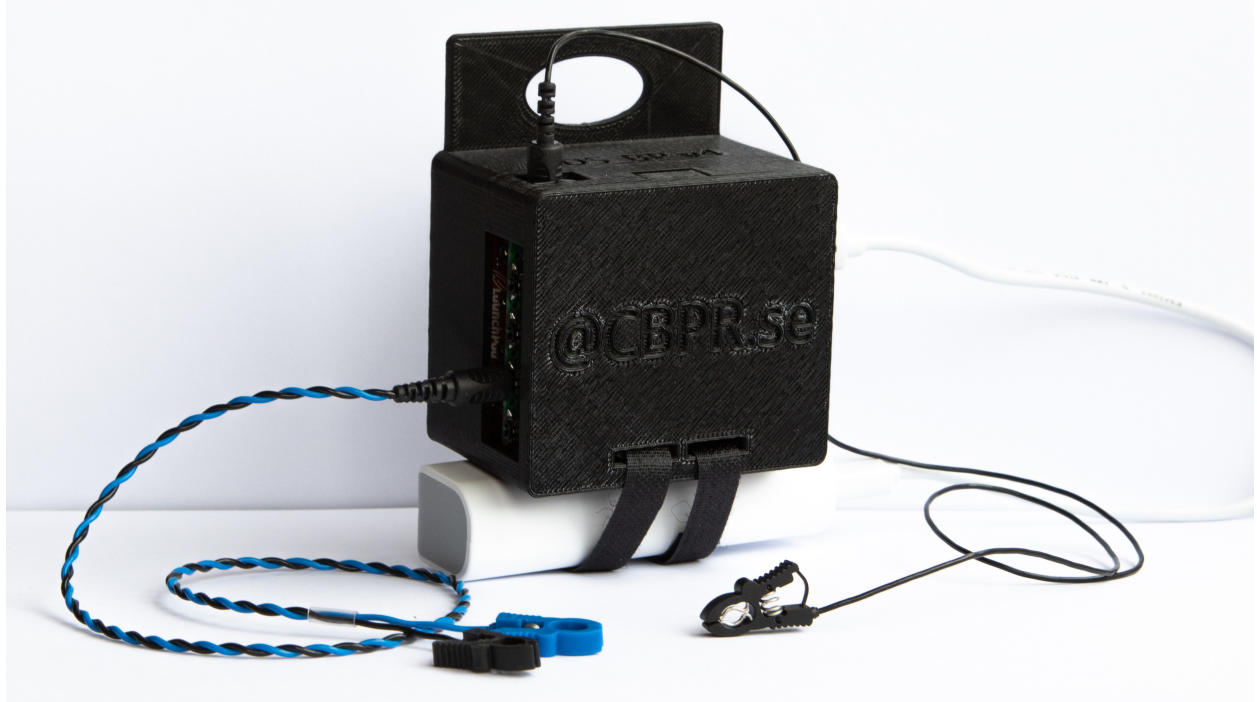




**CHALMERS**  
UNIVERSITY OF TECHNOLOGY



# Wireless communication validation and housing development for an open-source signal acquisition hardware

ADS\_BP v4

Master's thesis in Biomedical Engineering

NATHALY SIMUY SÁNCHEZ CHAN

DEPARTMENT OF ELECTRICAL ENGINEERING

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CHALMERS UNIVERSITY OF TECHNOLOGY  
Gothenburg, Sweden 2022  
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MASTER'S THESIS 2022

**Wireless communication validation and housing  
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NATHALY SIMUY SÁNCHEZ CHAN



Department of Electrical Engineering  
*Biomedical Engineering Programme*  
Center of Bionics and Pain Research  
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NATHALY SIMUY SÁNCHEZ CHAN

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## Abstract

Open-source signal acquisition devices are important for research on myoelectric prosthesis development. Our research group had previously developed the ADS\_BP, an open-source bioelectrical signal acquisition device. However, the use of wired connections limited potential applications for the device. This study expands upon the previous work of the research group, by installing a wireless communication board to permit untethered signal acquisition. Furthermore, we investigated the best practices for optimal communication stability. After the data analysis performed, we found that communication significantly improved when the network analyzer was not being used, the auto scanning feature was disabled, and the wireless channel was not overloaded. Additionally, the ADS\_BP, its 3D housing design, and the BioPatRec have an open-source release document and files available on GitHub. With this release, a complete low-cost acquisition system that guarantees portability and stability while recording and uses specialized pattern recognition software can be used by researchers around the world.

Keywords: myoelectric prosthesis, pattern recognition, wireless, portability, stability, open-source, low-cost.



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# 1

## Introduction

Removing a limb, or amputation occurs when the patient suffers from trauma, diabetes Mellitus complications, or vascular disease [1]. Depending on the amputation and the patient's recovery process, some medical doctors recommend using a prosthesis [1]. In particular, active prostheses can help the user execute voluntary actions with the help of actuators [2]. For upper limbs, active prostheses can aid the patient with opening and closing the hand, moving the fingers, and grabbing objects [3]. To function, the prosthesis must understand the intention of movement of the user. However, the more complex the prosthesis movements, the more data is needed to control the prosthesis.

### 1.1 Background

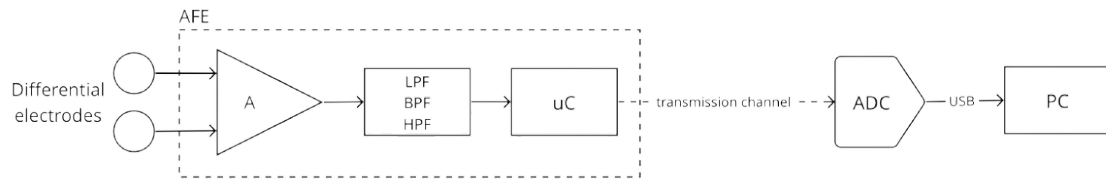
In the past decades, different authors have explored the field of active prostheses [2], [4], [5]. The fundamental and common factor among authors for the control of the prosthesis is myoelectric signals. Electromyographic (EMG) systems acquire and process the electrical signals produced by the muscles, often as measured from the skin via surface EMG (sEMG). The electrodes used for sEMG are straightforward to handle, and can be used in non-sterile environments, making these systems accessible to more researchers. Surface EMG systems have been in high demand in the past years, and thus there is a need for low-cost signal acquisition devices.

#### 1.1.1 Overview of available low-cost devices

Numerous researchers have aimed to develop low-cost signal acquisition solutions and make those available to the research community [6]–[12]. The fact that these systems work towards the same type of biological signals, makes them follow a similar structure as shown in Figure 1.1. However, the selection of the Integrated Circuits (IC) is a clear remark on the difference among the analyzed systems.

Likewise, researchers have explored using wireless methods as the transmission channel to reduce noise caused by movement. RF, Wi-Fi, Bluetooth, and BLE are the preferred wireless transmission channels used to send data from the acquired signal to the Analog-to-Digital Converter (ADC) [6], [7], [10]–[12]. However, the communication between the Analog Front End (AFE) and software is preeminently performed by a wired USB connection.

## 1. Introduction



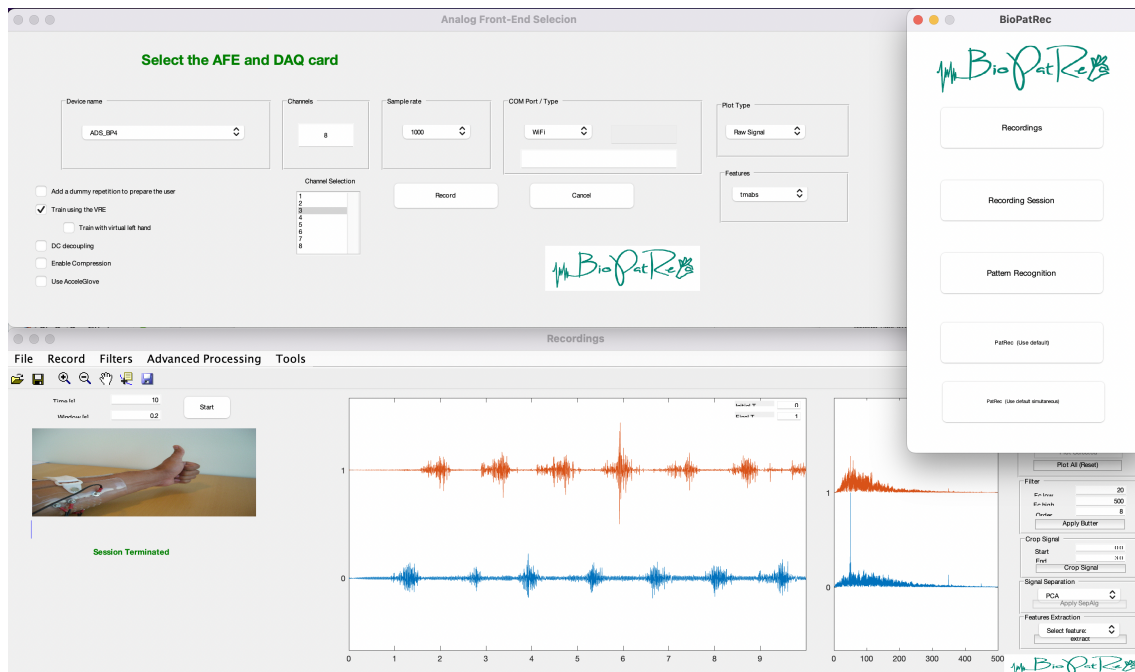
**Figure 1.1:** Process for available EMG acquisition devices

In the case of prosthetic control, the software needs to have extra features, like algorithms for pattern recognition [13]. Those extra features are essential to developing prostheses with better controllability features [14].

However, the limitation is the lack of features such as feature selection and extraction, real-time control, and a Virtual Reality Environment (VRE). The mentioned features are necessary for the development of prosthetic devices. Therefore, the ADS\_BP device was designed and developed to overcome those feature limitations.

