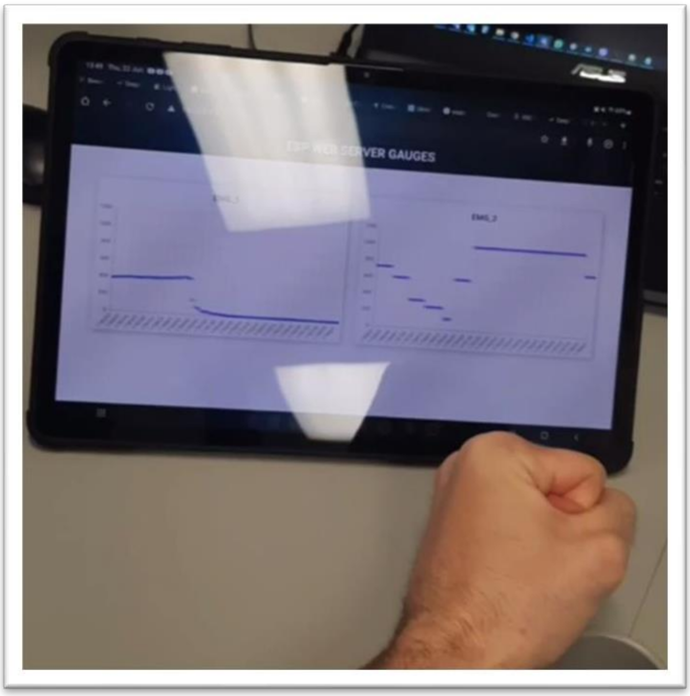


Fig. 3.9 Web page opened from the tablet, which visualizes the EMG signal graphs of 2 sensors.

7) After developing the circuit, the microcontroller has 4 free GPIOs. They were brought out to separate connectors for connecting additional elements, such as buttons, light or sound indicators (free pins support PWM)

3.10. PCB DESIGN

When developing the PCB, several important conditions had to be met:

1) The board should be small. It is planned to place 5 identical sensors around the arm, so dimensions are a very important parameter. For this purpose, we used components only in SMD packages. For the passive ones, it was 0805.

2) Since the device is supposed to measure a signal that is quite unstable to noise and interference, the board had to be designed so that all lines except GND were on the same side, and GND itself was like a shield. The number and length of jumpers had to be minimized.

3) Installing stabilizing capacitors as close as possible to the chips was critical to improving the circuit's noise immunity.

4) The development of mounting holes is mandatory for boards to install and secure them in the chassis.

