Design and Power Consumption Measurement of an integrated Accelerometer Sensor Board with Bluetooth Data Transmission.

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Abstract

This thesis work addresses the design and implementation of a MEMS accelerometer into an electronic sensor board from ST Electronics. The main objective is to measure its energy consumption and obtain acceleration data via Bluetooth communication with a mobile device.
The software configuration used to implement an application in a high-level language, based on one previously developed by the manufacturer, is detailed. Additionally, the software used for programming the sensor board is described. The configuration of the accelerometer to monitor energy consumption through an electronic circuit specifically designed for this application, fabricated on a PCB, is also explained. This circuit uses an INA219 current sensor, whose values are processed by an Arduino UNO board and sent to a computer via a wired connection. The data reading and processing are carried out using a MATLAB application, responsible for calculating the main energy consumption parameters and analysing the different operating stages of the board: warning, connection to the mobile device, and data transmission. This application also allows for graphical visualization of the energy measurements.
The methods for obtaining acceleration data are based on the use of a mobile phone and an application provided by the manufacturer to send the data via mail or using a program developed in Python to read the data published by the board. Additionally, a MATLAB application was developed to graphically display the acceleration measurements in the three axes: X, Y, and Z. A comparative analysis of energy consumption under various operating conditions is also conducted, such as the activation or deactivation of other sensors integrated into the board, as well as changes in the data publication frequency, allowing the identification of the device's energy demand under these circumstances.
The work also includes an analysis of energy consumption and acceleration data acquisition during a test in which the device is placed on a person running at different speeds on a treadmill, simulating a potential real-world application of the system.
The results demonstrate that both the configuration of the accelerometer for data acquisition, transmission, and measurement range, as well as the configuration of the other sensors integrated into the board, significantly influence the device's energy consumption, which is powered by a CR2032 battery. This study provides a reference framework for the development of systems requiring low-power wireless sensors in limited mounting spaces, facilitating data acquisition through Bluetooth communication with portable devices.
Finally, an additional study is presented on the STENH02 device, which collects electrical energy from a piezoelectric device. The analysis seeks to determine whether this stored energy can be used as a power source for another electronic device, concluding that it is not feasible to implement it for this purpose.

Introduction

In these times, the use of sensors is becoming increasingly common and can be found in both everyday devices and in specific applications in areas such as sports, art, or industry, to name a few. In many of these applications, the physical configuration between the device where the sensor is mounted and the element responsible for recording its measurements may pose a limitation, requiring that the measured data be transmitted wirelessly.

Fortunately, technological advancements today allow for the development of electronic devices that incorporate a variety of sensors capable of transmitting their measurements wirelessly. This is the case of the STEVAL-BCN002V1B sensor board, manufactured by ST Electronics, which includes sensors such as an accelerometer, gyroscope, pedometer, magnetometer, humidity and temperature sensor, as well as a proximity sensor. This board integrates a processor that allows data from these sensors to be sent wirelessly using a low-energy Bluetooth module.

Typically, these devices are powered by batteries to maintain their portability. However, due to the growing interest in the use of alternative energy sources, it is convenient to analyse the energy consumption that these devices require for their operation, in case an alternative power source is chosen.

This thesis presents an analysis of the energy consumption of the aforementioned sensor board, with a specific focus on the use of the LSM6DSO accelerometer and the necessary conditions to achieve energy measurements with the help of a device specifically developed for this task. The different possible configurations of the sensor board are also explored, based on the documentation provided by the manufacturer, as well as the retrieval of data measured by the sensor through Bluetooth transmission.

As a complementary study, a preliminary analysis of the STENH02 device is included, which was originally considered a possible alternative to the battery to power electronic devices with characteristics similar to the sensor board.