### 1.1.2 ADS\_BP

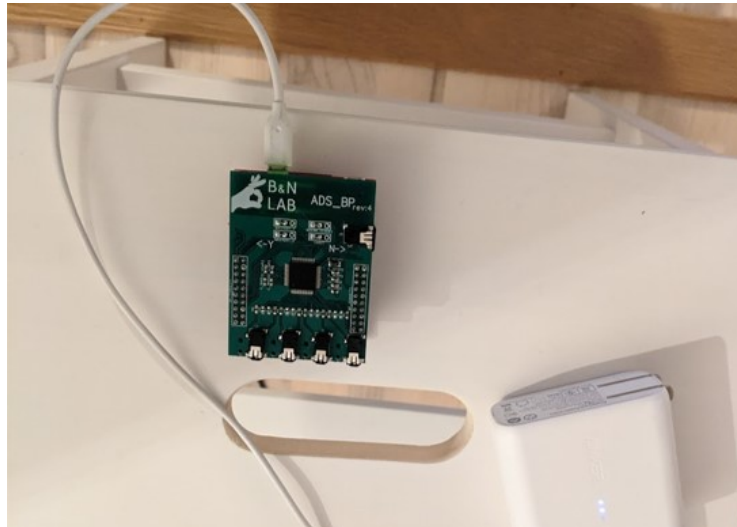
In 2013, Ortiz-Catalan developed BioPatRec, an open-source research platform implemented in MATLAB and focused on pattern recognition algorithms for controlled prostheses [14]. BioPatRec includes all the required features used for myoelectric control as well as VRE and a Graphical User Interface (GUI) to make it user-friendly. BioPatRec's users could develop or use any existing acquisition system for EMG signals and deliver them to the platform. Figure 1.2 shows the BioPatRec GUI displaying some of its available features and settings.



**Figure 1.2:** BioPatRec platform's GUI for recording bioelectrical signals with the possibility to use VRE and pattern recognition.



To deliver a complete EMG signal acquisition system, Mastinu developed a low-cost EMG acquisition device called ADS\_BP, shown in Figure 1.3, that is compatible with BioPatRec [15].



**Figure 1.3:** Current version of the ADS\_BP, acquisition device for bioelectrical signals.

The most recent update of the ADS\_BP version 4 includes a Wi-Fi module for transmitting the signals to the software with pattern recognition process, BioPatRec. The wireless feature is introduced to reduce unwanted disturbances caused by motion during the acquisition of the signals. Furthermore, a power bank was selected as the device power supply to add more wire independence. A previous work analyzed the system's performance with Bluetooth, Wi-Fi, and wired data transmission resulting in the selection of Wi-Fi as the transmission method [16]. Now, a more specific analyses need to be performed to evaluate its stability.

## 1.2 Problem definition

Currently, version 4 of the ADS\_BP improves the device's portability by implementing wireless communication between the digital data and the computer. ADS\_BP v4 includes a TIVA LaunchPad development board and a COMBATT board to implement Wi-Fi communication. However, the wireless communication with the test computer is not yet stable.

Likewise, the power bank needs to be placed near the device to make it more portable. Thus, a power bank housing is introduced to have a compact product.

Finally, the improvements to the ADS\_BP should be merged to the current publicly-available open-source release, so that other researchers can benefit from this development.

### 1.3 Aims

- Thoroughly test the Wi-Fi capabilities of the ADS\_BP to determine the cause of the unreliable communication.
  - Propose and implement solutions to have a more reliable communication
- Develop a power bank housing based on the user's requirements.
- Release an open-source device compatible with BioPatRec.

### 1.4 Research Questions

In terms of the reliability of the communication, the research questions are defined as follows:

1. Does the number of wireless devices in the proximity of the measurement affect the communication?
2. What other variables are causing communication errors?

# 2

## Theory

This chapter aims to provide an overview of the concepts regarding the bioelectrical acquisition process, with emphasis in sEMG signals. The review of concepts is followed by the findings of a literature review to establish a current low-cost and open-source acquisition systems baseline. Features such as type of bioelectrical signals, number of channels, resolution, Signal-to-Noise Ratio (SNR), sampling rate, kind of AFE used, data transmission methods, and software compatibility were the main focus of the literature research. Finally, the current status of the ADS\_BP is also detailed in this chapter.

### 2.1 Concepts

A complete acquisition system is formed by a device handling the analog signals and digital conversion, with its respective platform or software containing the digital signal processing and GUI. For the hardware, due to the amplitude of the bioelectrical signals and the presence of motion artifact noise, the acquisition process usually starts by connecting the electrodes from the human body to a differential amplifier [17], [18]. The acquired measurements need to go through an analog signal conditioning process previous to the conversion to digital data where it receives further treatment.

#### 2.1.1 Analog and digital signal processing

For processing an analog signal the amplitude and frequency ranges must be defined to determine the gains and cut-off frequencies of the amplifiers and filters. sEMG signals are in the range of 0.01 Hz to 150 Hz, meaning that everything outside that range must be removed since it is considered noise or disturbance [18]. There are different IC to develop an analog acquisition device for each stage of the conditioning. However, nowadays there are several commercially available AFE specifically designed for biopotentials and its main differences are the number of electrodes at the input, the common-mode rejection ratio (CMRR), and the SNR.

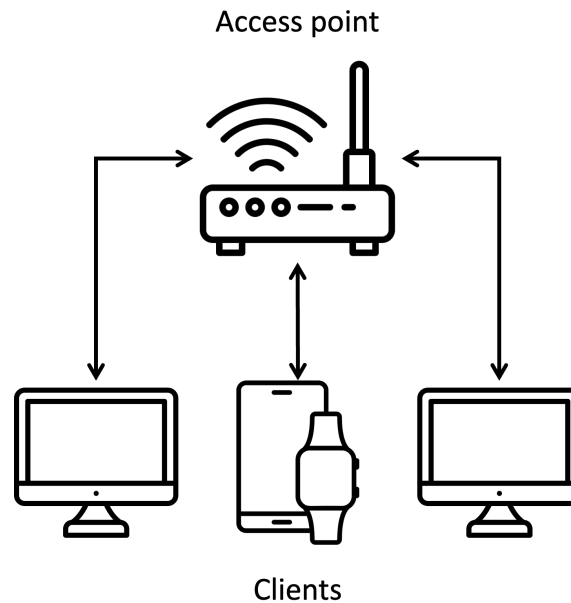
Once the signal is conditioned, it is sent to an ADC for starting the digital preprocessing and processing of the data. There are different ways to preprocess the digital signal. The most simple method is by applying digital filters to remove any high or low frequency interference [18]. However, there are more advanced methods as the adaptive noise canceler which records the signal during a non-movement period to have that signal as a reference. The algorithm then subtracts that reference signal

from any other measurement taken [9]. The Wavelet Transform (WT) and Empirical Mode Decomposition (EMD) are other digital noise cancelling methods frequently used for EMG signals [18], [19].

### 2.1.2 Wireless data transmission – Wi-Fi IEEE 802.11b

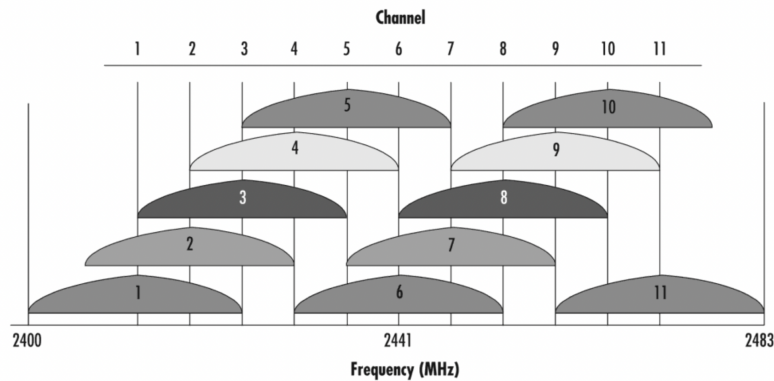
There is a lot of flexibility when transmitting signals from one processing stage to another. The transmission channel can be either wired or wireless, and it can be performed before or after the digital conversion. This research mainly focuses in the transmission of a digital signal through a wireless channel.

Due to the features of bioelectrical low-cost acquisition devices, one important requirement is that the communication channel used should be unlicensed, and an example of that is the Industrial, Scientific and Medical (ISM) band. Wi-Fi is a wireless communication data service that works with an ISM band at two frequencies, 2.4 and 5 GHz [20]. Wi-Fi helps connecting two important sets of devices, the Access Points (AP) with the clients. Access Points can offer the connection of each client to the internet, and can also connect two or more clients together for sharing resources [21]. The infrastructure for the mentioned communication concept is shown in Figure 2.1.



**Figure 2.1:** Wi-Fi communication infrastructure between an AP and its clients.

The Wi-Fi frequency band has an additional division or sub-band called a communication channel. There are a total of 11 channels available for transmitting data using a different frequency range with a 22 MHz bandwidth. The channels are designed to reduce the communication interference when there are more than one AP in an area. The client distinguishes the frequency and determines its corresponding AP [22]. From those 11 channels, only three – channel 1, 6 and 11 – do not overlap between themselves as shown in Figure 2.2.



**Figure 2.2:** 2.4 GHz Wi-Fi band communication channels emphasizing channels 1, 6 and 11 for being the non-overlapping channels of this band [22].

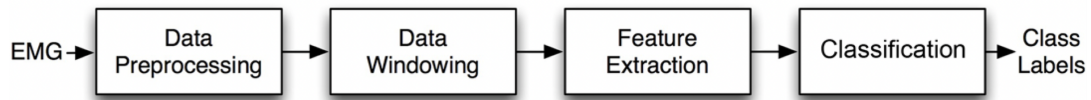
Due to the non-overlapping characteristic of channels 1, 6 and 11, APs are configured to work in one of those channels with a dynamic selection depending on how overloaded is each channel. The AP then uses the less crowded channel available. It is important to highlight that an AP can be a wireless module able to create a Wi-Fi network for clients to connect. This Wi-Fi module does not necessarily has internet access, but it is mainly used for data transmission between a sensor and a data recording device. As any AP, the Wi-Fi module selects a channel to transmit the data to its client.

In this case, the AP is a Wi-Fi module and its client is a computer containing the software for processing the received signals. The software has features like extraction and pattern recognition algorithms, as well as a GUI for interacting with it and displaying the signals.