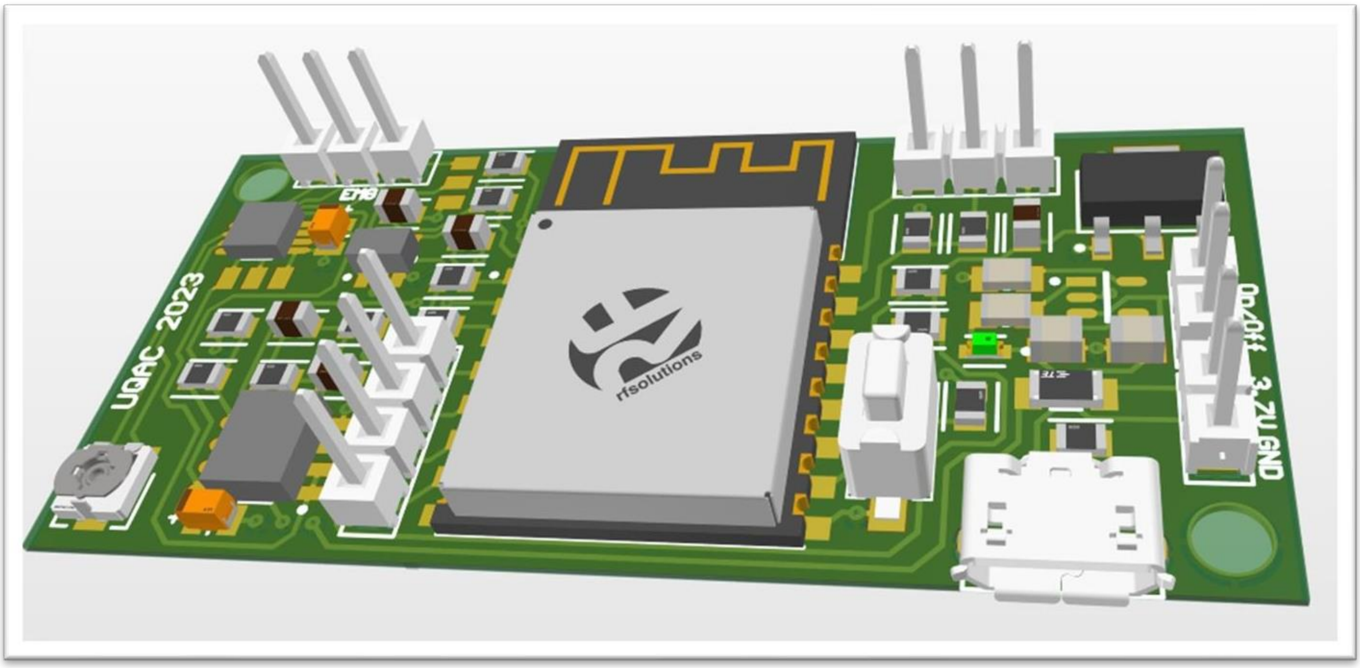


Fig. 3.11 3D view of the developed printed circuit board

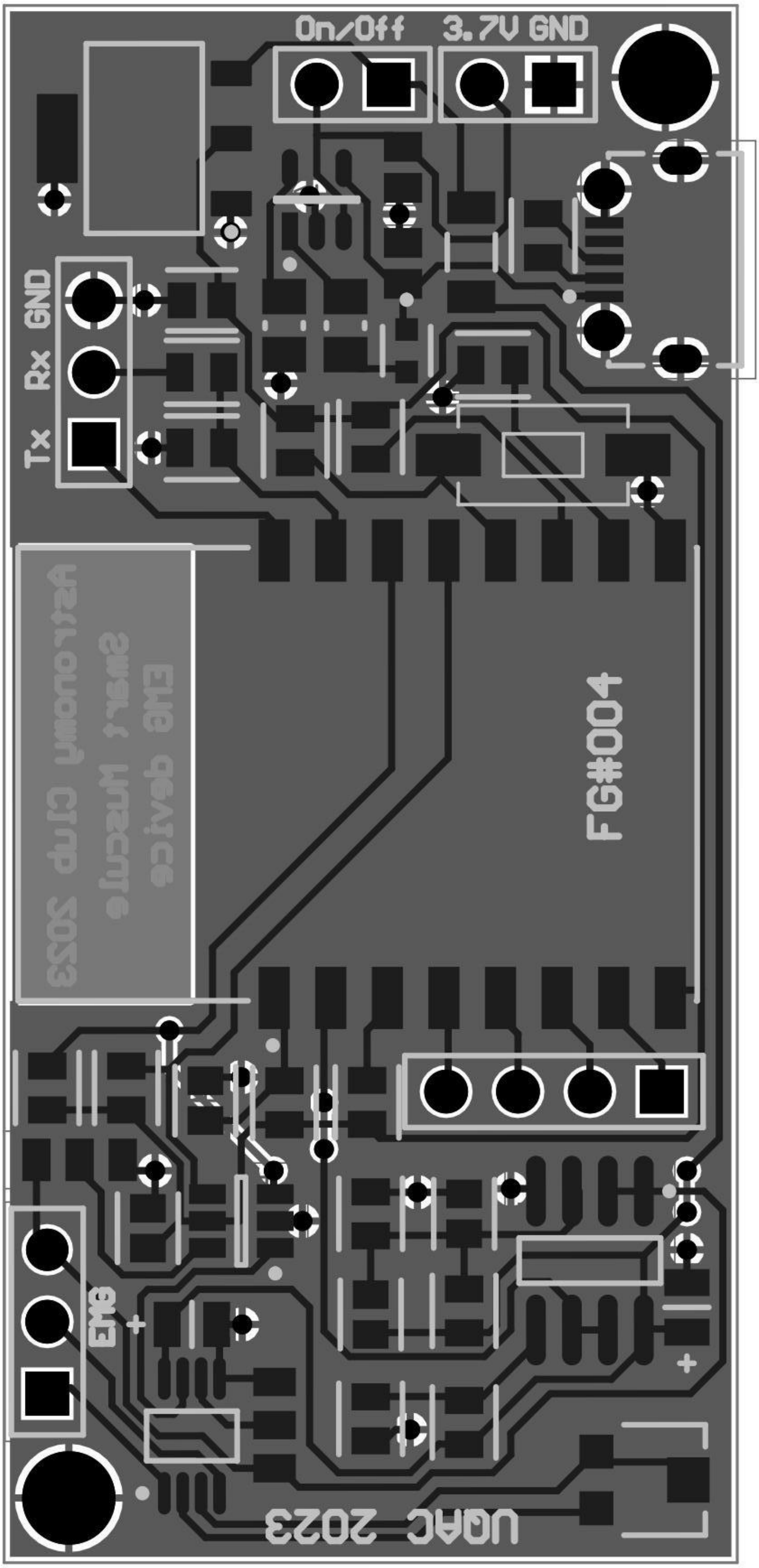


Fig. 3.10 drawing of the printed circuit board.