This document is structured as follows: the first chapters present detailed information about the STEVAL-BCN002V1B sensor board, including its composition, main features, and the process of programming a specific application for its use. Subsequently, the development of a device capable of measuring the energy consumption of the board under various operating conditions is described, and a comparative analysis of the results obtained is presented. The methods used to obtain data from the accelerometer are explained, and finally, a test is detailed in which a person, in a real-world scenario, uses the device to measure both energy consumption and acceleration data while running at different speeds.

1. Electrical energy harvester STENH02

1.1 General description

The STENH02 is an electronic device that harvests electrical energy from an electromagnetic transducer. The energy is stored in an external capacitor that is used as an input for a single inductor quadruple DC/DC with independent regulated outputs that provide electrical tension values between 1V and 2.5V. As Figure 1.1.1 shows, the printed circuit board (PCB) is built with surface-mount technology (SMT) elements including the integrated circuit (IC) which internally is divided in three main blocks: adaptative scavenger interface (ASI), single inductor quadruple output buck DCDC converter (DCDC), digital communication and configuration block (DIG).

Figure 1.1.1 – STENH02 PCB.

1.2 Pinout

Integrated circuit pins of the STENH02 are numerated and disposed according to a circular mark on the top left corner of the integrated circuit as is clearly indicated in Figure 1.2.1. The pins general description is presented in Table 1.2.1.

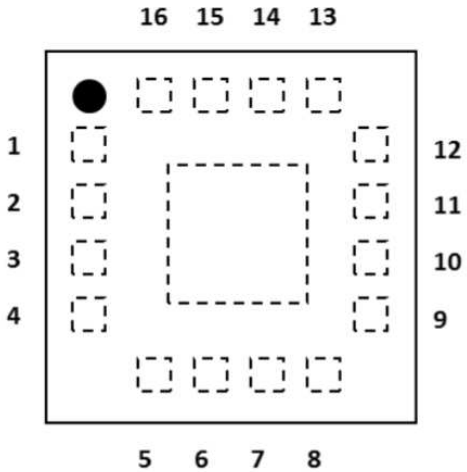

Figure 1.2.1 – STENH02 pin disposition.

Table 1.2.1 – STENH02 pin description.

Pin name	Number	Description
VPOS	1	Positive connection to the electromagnetic transducer
GND_SCAN	2	Power ground
VNEG	3	Negative connection to the electromagnetic transducer
HV_SAF	4	Voltage input for configuration writing (not used)
I2C_SCL	5	I2C SCL input line with internal pull-down resistor
I2C_SDA	6	I2C SDA input/output
TEST1	7	For testing purpose (not used)
DCDC<0>	8	LDO of DCDC converter. Provides power supply for all internal analogue low voltage blocks
DCDC<1>	9	DCDC regulated output
DCDC<2>	10	DCDC regulated output
DCDC<3>	11	DCDC regulated output
PHDX	12	DC/DC phase switch node; external inductor should be connected between PHsx and PHdx
GNDP_DCDC	13	DCDC converter ground pin.
PHSX	14	DC/DC phase switch node; external inductor should be connected between PHsx and PHdx
VOUT	15	Scavenger interface output / DCDC converter input. A 40V external capacitor must be connected between this pin and GNP_SCAV
TEST2	16	For testing purpose (not used)

1.3 Typical application and internal elements

The typical application of the STENH02 consists in transferring electrical energy to an external capacitor, COUT, using the circuit diagram clearly described in Figure 1.3.1.