### 2.1.3 Pattern recognition algorithms

For prostheses control, the pattern recognition algorithms has shown promising results for working with multiple degrees of freedom [23]. The prostheses with more degrees of freedom allow the user to have a more functional limb, which is specially important for hand and arms prostheses.

The pattern recognition algorithm has four identified stages. The first stage is the data pre-processing, typically formed by digital filters. The data is then windowed and per each window there is a stage of feature extraction and classification. The feature extraction serves to discriminate the important sEMG information from the irrelevant data [23]. As for the classifier, it aims to group together a set of signals following the same pattern and assign a label to it where each identified group is called a class [24]. For example in sEMG signals, each class corresponds to a muscle contraction or relaxation, resulting in a certain movement or position of the limb. The process for the pattern recognition algorithms is shown in Figure 2.3.



**Figure 2.3:** Pattern recognition algorithms process for EMG signals [23].

In the prosthetic research field, the acquisition systems are implementing pattern recognition algorithms in its platforms. This algorithm is then becoming an essential feature for competitive bioelectrical acquisition systems.

## 2.2 Available acquisition devices

In 2014, Benetau et al. presented a system for acquiring EMG signals with a single channel and an analog AFE based on the INA126 IC. The electrodes used by Benetau include an electronic board capable of converting the samples, with 8 bits of resolution, to digital data and wirelessly transmitting them to the MSP430 receiver. However, the data transmission between the MSP430 and the computer is wired by using the UART protocol to transmit data through an USB. The computer contains a self-developed software based on MATLAB for data processing and for displaying the acquired signals [6].

During the same year, Jamaluddin et al. also released a system for EMG signals acquisition. It was possible to use up to 13 channels and an ADC with a resolution of 12 bits. The IC used for acquiring the bioelectrical signals is the AD620 working together with the IC dsPIC30F4013 which prepares the signal to be transmitted to the computer with UART protocol. However, the type of software used for displaying the obtained data is not specified by the authors [7].

In 2015, Brunelli et al. developed a system that can use up to 32 channels with a 12-bit resolution thanks to the MSP430F5529 MCU. The digital samples are transmitted via Bluetooth using the UART protocol. The wireless communication is used to send the information to the GUI and digital processing that includes extracting and classifying the signals using LabVIEW. The communication between the microcontroller and the computer is performed by a USB connection also using the UART protocol [10].

Fortune, in 2019, designed an EMG acquisition system called POLE. The AFE used by POLE is the IC INA128U followed by analog signal conditioning. The ADC conversion is performed with the AD7768-1 and an Arduino, with a resolution of 24 bits. The samples are transmitted through USB with the UART protocol. Fortune uses the software MATLAB with a self-developed firmware to validate and characterize the received samples [8].

In 2020, an EMG acquisition system is released by Huang et al. using up to 30 electrodes. However, the type of AFE used by these authors was not specified. The ADC and firmware is developed with the ARM Cortex M0 with a 12-bits resolution. The processed raw signal is transmitted using the UART protocol with a Wi-Fi module [12]. Further digital processing is performed with the help of the detection system Trigno by the commercial brand, Delsys.

The author, Luna, also released an EMG acquisition system in 2021. Luna does not specify the AFE used in this 1-channel system but performs the signal conditioning analogically. Luna’s system uses a 16-bit resolution for digital conversion. The MCU used for processing the digitized signal is the ARM Cortex M4. It is important to highlight that Luna’s proposal also includes a pattern recognition stage. For that purpose, the digital samples will be transmitted to a computer via USB. However, it is not specified the program used for developing the algorithm [9].

In 2021, Zhu released an EMG acquisition system of 8 channels using the IC by Texas Instruments ADS1299. This IC is used for differential amplification and ADC conversion with 24 bits of resolution. The MCU used by Zhu is the ARM Cortex M4 which includes more digital processing. The samples are later sent using the USART protocol via BLE. The receiver could be a mobile device for displaying the signals or a computer for displaying and performing an analysis. The pattern recognition is developed by Zhu using MATLAB [11]. This is the only device that can wirelessly communicate with the software platform from all the above mentioned systems.

**Table 2.1:** Summary of the available analyzed acquisition devices.

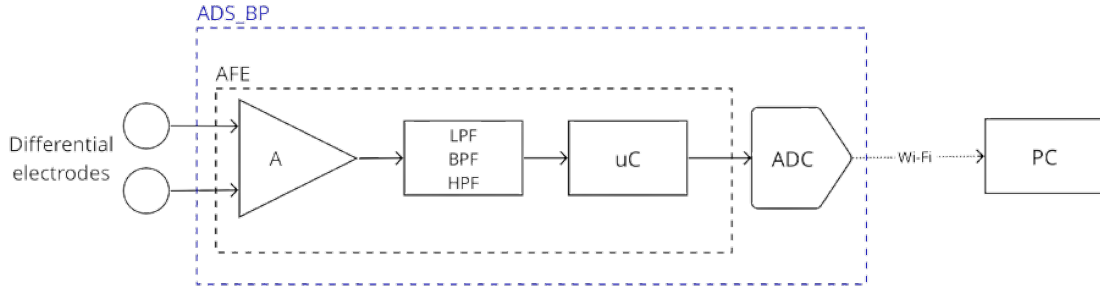
Author	Year	Bioelectrical signals	Number of channels	Transmission	Software
Benetau [6]	2014	sEMG	1	RF	MATLAB
Jamaluddin [7]	2014	sEMG	Up to 13	RF	Not specified
Brunelli [10]	2015	sEMG	Up to 32	Bluetooth	LabVIEW
Mastinu [15]	2017	(sEMG/EEG/ECG)	8	Wired	MATLAB
Fortune [8]	2019	sEMG	Not specified	Wired	MATLAB
Huang [12]	2020	sEMG	Up to 30	Wi-Fi	Trigno, Delsys
Luna [9]	2021	sEMG	1	Wired	Not specified
Zhu [11]	2021	sEMG	8	BLE	MATLAB

The sEMG acquisition hardware developed by the mentioned authors is performed mainly with analog circuitry with similar cut-off frequencies and overall gains, making it difficult to spot major difference between authors. However, the main differences among the analyzed systems lie in the AFE selection, the data transmission and the software implementation with their respective features. The sEMG system’s platforms are either self-developed or use third-party software. Of the selected low-cost systems, 80% of them developed their software. Likewise, 50% of the EMG systems implement their software in MATLAB.

In Table 2.1, there is one more author that has not been discussed yet. Mastinu is part of our research group and also developed a bioelectrical acquisition device called the ADS\_BP which is the main focus of this research.

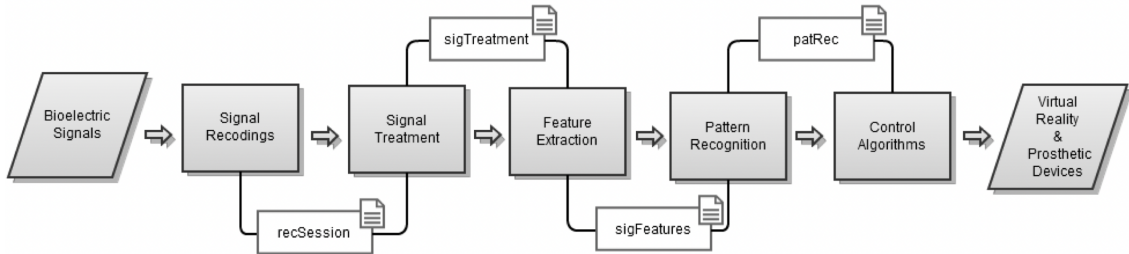
### 2.3 ADS\_BP and BioPatRec – the complete system

The ADS\_BP is not only a sEMG acquisition device, but it is also possible to acquire EEG and ECG signals. A previous work by Mastinu is focused on the AFE selection of the ADS\_BP [25]. The analysis performed around the SNR concluded that the recommended AFE is the ADS1299, having the possibility to work with up to 8 differential channels. Once digitalized with 24 bits of resolution, the samples are sent to the MCU ARM Cortex M4. Finally, to connect with the software, previous versions transmitted the samples to the computer via USB with the UART protocol. The late updates include a Wi-Fi module for a wireless communication with the computer where BioPatRec is running. The type of communication is the main difference between the analyzed available devices and the ADS\_BP as shown in Figure 2.4.



**Figure 2.4:** Acquisition process and communication for the ADS\_BP v4.

The ADS\_BP is designed to work together with the BioPatRec open-source platform focused on its pattern recognition algorithm and virtual reality environment to acquire sEMG signals and perform prostheses control. Figure 2.5 shows the flow followed by BioPatRec displaying its important features like signal recording, signal treatment, feature extraction, pattern recognition and control algorithms.



**Figure 2.5:** Flow diagram corresponding to the open-source platform BioPatRec for bioelectrical signal processing [14].

Since this research is focused on the wireless communication from the ADS\_BP and BioPatRec, the feature used is the one that joins these two components – Signal Recordings.



# 3

## Methods

Data collection, data computation and analysis, and the housing design were the three stages of this research. For collecting data, it was essential to first determine the test environment. In this case, the tests were designed to determine the source of communication errors between the ADS\_BP and the BioPatRec software.

### 3.1 Testing setup

For setting up a good test environment, there were identified three types of variables. The first variables were considered fixed since those remain invariable during the entire data collection process. The second set of variables were the ones that changed their values every set of tests, meaning that these were only fixed during a specific interval. These first two variables were the parameters of the test and therefore, it was possible to assign a value to them. Finally, the third variables were the measurements, meaning that they changed every time a new test started.

The fixed variables during these tests were the sampling frequency, the distance between the device and the test computer, and the device's channels where the electrodes were connected. The set values for these variables are shown in Table 3.1.