3.11. PROJECT COST

After the drawings were developed, it was time to order components and manufacture printed circuit boards. For convenience, all components were ordered from www.mouser.ca. Except for the batteries, which I found only at www.canadarobotix.com. I ordered the production of printed circuit boards on the service www.seeedstudio.com for $1 CAD per board. The cost of 1 bracelet with 5 sensors was 180$ CAD.

Number of devices:			5			
			common components			
Element	Datasheet	Price $	Price per board	Quantity on board	Total price $	Link on shop 1
MCP73831	https://ww1.micr	1.10$	1.10$	1	5.50$	https://www.mouse
LM1117	https://www.ti.co	1.10$	1.10$	1	5.50$	https://www.mouse
MCP6002	https://www.mou	0.60$	0.60$	1	3.00$	https://www.mouse
AD8226A	https://www.mou	5.80$	5.80$	1	29.00$	https://www.mouse
ESP12-E	https://randomne	10	10	1	50	https://www.mouse
USB micro	-	1.50$	1.50$	1	7.50$	https://www.mouse
LED SMD	-	0.60$	1.20$	2	6.00$	https://www.mouse
R8(0K-15K)	-	0.50$	0.50$	1	2.50$	https://www.mouse
1K 0805	-	0.20$	1.00$	5	5.00$	https://www.mouse
2K 0805	-	0.20$	1.00$	5	5.00$	https://www.mouse
10K 0805	-	0.20$	1.00$	5	5.00$	https://www.mouse
3K 0805	-	0.20$	0.40$	2	2.00$	https://www.mouse
R470 0805	-	0.20$	0.40$	2	2.00$	https://www.mouse
4.7uF 0805	-	0.60$	1.20$	2	6.00$	https://www.mouse
0.1uF 0805	-	0.20$	0.60$	3	3.00$	https://www.mouse
10uF 0805	-	1$	3$	3	15$	https://www.mouse
MCP3421	https://www.mou	4.5	4.5	1	22.5	https://www.mouse
22uF 0805		0.6	1.8	3	9	https://www.mouse
button		0.9	0.9	1	4.5	https://www.mouse
Total $			30.40$		152.00$	

Fig. 3.12 Table of components and their cost. It can be noted that buying these components in Ukraine or China will be much cheaper.

3.12. SOFTWARE DEVELOPMENT

At the moment, I am waiting for all the components ordered, but I already have 2 working sensors for EMG measurement, so I have started developing the software:

- Software for the ESP8266 microcontroller in C++ in the Arduino.ide environment. There are 2 different codes for the "master" and "regular" ESP8266.

  To ensure stable data transmission from all sensors to the main sensor and then to the computer every 10 ms, an algorithm was developed in which information is transmitted in a snowball fashion. From the last sensor to the main one through all the others in turn. Using the principles of OOP, it was possible to create a universal code for all secondary ESP8266s, and one code for the main controller.

- Web pages for data visualization using HTML, CSS, JS.

- Software for working with ML in real-time via wireless. It was developed a web page parser in Python.

Fig. 3.13 Part of the program code of the main microcontroller.

4 CONCLUSION

Despite being only two-thirds of the way through my internship, I believe I have already accomplished a lot of work. The results of the tests allow me to make a cautious assessment of my project and the circuitry of my own EMG sensor. Thanks to the achievements already made, I am continuing to develop the device and write software. My main aspiration is to create a device that can help people with amputated limbs lead a full life.

I would also like to emphasize the importance of the experience and contacts I gained during my internship with the Mitacs Globalink program and Université du Québec à Chicoutimi. This experience provided me with the opportunity to meet professionals in the field of research and development, as well as other students from different countries. We exchanged ideas, experiences and knowledge, which was extremely valuable for my personal and professional growth.

In addition, the knowledge and practical experience gained are relevant to my professional goals and will contribute to the further development of my project. I am confident that this experience and the skills gained during the internship will be of real value in my future career and will help me succeed in the field of research and technological development.

LIST OF SOURCES

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