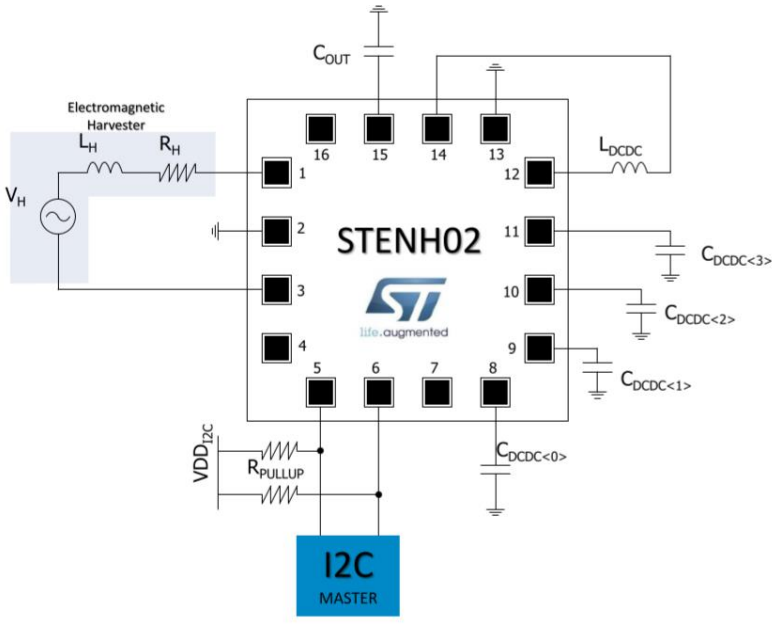

Figure 1.3.1 – STENH02 typical application circuit diagram.

The harvester circuit is a fully active boost converter that consists in an arrangement of two switches and two diodes that transfer the energy to the output capacitor depending on the polarity of the transducer input voltage signal. The typical capacity value for the output capacitor is 22µF and voltage class 20V or higher. To illustrate better the harvester circuit the Figure 1.3.2 presents the logic block corresponding to the circuit that controls the switching operation.

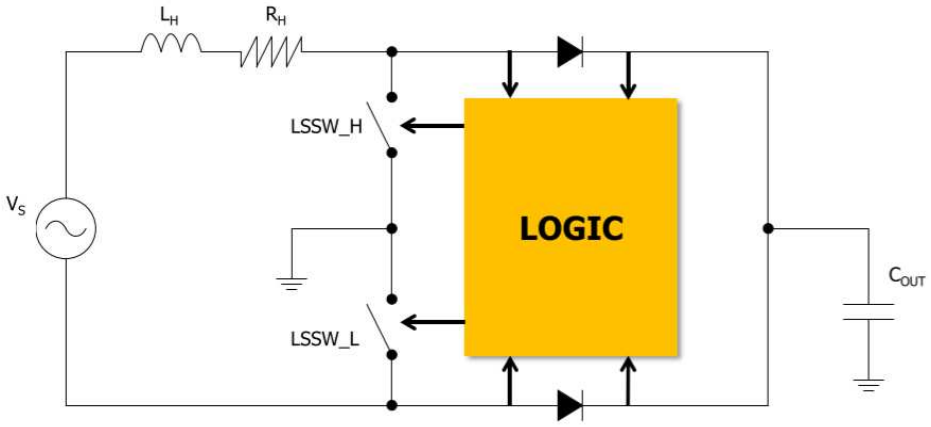

Figure 1.3.2 – STENH02 harvesting circuit.

The control logic algorithm consists in two states of operation due to the combination of the switches LSSW_H and LSSW_L shown in Figure 1.3.2 where the state 1 makes the control logic to keep both switches closed and store energy in the inductance L_H. After a fixed T_{DELAY} time, and a minimum current threshold I_{TH} has been reached in the inductance, one of the LSSW_H or LSSW_L switches is opened, depending on the polarity of the current. Table 1.3.1 summarizes the logic states.

Table 1.3.1 – Harvester circuit logic states.