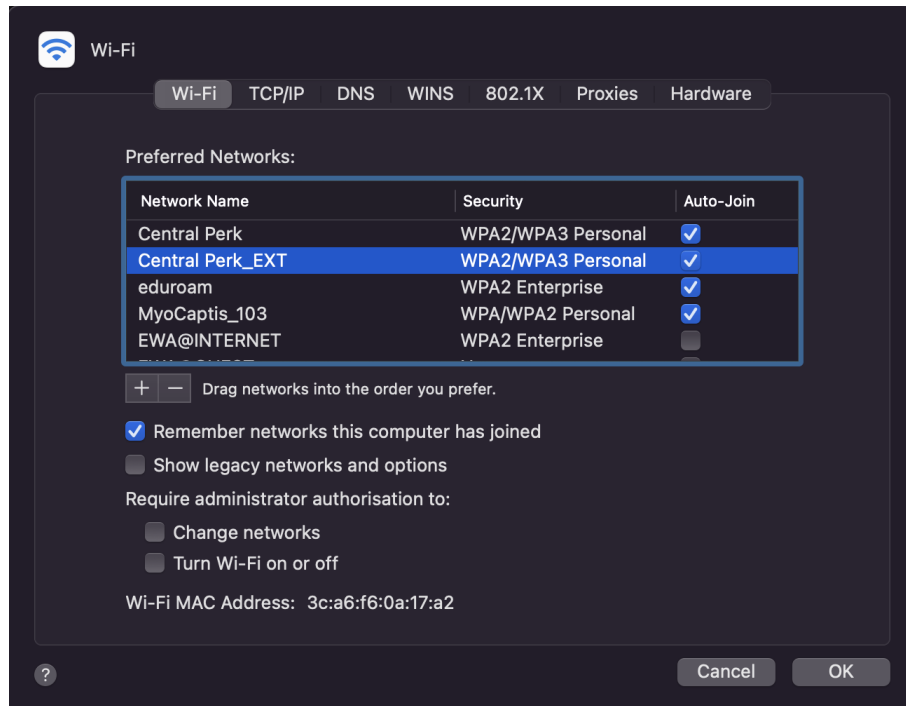
**Table 3.1:** Values set for the fixed variables during the data collection.

Sampling frequency	1 kHz
Electrodes channels	2 and 3
Distance	6 meters

The variables that changed every set of tests were the ones that were analyzed once the data was collected. To establish the variables that were part of the test, the starting point was to determine if other wireless devices interfere with the ADS\_BP communication. However, the number of wireless devices in the near area of the test, was not sufficient data for an analysis. There were considered other variables that might be correlated to the communication error onset.

Computers have a feature that analyzes nearby available wireless networks even if they are already connected to one. This wireless auto-scanning feature is enabled by factory and could lead to interference resulting in communication errors. To disable it, all other wireless networks must be forgotten from the test computer. There might be more advance and sophisticated solutions that involves deep knowledge in computer settings. However, by forgetting all other wireless networks, the computer

did not have any other network to attempt to connect. Figure 3.1 shows a snip of the settings window for forgetting all the stored wireless networks from the test computer.

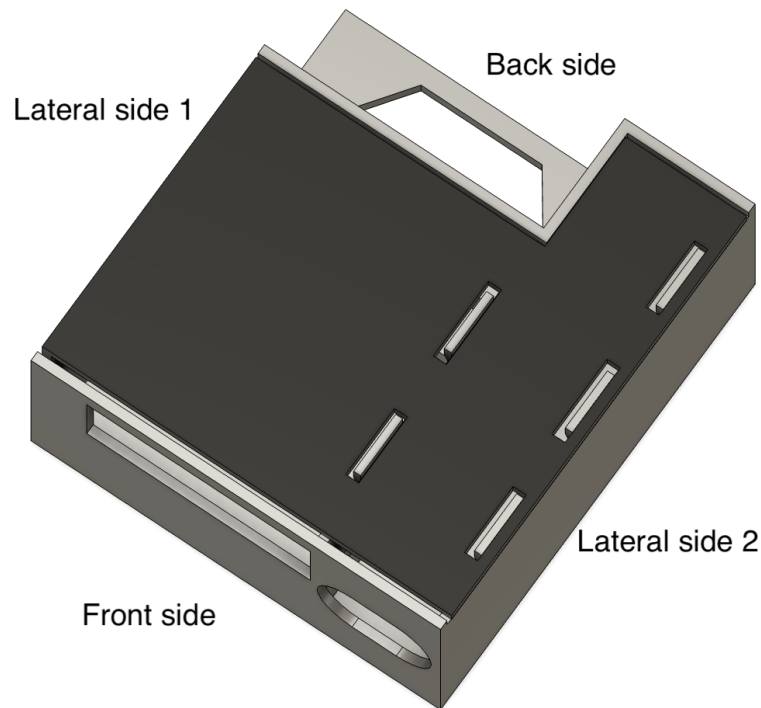


**Figure 3.1:** Settings window where the stored wireless networks are. By disabling the auto-join option from all the networks but the ADS\_BP it is possible to get a similar effect than disabling the wireless auto scanning feature.

The location was another variable considered for these tests. Since the device was developed and most commonly used in a lab environment, that was one scenario for taking measurements. On the other hand, since the device will be publicly available, it should not be tightened to only one test environment. A set of measurements were taken from a home environment.

Also, despite the improvement on portability the power bank offers, it could also lead to unwanted voltage peaks. Specially if the power bank has a low-quality regulation system resulting in high ripples which can interfere with the performance of the electronic boards. Therefore, the type of power supply used was also an analyzed variable.

Moving on to the orientation of the device, since the COMBATT board has an antenna, the position of the device with respect to the test computer, could be an influencing factor. The orientations were based on the previous housing design for the ADS\_BP and are shown in Figure 3.2.



**Figure 3.2:** Guide of positions of the ADS\_BP's previous version for testing different orientations with respect to the test computer.

For taking the data measurements, it was used a free available software to identify nearby access points with its respective information, called inSSIDer [26]. From the free Network Analyzer software there were taken the measurements of the Received Signal Strength Indicator (RSSI) also called power output (PO), and the number of access points connected to the same communication channel as the ADS\_BP. Finally, the number of communication errors were given by the BioPatRect software. To sum up, there were identified seven variables used to quantify the communication reliability.

1. Received Signal Strength Indicator (RSSI) or Power Output (PO)
2. The number of access points connected to the same wireless channel or Co-channel
3. The number of wireless devices nearby
4. The type of power supply used
5. The orientation of the device
6. The status of the wireless auto-scanning feature of the test computer
7. The use of a network analyzer software

## 3.2 Data computation

Once all the data was collected, it needed to be pre-processed before analyzing it. From the selected variables, a new classification was done to determine the next step in the pre-processing of the data. According to Gogtay in [27], the variables can be quantitative or qualitative, and depending on the classification these variables are pre-processed differently.

Likewise, two different approaches were selected for the statistical analysis. The first one was to graphically evaluate the relation of a selected variable with the errors obtained. Given that there were four qualitative variables, there were generated box plots for an easier visualization when contrasting the number of errors with each of the variables. The second approach was to perform a correlation analysis, with a 5% of significance level, to determine the relation of each identified variable on communication reliability.

Finally, to contrast the effect of the variables to the communication errors occurring, there were used the cumulative density function (CDF) and the Mann-Whitney U test with a significance level of 5%.

### 3.2.1 Pre-processing

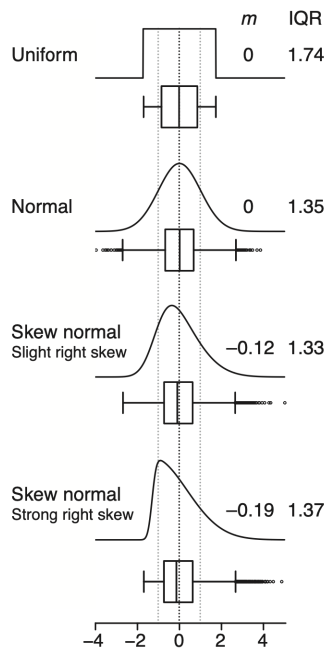
The qualitative or categorical variables needed to be assigned a numerical value for performing analysis with them. In this case, the type of power supply, the use of a network analyzer, and status of wireless auto-scanning were considered categorical and therefore assigned a binary numerical value. The orientation was also a qualitative variable but it is not binary since it had four possible options. For the orientation, the assigned values went from 0 to 3.

Quantitative variables, specifically the number of errors, might contain outliers and it was essential to remove them. To detect those outliers, the first and third quartiles (Q1 and Q3) were calculated to obtain the inter-quartile range (IQR). With the IQR and Q3, the outliers were detected with the following equation [28].

$$Outlier > Q3 + 1.5(IQR) \quad (3.1)$$

### 3.2.2 Box plots and correlation analysis

Visualization was the first step for analyzing data, and box plots is ideal for attempt to characterize it specially when its distribution is unknown, asymmetric or has an irregular shape [29]. There were three key elements when visually analyzing box plots, the median, the IQR, and the upper/lower adjacent. If there are displayed different sets of data, those can be compared by looking at the median representing the value from the 50% of the measurements. Moreover, the width of the IQR indicated how dense are certain measurements in a determined interval. Finally, the adjacent represented how skewed a distribution was [28]. Figure 3.3 displays the box plots corresponding to different distributions.



**Figure 3.3:** Data sets with different distributions and its respective box plot. This helps identifying how the distribution of the data should look [29].

For the correlation analysis, it is important to first highlight that the correlation can work on both ways. For example, set A can be influencing over set B, or set B influences set A. When performing a correlation analysis the results will not determine which set is influencing the other. However, to determine if two sets of data are correlated is still an essential finding for this research. The key elements for the correlation analysis were the p-value and the correlation coefficient – rho ( $\rho$ ). The correlation coefficient is a value that goes from 0 to  $|1|$  and the closest it gets to  $|1|$  the more correlated these two sets of data are. The p-value is the statistical level of significance and it is used to accept or reject the null hypothesis. The null hypothesis for this correlation analysis was that both set of samples are correlated. If the resulted p-value of a correlation analysis raised above the statistical level of significance, it meant that there was enough evidence to reject the null hypothesis and therefore, the sets were not correlated [27].

### 3.2.3 Mann-Whitney U test

The test helped determining if one set of samples was stochastically greater than another one and if there was any statistical significance over that difference [30]. The key elements of this test were the p-value and the result from the test which was represented by a logical 0 or 1. Getting a logical value of 1 means that there was enough evidence to reject the null hypothesis of having equal medians between the compared two sets.