States	Current	Time	LSSW_H	LSSW_L	Description
E1	$I_{SW}<I_{TH}$	$T<T_{DELAY}$	0	0	Energy stores in L_H
E2	$I_{SW}\geq I_{TH}$	$T\geq T_{DELAY}$	1	0	Energy stores in C_{OUT} (VIN+)
	$I_{SW}\leq -I_{TH}$	$T\geq T_{DELAY}$	0	1	Energy stores in C_{OUT} (VIN-)

If the voltage in the capacitor V_{COUT} is lower than $V_{DCDC-START}$, programmable by the manufacturer between 6.5V and 9.5V, all the analogue and digital blocks are powered by a 2.5V linear regulator (LDO). When the capacitor tension is higher than $V_{DCDC-START}$ all the internal blocks are self-biased by the buck converter. When the capacitor tension becomes lower than $V_{DCDC-OFF}$ all the internal blocks are powered again by the LDO. Figure 1.3.3 shows the STENH02 DCDC element which has a four-output buck converter able to provide four independent power supplies selectable between 1.0V and 1.2V. The four outputs are multiplexed to share the only inductor that this kind of DCDC converter has; this means that operates in a discontinuous conduction mode and to regulate each output tension an external control loop is implemented made of comparators that correct each output tension turning on a switch on every DCDC output. The value of the decouple capacitors connected to the DCDC outputs is 10 µF and the inductor is 10mH.

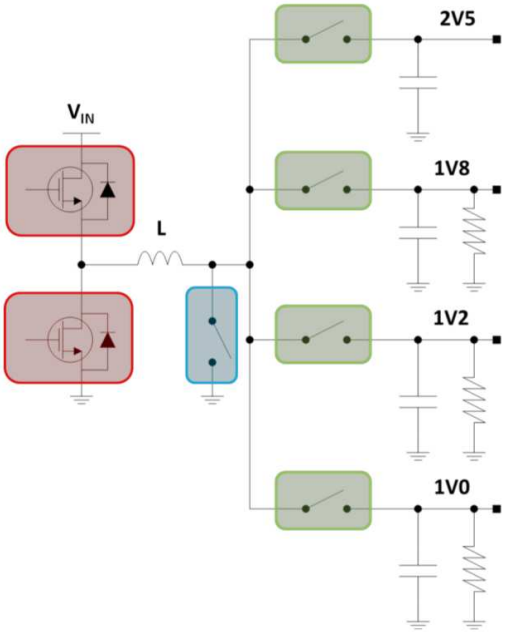

Figure 1.3.3 – STENH02 DCDC element circuit diagram.

Figure 1.3.4 shows the block schematic description of the STENH02 presenting the three main blocks and how they interact between each other apart from the possibility to identify some other internal elements involved in the chip's operation.

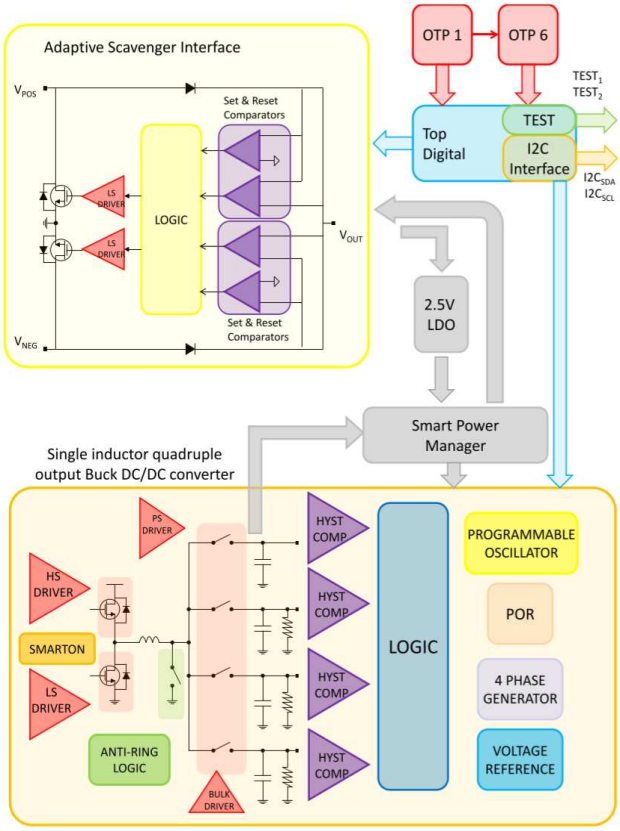

Figure 1.3.4 – STENH02 block schematic description.

1.4 Main electrical parameters

After a datasheet analysis of the device, the most relevant electrical characteristics of the STENH02 and the electromagnetic transducer needed to build the application previously described in previous section are shown in Table 1.4.1 including their typical values.

Table 1.4.1 – Relevant electrical parameters description.

Symbol	Parameter	Values
Electromagnetic transducer:		
L_H	Scavenger transducer equivalent inductance	Typ. 65mH
R_H	Scavenger transducer equivalent series resistance	40 ~ 1260Ω
T_H	Scavenger time constant (T_H=L_H/R_H)	30 ~140μs
STENH02 scavenger interface:		
V_{IN}	Scavenger interface input voltage: VIN=VPOS-VNEG	Typ. 2.5V
V_{OUT}	Storage capacitor voltage	Min. -0.4V / Max. 20V
I_{TH}	Minimum short circuit scavenger current	Min. -175μA / Typ. 700μA / Max. 1500μA
STENH02 DCDC:		
DCDC<0>	LDO/DCDC output voltage	Min. 1.0V / Typ. 1.2V / Max. 1.7V
DCDC<1>	DCDC regulated output	Min. 1.8V / Typ. 1.8V / Max. 2.5V
DCDC<2>	DCDC regulated output	Min. 1.0V / Typ. 1.2V / Max. 1.7V
DCDC<3>	DCDC regulated output	Min. 1.0V / Typ. 1.0V / Max. 1.7V
$V_{DCDC-START}$	DCDC start-up input voltage	6.5~10V
$V_{DCDC-OFF}$	DCDC turn-off after start-up	3.5V
External components requirements:		
C_{OUT}	Scavenger interface storage capacitor	22μF
$C_{DCDC<0\sim3>}$	DCDC decoupling capacitors	4.7fμF
L_{DCDC}	DCDC inductor	Min. 8μF / Typ. 10μF / Max. 12μF

1.5 Charge and discharge measurements

The aim of the test performed to the STENH02 board was to know its performance when it is connected to an electromagnetic transducer and the amount of energy that the user can dispose of it. The first step was to identify the pins of the integrated circuit and their corresponding headers through the analysis of the printed circuit board considering the information in section 1.2 and are now presented in Figure 1.5.1.

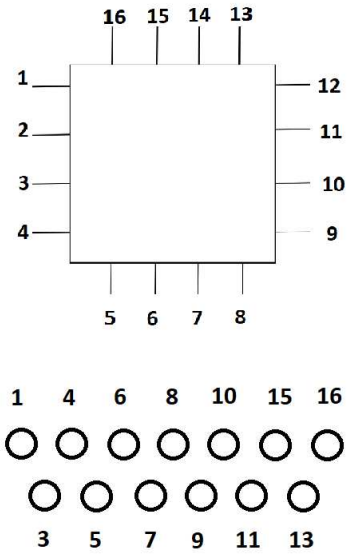

Figure 1.5.1 – STENH02 board pins and headers disposition.

The PCB is printed on a double layer copper board and its corresponding sides, top and bottom are shown in Figure 1.5.1 and Figure 1.5.2 respectively.

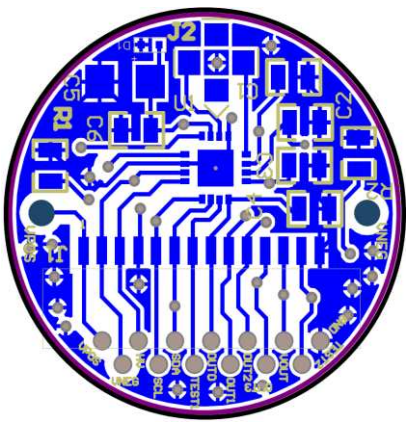

Figure 1.5.1 – STENH02 PCB's top layer.