## 3.3 Housing design

Based on the user requirements, the considerations for the design were:

1. Should have an attachment point for a lanyard
2. Should not have sharp edges
3. Should have access to the 8 channels, the reference channel, and the USB port of the TIVA board for power supply.
4. The external battery power can be replaceable, so the housing should be standard.

For the design and development of the housing it was used the software Fusion 360, from Autodesk, and the Flash Forge Dreamer 3D printer.

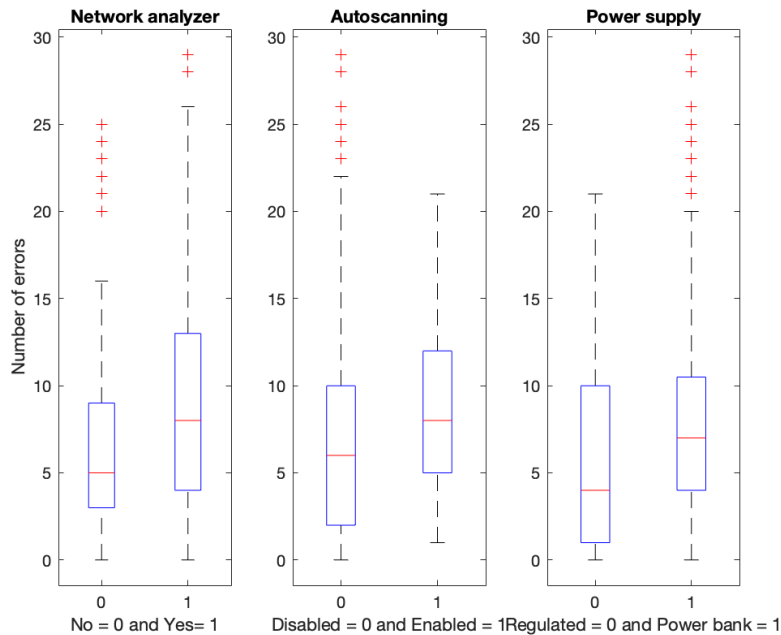
# 4

## Results

A total of 388 tests were performed for the data collection process. By using the Equation 3.1, all the measurements points corresponding to more than 23 errors were considered outliers. After removing those outliers, the total number of measurements used for the data analysis was 372. The results from the wireless communication analysis and the 3D housing design are shown in this section.

### 4.1 Wireless communication

The first analysis from the box plots shown in Figure 4.1, indicate that the variables with more influence over the errors were the use of the network analyzer, the status of the auto scanning feature, and the type of power supply used.

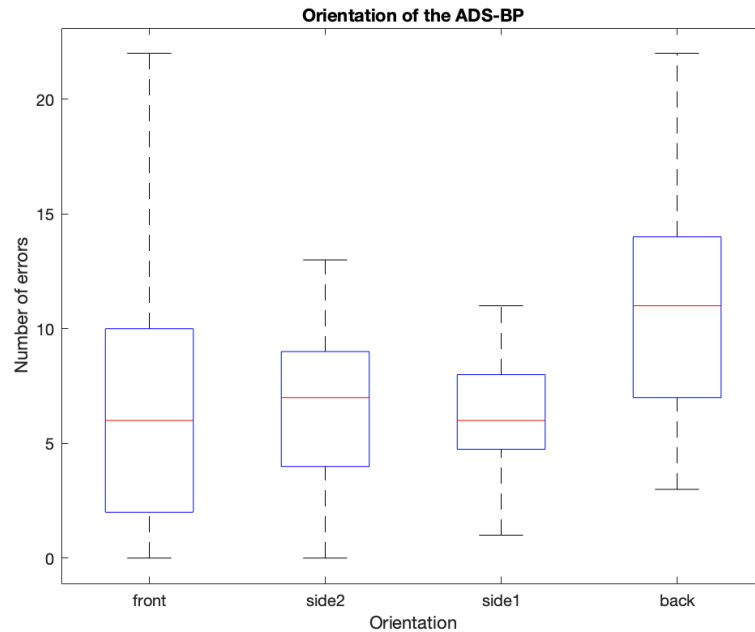


**Figure 4.1:** Box plots from the qualitative variables with higher relation with respect to the number of errors – the use of a network analyzer and the status of the wireless auto scanning feature.

Similarly, the orientation does not show a major difference between placing the device with a front or any side orientation. However, according to the box plot in

## 4. Results

Figure 4.2, when placing the device with a back orientation then number of errors increase.



**Figure 4.2:** Box plot from the four possible orientations of the device with respect to the number of errors.

For a better understanding, Table 4.1 shows the most important information extracted from the plot in Figure 4.1 and Figure 4.2.

**Table 4.1:** Statistical data extracted from the box plots showing each variable with different layouts.

Variable	Layout	Minimum	Median	Maximum
Network analyzer	With	0	8	22
	Without	0	5	16
Wireless auto scanning	Disabled	0	6	19
	Enabled	1	8	21
Power supply	Regulated	0	4	21
	Power bank	0	6	19
Orientation	Front	0	6	22
	Side 2	0	7	13
	Side 1	1	6	11
	Back	3	11	22

The minimum and maximum represent the lowest and highest possible errors with each layout. Those values and the median help to understand the possible relation of each variable layout with the number of errors generated. By looking at the minimum, it is noted that having the wireless auto scanning feature enabled and



placing the device with a back orientation guarantees to have at least one error. Then, by looking at the median, it can be inferred that less errors occur depending on the layout.

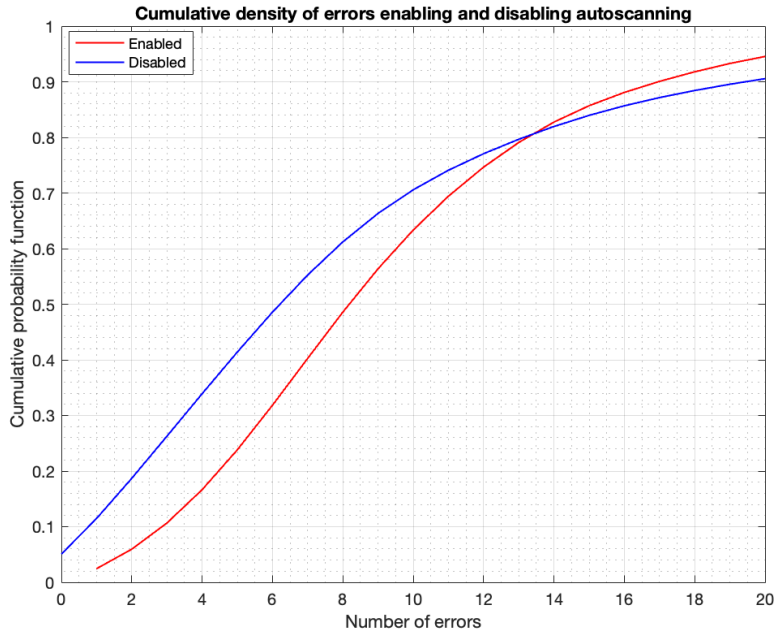
To establish a more analytical difference between each test layout, the correlation analysis is run. Table 4.2 shows the correlation between each qualitative and quantitative variable and the number of errors.

**Table 4.2:** Correlation results between each variable and the number of errors obtained.

Variable	$\rho$	p-value
Network analyzer	0,209	1,28E-04
Wireless auto scanning	0,207	1,46E-04
Power supply	0,096	8,02E-02
Orientation	0,139	1,10E-02
RSSI	0,252	1,22E-03
Number of overlapping channels	0,232	1,25E-02
Number of wireless devices	0,082	6,24E-01

The qualitative variables – network analyzer, wireless auto scanning feature, power supply used, and orientation, can be compared to the results from the box plots. Similar as what Figure 4.1 and Figure 4.2 depicted, the highest correlation to the errors was the use of a network analyzer, followed by the enabling of the wireless auto scanning feature. The correlation factor was 0.209 and 0.207 respectively with a p-value lower than the statistical level of significance of 0.05, which confirms there is a correlation. From the numerical variables – RSSI, number of overlapping channels, and number of wireless devices nearby, it was shown to have a high correlation between the power output, and the number of overlapping channels. The RSSI have the greatest correlation compared to the other variables with a correlation factor of 0,252, followed by the number of overlapping channels with rho equals to 0,232 both variables with a close-to-zero p-value.

It is important to remark that under normal conditions the user will not need a network analyzer tool while taking the bioelectrical measurements. Therefore, by excluding the samples from using a network analyzer software, 170 measurements were used for performing one more analysis. The CDF is calculated and plotted for each status of the wireless auto scanning feature to validate its influence over the error onset.



**Figure 4.3:** Cumulative density function of the two sets of samples corresponding to enabling and disabling the wireless auto scanning feature.

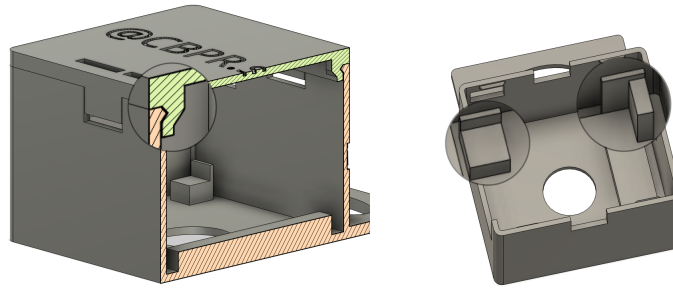
Figure 4.3 demonstrates that there are higher probabilities to have less errors when the auto scanning feature is disabled from the test computer. To motivate this finding from an analytical perspective, there is used the Mann-Whitney U test, and the results are shown in Table 4.3.

**Table 4.3:** Results from the Mann-Whitney U test to accept or reject the hypothesis of having equal medians with the wireless auto scanning feature enabled and disabled.

p-value	Null hypothesis outcome
8,36E-05	Reject

## 4.2 Housing design

When designing the housing, besides the given requirements there were added three more considerations. Since the housing consists of the case and a cover, it was necessary to determine the way those two parts are attached to each other. Also, even though the device is not intended to be assembled more than once, it should be easy to remove its cover and the PCB inside the case. Finally, it was also considered that the PCB should not be loose inside the housing in any axis.