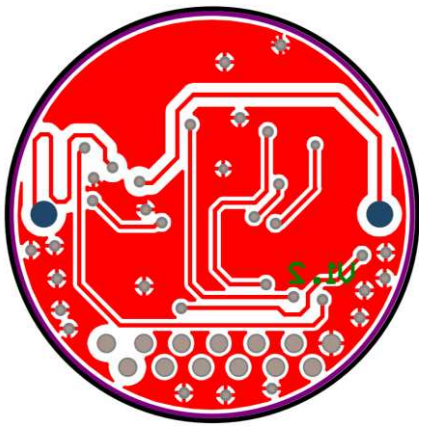

Figure 1.5.2 – STENH02 PCB's bottom layer.

Once the pins are known the board is connected to the oscilloscope to get the four STENH02 DCDC output voltage values, the output capacitor electrical tension and the input signal given by the transducer which has two components, positive and negative. During the test only positive component of the signal was considered due to symmetry and can be observed in both Figure 1.5.4 and Figure 1.5.5.

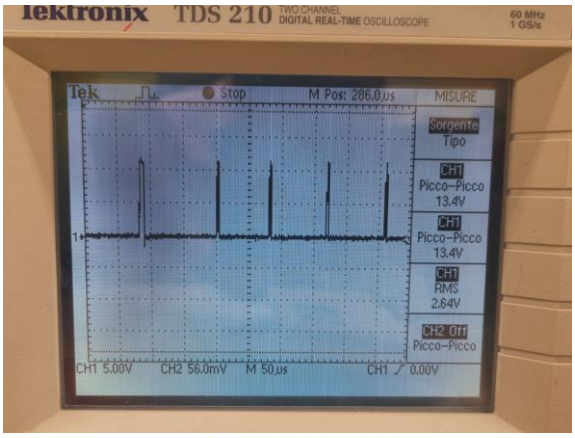

Figure 1.5.4 – Transducer positive signal.

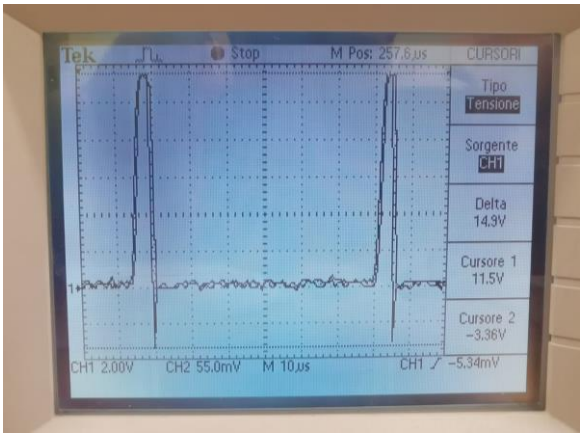

Figure 1.5.5 – Zoom of positive signal.

The amplitude of the peaks depends on the intensity of the vibration applied to the transducer, that was manipulated manually. As this is not DC voltage, what really enters to the STENH02 is close to the average voltage value of half wave signal, approximately the peak value divided by pi. Measuring of the DCDC outputs can be seen from Figure 1.5.6 to Figure 1.5.9 where is possible to see the RMS value of the voltage and confirm that each output gives no more than 2.5V.

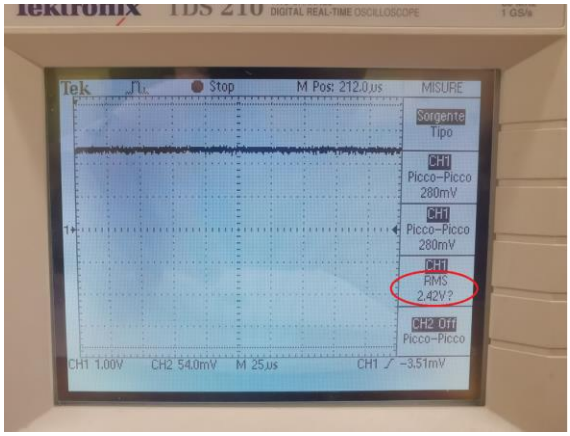

Figure 1.5.6 – DCDC<0> output.

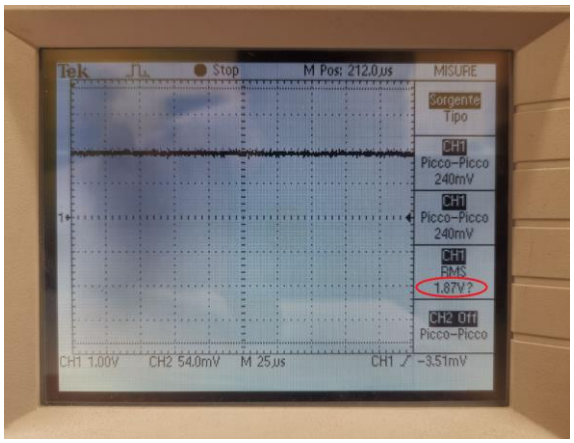

Figure 1.5.7 – DCDC<1> output.

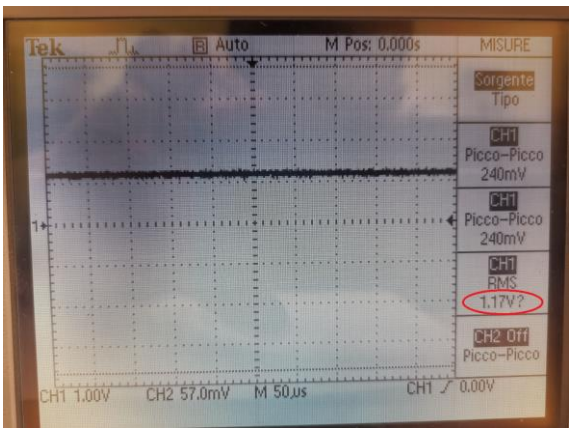

Figure 1.5.8 – DCDC<2> output.

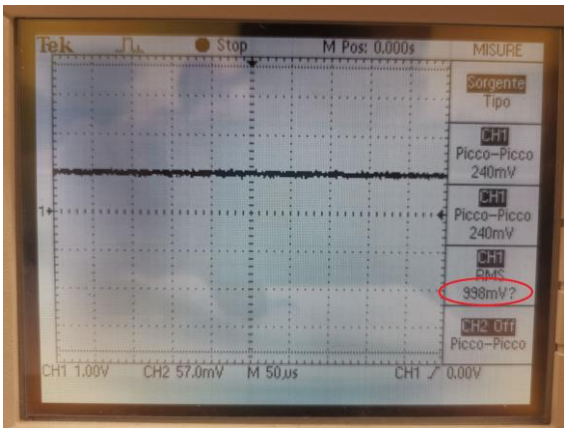

Figure 1.5.9 – DCDC<3> output.

During the test was possible to appreciate a continuous adjustment on the voltage values due to the comparators the chip has at each output; they that have the task of maintaining it until the external capacitor is fully discharged. The voltage value of each output is fixed due to internal logic and there is no way to add these signals into one only. Finally, to corroborate the negative component of the input signal it was measured on the oscilloscope and can be seen in Figure 1.5.10 and Figure 1.5.11.