**Figure 4.4:** Design for meeting the additional requirements of holding case and cover together, making it easier to push out the PCB from the bottom, and preventing the PCB to be loose inside the housing.

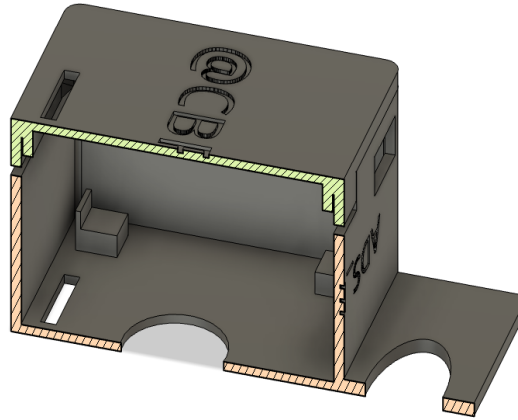
Figure 4.4 shows the cross-section of the design with emphasis in the snap fit used. In this case, the catch – or the entrance side, is in the case while the holes are in the cover. To fit the PCB inside the case, there were added four supports two in each 2D axis. For the depth axis, it was not necessary since the friction from the lateral sides with the supports is enough to hold it in place. The figure also shows the back hole for aiding in the push out of the PCB from the housing.

For the main requirements, Figure 4.5 illustrates the point of lanyard for easily hanging the device while measuring. It is also possible to see the rounded edges to prevent injuries caused by sharp edges, and for a more esthetic design. The figure also shows the access space for the eight electrodes, the reference electrode, and the micro-USB for the power supply.



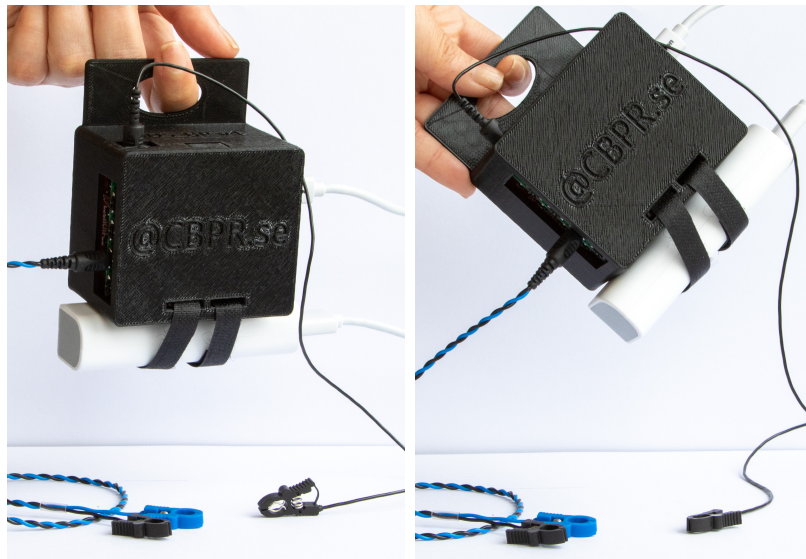
**Figure 4.5:** Renders from Fusion360 of the ADS\_BP design that meets the initial requirements.

Finally, to have a standard housing that holds the power bank to the case there were included two additional spaces. Those spaces were designed for having a Velcro strip passing through the case and cover. That method also offers extra support from the case to the cover.



**Figure 4.6:** Cross-section to show the spaces where the Velcro strip passes through to hold the power bank.

The housing design was 3D printed with non-flexible material and hexagon-shape infills after printing five solid layers to save material while keeping a stable structure. Figure 4.7 displays the final result of the housing with all its elements connected proving that the housing meets the design requirements.



**Figure 4.7:** Final result of the housing with the electrodes and cable connected corresponding to the channels 2 and 3, reference, and power supply.

# 5

## Discussion

Similarly than in the previous chapter, the discussion will be based on the wireless communication analysis and the housing design outcome.

### 5.1 Wireless communication

From communication concepts, it is known that the power output and the number of wireless networks in the same wireless channel is highly related. When there are fewer overlapping access points in a determined channel, the RSSI increases and vice versa. However, despite having eleven channels available, most of the wireless access points have a dynamical selection of channels with only three possibilities; 1, 6 and 11. That is why an initial solution for improving the communication between the device and the test computer was to configure the COMBATT board to have a set wireless channel different from those three common values. Considering that the number of access points connected to a channel is an stochastic variable, it is not possible to select only one channel which always assures the communication stability.

The following variables with high relation to the number of errors were the use of a network analyzer and the wireless auto scanning feature. As mentioned in the previous section, the purpose of using a network analyzer was collecting data for this research. Therefore, the user of the ADS\_BP will not need to have this software open, reducing the onset of errors related to that variable. The wireless auto scanning feature is something that could be easily switched from enabled to disabled. However, it is not a definite and radical disabling, rather a simpler solution to prevent the computer connect to another wireless network with higher power output and ethernet connection. Since the computer does not recognize any other network, will have no other option than to stick to the only network stored in its memory – the ADS\_BP.

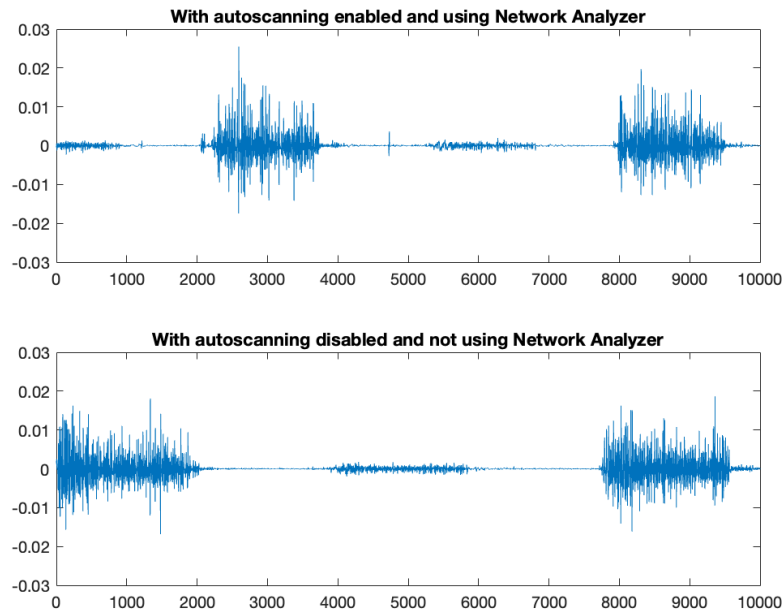
After presenting the results, despite they indicate there is a significant statistical difference between having the feature enable and disable, the next step is to analyze if it influences or not the error onset. From statistical concepts it is known that correlation does not mean causation, and the results presented in this research are based on correlation. However, by setting the events in a timeline, it is possible to notice that the BioPatRec platform error detection cannot influence the status of the wireless auto scanning feature. Therefore, we can say that the variables are correlated only in one direction, making the wireless auto scanning feature one of the influential variables over the communication errors. With the results obtained,

it is clear that having the wireless auto scanning feature enabled is not the main cause of errors. However, it is worth to disable that feature and expect to have less communication errors.

The orientation of the device also showed evidence of being slightly related to the number of errors. With a correlation coefficient of 0,139 and a p-value of 0,011, the null hypothesis of having no correlation between the orientation and the errors, is rejected. The box plot helped determining that placing the test computer to the back or to the lateral side 2 of the device, can result in higher number of errors.

From the analyzed variables, the p-value of the correlation between the number of wireless devices in the proximity of the ADS\_BP and the errors was 0,62. Having a p-value greater than the significance level of 0,05 indicates that there is enough evidence to reject the hypothesis of those variables being related. Similarly, the type of power supply used also had a p-value greater than the significance level. Which leads to ensure that the performance of the device is not affected by the portability feature – offered by the power bank.

To visualize how these communication errors affect the final output, there were taken two sEMG measurements from a person for 10 seconds while flexing and relaxing the hand. The first measurement was taken having the network analyzer inSSIDer open and the wireless auto scanning feature enabled. For the second measurement, the feature was disabled, and the network analyzer was never opened.



**Figure 5.1:** sEMG measurements contrasting the two variables that showed to have higher correlation with the error onset.

For these measurements in Figure 5.1, the communication error is visible between 4000 and 5000 milliseconds when having the network analyzer open and the auto scanning feature enabled. In contrast to the second measurement that does not display any error during those 10 seconds.

## 5.2 Housing design

The most critical decision regarding the housing design was around the use of any type power bank. There were analyzed two different perspectives like the place where the power bank will rest, and the way it will be attached to the case. Since there are three ports that needed accessibility for connecting the electrodes and power supply, three out of four lateral sides were disregarded. Narrowing down the options, the battery could rest at the back of the case, or in the only lateral side with no ports. Since the housing needed a point of lanyard and the power bank was going to change the center of gravity, it was decided to place those two requirements in opposite sides respect to each other. In that way, when taking the measurements, the battery will rest in the bottom while the device is hanged through the point of lanyard.

Another important decision taken was related to the way the case and the cover were joined together. An initial thought was to use commercially available screws in a way that the design needed to include the threaded hole. Considering that this device is open-source, the quality of the 3D printer varies from user to user making it difficult for lower quality printers to have a good accuracy when printing the threaded holes. The snap fit was selected to guarantee that the cover and the case are always properly attached despite the 3D printer used.

To hold the power bank to the housing, it was discussed different types of materials. The options were plastic tie strips, rubber bands or Velcro strips. The first option was ruled out since there was not enough friction to hold the battery without slipping. The second option was ruled out because of the life-span of the rubber material. It might have worked perfectly during a short period, but eventually the resistance of the material will decrease provoking a similar effect than using the plastic strips. Although, it is worth to mention that it is a good option in terms of friction since the material would have stick to the power bank. Therefore, the Velcro strips were the option that met both requirements of not having a short life-span and having higher friction than the plastic strip. However, to add more friction and improve stability, double-sided tape was used to hold the power bank and the Velcro together.

## 5.3 Limitations

The ADS\_BP v4 was already developed by a previous author from our research group. Those modifications included the new COMBATT board with its updated firmware, and the BioPatRec adaptation for receiving the signals wirelessly. It is important to highlight that this research was mainly focused on the hardware layout and user settings. Therefore, the code for the firmware nor the platform was modified for the purpose of this research.

### 5.4 Future work

A future approach should be to investigate if the digital signal processing can be improved. The modulation and demodulation stages play an important role when performing wireless communication. Also, the synchronization between the transmitter and the receiver can be analyzed and determine if there are any improvements to be made.

Furthermore, it is essential to measure and evaluate the impact of the communication errors in the acquired bioelectrical signals. This is of high importance to assure that the displayed signals and acquired measurements are a faithful representation of the bioelectrical activity of the individual.



# 6

## Conclusion

To answer the research questions, there were used a visual and analytical approach. The results showed that the number of wireless devices around the ADS\_BP did not affect the communication. However, there were other variables that were correlated to the error onset.

The correlation factor obtained between the wireless auto scanning feature and the error onset was 0,207 and the difference in medians between enabled and disabled differed in 2 units. These results can be interpreted as insignificant since the improvement rounds only the 10%. However, since it is a feature that can be easily implemented it is worth to disable it when setting up the device and the test computer.

A higher correlation was found with the number of overlapping channels, but it is not recommended to implement an action regarding this variable. The dynamic nature of the access points makes it difficult to determine which channel is always less overloaded. When the device is used in an area with fewer access points – like a lab environment, it is less likely to have an overloaded channel.

Based on Table 4.2, the power supply showed enough evidence to determine that it is uncorrelated to the onset of errors. However, any DC electronic board needs a well-regulated power supply for guaranteeing a good performance during its useful life. Hence, it is recommended to select a power bank with a good DC regulation, even though it does not affect the wireless communication.

The orientations were selected with respect to the previous housing and its lanyard. Since the point of lanyard was moved from its initial position, the reference for the orientations were changed. In the new design, the left side of the device corresponds to the back of the previous housing, which is the one causing higher communication errors. It is then not recommended to place the test computer to the left of the ADS\_BP v4.

Furthermore, the housing was printed with a Flash Forge Dreamer 3D printer with a raft to guarantee the quality of the first layer of the housing. Also, there were added infills in the form of hexagons with five solid layers on the top and on the bottom of the structures. The infill saves printing material, and the solid layers guarantee the stability of the housing.

The full instructions and documents for the open-source release were prepared and will be uploaded on GitHub. The ADS\_BP 4 will be publicly available which includes the firmware for the ADS\_BP, the hardware files for assembling, the instructions for the communication settings, and the 3D files for printing the housing. All the mentioned files correspond to the complete low-cost bioelectrical acquisition system that is soon to be available for the research community.



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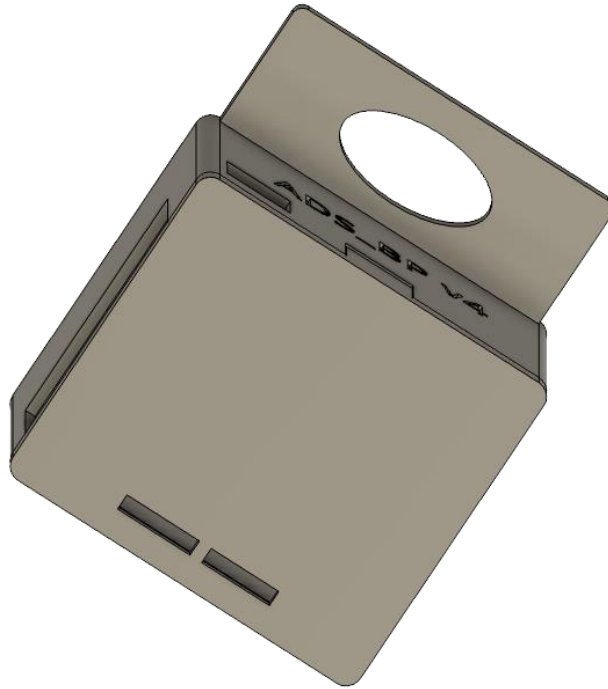
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# A

## Instructions for building the ADS\_BP4

# Welcome to the ADS\_BP v4



**June, 2022**



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## Introduction

ADS\_BP provides a **low-cost** open-source solution for signal conditioning of bioelectric signals. This can be used conjointly with a micro-controller unit and a software as a human-machine interfacing system. This PCB provides the Analog Front End (AFE) and the communication for a 2-part signal acquisition system. This project was motivated by the need for hardware for the acquisition of the bioelectric signals to be used with [BioPatRec](#).

### Features

- [ADS1299](#) providing 8 simultaneous bipolar channels at 24-bit resolution.
- Allows multiple stacking of other ADS\_BP boards allowing higher channel acquisition with the ability to set Parent/Child status with jumpers
- Opto-isolated USB port.
- Allows RC filtering of input signals (optional)
- Leads' shielding amplifier (optional)
- Programmable Gain: 1, 2, 4, 6, 8, 12, 24
- Wireless communication through Wi-Fi

## Firmware

The ADS\_BP firmware is part of an open-source project designed to help provide an extensible, low-cost solution for bioelectric signal acquisition. It is designed to run on a [Texas Instruments Tiva C-series Launchpad](#) board in conjunction with a [Texas Instruments ADS1299 analog front-end](#) and the [BioPatRec](#) software suite. Documentation about the project can be found [here](#).

### Building from Source

Before you begin:

You will need to install [Code Composer Studio \(CCS\)](#) to compile the firmware. If you are unfamiliar with CCS, firmware development, or the capabilities of the Tiva Launchpad, you may want to review some of the tutorial projects provided by Texas Instruments [here](#). The tutorial also provides instructions on how to install CCS with the correct toolchain for the ARM processor and set up any necessary dependencies.

Note that, for this project, it is not necessary to install the TivaWare library suite.

### Download the Source:

Download the project source code through the web or using the following git command to clone the repository to a folder called ADS\_BP:

```
$ git clone https://github.com/biopatrec/ADS_BP.git ADS_BP
```

### Compiling the Project:

Import the project into CCS using the File->Import dialog and select the folder downloaded above. Once the project is loaded, selecting the Build option should compile the appropriate firmware.

### Troubleshooting

Depending on which options were selected during Code Composer Studio, importing the project into CCS may fail with a warning about not having the correct compiler installed. If this happens, open the CCS App Center, and install the TI ARM Compiler. Then, try importing the project again.

## Hardware

The design files for the ADS\_BP printed-circuit-board (PCB) are provided freely in this project. The board was designed with **DipTrace** software and thought as a module that can be plugged on the top of the Tiva board, namely also **booster-pack**. The board provides an isolated USB port that can be used for safely acquiring data, thus always keeping the subject isolated from main power lines. However, since no power transfer is possible through this USB port the system cannot be powered from it. For this reason, a regulated 5 Volts voltage must be provided. A battery and a simple voltage regulator are the easiest way to power it.

Texas instruments provides a power booster pack (**FuelTankMKII**) that includes Li-Ion Battery and all voltage regulators necessary for powering your ADS\_BP stack and recharging the battery via USB. This booster pack is definitely a valid and helpful option to power on the ADS\_BP acquisition system. We tested and we suggest this combination. Please note that some pins are conflicting between these two boards. To avoid this, you can remove the 0-ohm resistors (if present) from the FuelTankMKII board, namely R11, R13, R26 and R27.



## Wireless connection - Wi-Fi module (AMW136)

### Preparations

You must do some preparations for the configuration.

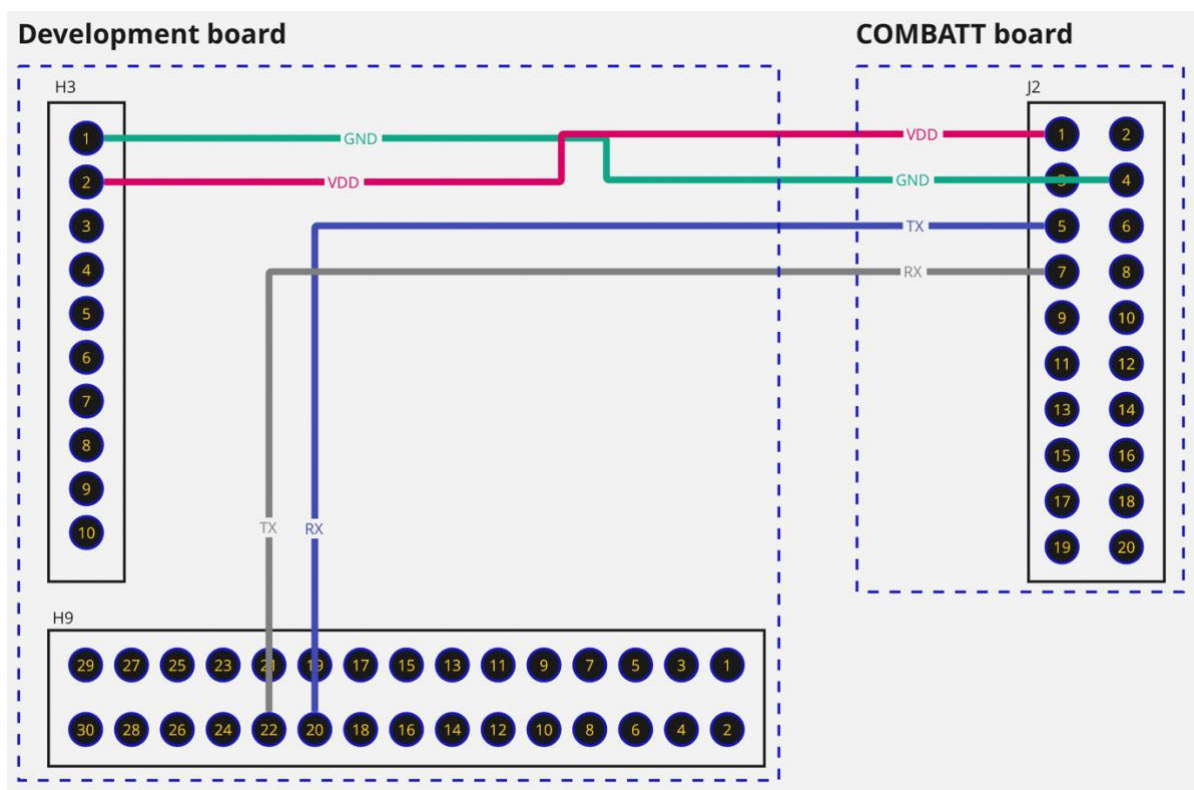
- Firstly, you need to install Terra Term. Please follow the link here to download and install the terminal <https://ttssh2.osdn.jp/index.html.en> (Any other serial terminal will also work)
- Secondly, you need to have the **Development Board**.

### Connections

Once you install the Terra Term and have the development board at hand, connect the COMMBATT board and the development board.

Development board	COMMBATT board
VDD (H3 - Zentri IC pin 3 – physical pin 2)	VDD (J2 - pin 1)
GND (H3 - Zentri IC pin 2 – physical pin 1)	GND (J2 - pin 4)
RX (H9 - pin 20)	TX (J2 - pin 5)
TX (H9 - pin 22)	RX (J2 - pin 7)

The terminal block H3 of development board is internally connected with the Zentri IC in such a way that the Zentri IC pin 1 is not used. Physically, the pin 1 of the H3 terminal block corresponds to the pin 2 of the Zentri IC.



## Terra Term setup

Open the Terra Term terminal and follow these steps.

- Go to Setup -> Terminal, a new window will appear. Make sure the settings would be the same as this:

Tera Term: Terminal setup

Terminal size: 80 x 24  
☒ Term size = win size  
☐ Auto window resize

New-line: Receive: CR, Transmit: CR+LF

Terminal ID: VT100  
Answerback:   
Coding (receive): UTF-8, Coding (transmit): UTF-8  
locale: american

☐ Local echo  
☐ Auto switch (VT<->TEK)

OK, Cancel, Help

- Go to Setup -> Serial port, a new window will appear. Here you must check which COM port is connecting to the development board. For initial setup, set the baud rate at 115200. If the Wi-fi module has been configured before, set the baud rate at 921600:

Port: COM12  
Speed: 921600  
Data: 8 bit  
Parity: none  
Stop bits: 1 bit  
Flow control: none

Transmit delay: 0 msec/char, 0 msec/line

Device Friendly Name: USB Serial Port (COM12)  
Device Instance ID: FTDIBUSVID\_0403+PID\_6015+AN1QB7VUAK  
Device Manufacturer: FTDI  
Provider Name: FTDI  
Driver Date: 8-16-2017  
Driver Version: 2.12.28.0

New open, Cancel, Help

After that, depending on which Wi-Fi mode you want to set, please check with either softap setup or wlan setup.

### Softap configuration

In this mode, the Wi-Fi module will serve as a source of Wi-Fi. In the Terra Term terminal, type these commands:

```
set softap.auto_start true
set softap.dhcp_server.enabled on
set softap.static.ip *Insert an IP for the board
set softap.ssid *Insert the name of the wireless network
set softap.passkey *Insert a password
set softap.dns_server.url adsbp.com
```

```
set tcp.server.auto_interface    softap
set tcp.server.auto_start        true
set tcp.server.port               8000
set tcp.server.idle_timeout      3000
```

```
set bus.mode stream
```

```
set uart.baud 0 921600
set uart.flow 0 off
set uart.data 0 8
```

```
save
reboot
```

After rebooting, the Wi-Fi module will be in stream mode, which will not respond until **\$\$\$** is sent via Terra Term or UART in general. Please notice that the baud rate has been changed to **921600**, so you need to change the serial port settings to 921600 to continue communicating with the Wi-Fi module.

## Wlan configuration

In this mode, the Wi-Fi module will join a specific source of Wi-Fi (the router). In the Terra Term terminal, type these commands:

```
set wlan.ssid          *Assigned name of the wireless network
set wlan.passkey       *Assigned password
set wlan.static.ip     *Assigned IP
set wlan.auto_join.enabled 1
set wlan.static.netmask 255.255.255.0
set wlan.dhcp.enabled 0
```

```
set tcp.server.auto_interface wlan
set tcp.server.auto_start true
set tcp.server.port 8000
set tcp.server.idle_timeout 3000
```

```
set bus.mode stream
set wlan.tx_power 31
```

```
set uart.baud 0 921600
set uart.flow 0 off
set uart.data 0 8
```

```
save
reboot
```

You need to focus on these commands and make any changes if possible:

```
set wlan.ssid          *Name of wireless network
set wlan.passkey       *Password
set wlan.static.ip     *IP
```

You must make sure the IP address is properly registered in the router (please check the router configuration for more details). After rebooting, the Wi-Fi module will be in stream mode, which will not respond until \$\$\$ is sent via Terra Term or UART in general. Please notice that the baud rate has been changed to **921600**, so you need to change the serial port settings to 921600 to continue communicating with the Wi-Fi module.

## Router configuration

A router is needed if Wlan mode is set. This tutorial is for setting up a mobile router named TP-Link TL-902AC.



- First power the router, connect your PC to the router's Wi-Fi network. Next, use your web browser to access this link: <http://tplinkwifi.net/>
- Next, please type admin to both username and password to access the router setup page.
- After that, click on **Quick Setup** to begin the configuration. Click Next and you will reach this page

### Quick Setup - Wireless 2.4G

---

Wireless: ☒ Enable ☐ Disable

Wireless Network Name:  (Also called SSID)

Security:

☒ WPA2-PSK (Recommended)

Wireless Password:

(Enter ASCII characters between 8 and 63 or Hexadecimal characters between 8 and 64.)

☐ Disable Wireless Security

☐ More Advanced Wireless Settings

---

- Here you need to set the Wi-Fi name and its password. These are the SSID and passkey that the Wi-Fi module requires to connect. After finishing setting up, proceed to the next page.



### Quick Setup - Wireless 5GHz

Wireless: ☐ Enable ☒ Disable

Wireless Network Name:  (Also called SSID)

Security:

☒ WPA2-PSK (Recommended)

Wireless Password:

(Enter ASCII characters between 8 and 63 or Hexadecimal characters between 8 and 64.)

☐ Disable Wireless Security

☐ More Advanced Wireless Settings

- You have to disable this network as the Wi-Fi module is working with 2.4GHz. Proceed to the next page.

### Quick Setup - Network Setting

LAN Type:

Note: The IP parameters cannot be configured if you have chosen Smart IP(DHCP)

(In this situation the device will help you configure the IP parameters automatically as you need).


IP Address:

Subnet Mask:

We recommend you configure this AP with the same IP subnet and subnet mask, but different IP address from your root AP/Router.

DHCP Server: ☒ Enable ☐ Disable

- Make sure to choose **Static IP** in LAN type. Regarding the IP address, this is the address for the router, you can set it as in the example. Follow the rest of the instructions and it will allow you to reboot the router. After being rebooted, the router will broadcast its Wi-Fi under the SSID you set up before. Connect to the Wi-Fi network and proceed to the setup page again.

**AC750 Wi-Fi Travel Router**  
Model No. TL-WR902AC

- Status
- Quick Setup
- Operation Mode
- Network
- Wireless 2.4GHz
- Wireless 5GHz
- Guest Network
- DHCP**
- DHCP Settings
- DHCP Clients List
- Address Reservation
- USB Settings
- System Tools
- Logout

### DHCP Address Reservation

This page displays the static IP address assigned by the DHCP Server and allows you to adjust these configurations by clicking the corresponding fields.

	MAC Address	IP Address	Status	Edit
<input type="checkbox"/>	4C:55:CC:19:7C:F8	192.168.0.101	Enabled	<a href="#">Edit</a>

- Click on **DHCP** tab, and then choose **Address Reservation**. Remember the static IP address that you set to the Wi-Fi module? Here you must register that address to the router so that it will always reserve that IP address for the Wi-Fi module. Here we need to know the MAC address of the Wi-Fi module. To do that, use Terra Term, switch the Wi-Fi module to command mode (by typing \$\$\$) and put this command on the terminal: `get wlan.mac`
- The Wi-Fi router will show its mac address on the terminal. Register that address to the router and enable it to finish the configuration.

## Housing

The ADS\_BP housing has a 3D printed housing design. The housing consists of a box with its respective cover. The case allocates the PCBs including the ADS\_BP, TIVA launchpad and COMMBATT board. The cover attaches to the box due to snap-fits. The housing has a hanger, to make it easier to handle and hold during the tests. The external battery power can be hold together with the case thanks to an allocated space where preferably velcro passes through. This housing is designed to hold any power bank in terms of size and model.

For assembling the PCBs into the housing, it is recommended to attach the velcro before inserting the PCB. Ideally, once the PCB is settled in the housing with its respective cover, it shouldn't be removed. In case you need to detach the PCBs from its housing, there is a gap in the bottom where the PCB can be pushed out once the cover is removed.

You can find the .stl files as well as the fusion 360 files for the case and cover.

## How to cite

When using the ADS\_BP, use the following publications as references.

1. M. Ortiz-Catalan, R. Brånemark, and B. Håkansson, "BioPatRec: A modular research platform for the control of artificial limbs based on pattern recognition algorithms," Source Code Biol. Med., vol. 8, no. 1, p. 11, Dec. 2013, doi: 10.1186/1751-0473-8-11.
2. E. Mastinu, B. Hakansson, and M. Ortiz-Catalan, "Low-cost, open source bioelectric signal acquisition system," in 2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN), Eindhoven, Netherlands, May 2017, pp. 19–22. doi: 10.1109/BSN.2017.7935997.
3. T. Sansanayuth, "Development of a Wireless Interface for Fitting, Training, and Monitoring of Advanced Prosthetic Limbs"

When using	Reference
Only the BioPatRec software	1
Only the signal acquisition device ADS_BP (without Wi-Fi)	2
Only the signal acquisition device ADS_BP (with Wi-Fi)	2, 3
ADS_BP (without Wi-Fi) with BioPatRec	1, 2
ADS_BP (with Wi-Fi) with BioPatRec	1, 2, 3

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