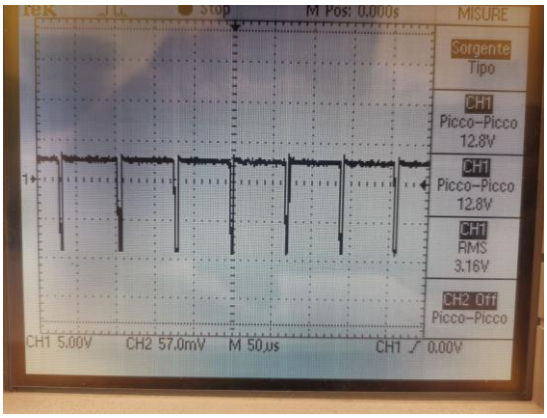

Figure 1.5.10 – Transducer negative signal.

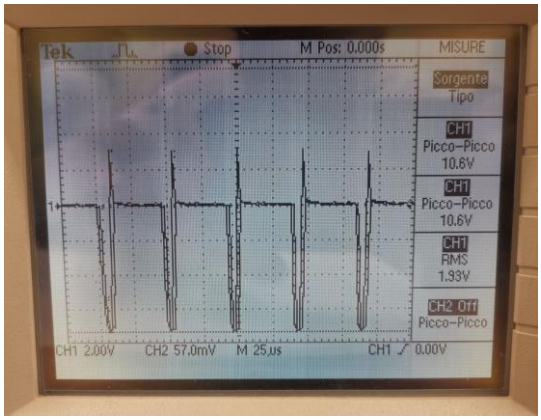

Figure 1.5.11 – Zoom of negative signal.

2. MEMS evaluation board STEVAL-BCN002V1B

2.1 Board's general description

The STEVAL-BCN002V1B Bluetooth LE node sensor evaluation kit includes two electronic devices, the multi-sensor board STEVAL-BCN002V1 based on BlueNRG-2 SoC Bluetooth LE application processor and the STEVAL-BCN002V1D adapter board used to program and debug the sensor board, both presented in Figure 2.1.1.

Figure 2.1.1 – STEVAL-BCN002V1B development kit, multi-sensor board and adapter board.

The multi sensor board is equipped with 6 different sensors that communicate with the BlueNRG-2 processor using I2C protocol which are disposed as shown in Figure 2.2.1 and enlisted in Table 2.1.1.

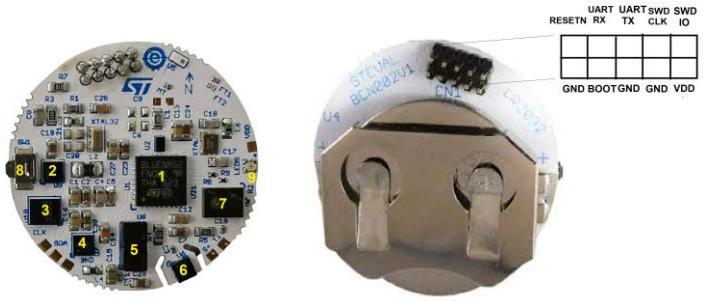

Figure 2.2.1 – Multi-sensor board main components.

Table 2.1.1. – List of main components.

Number	Name	Description
1	BlueNRG-2	SoC Bluetooth LE processor
2	LPS22HH	Ambient pressure sensor
3	LSM6DSO	Accelerometer and Gyroscope inertial module unit
4	LIS2MDL	Magnetometer sensor
5	VL53L1X	Proximity sensor
6	HTS221	Relative humidity and temperature sensor
7	MP34Dt05-A	Digital microphone
8	User button	Push button
9	RGB LED	Multicolour LED indicator

The STEVAL-BCN002V1 is powered by a 3.3V CR2032 lithium battery, attached to the board with the help of a holder element located on the opposite side of the board. In the bottom face of the board is possible to find a set of headers designed to be connect to the programming board. It is important to point that when both boards are connected to start a flashing process of the memory processor the battery must be removed.

As to the programming board refers, switches SW2 and SW3 must be set on P2-P3 position before connecting to the computer with a micro-USB cable.
The multi-sensor board has a pre-loaded application set to work with the iOS or Android version of the ST BLE Sensor smartphone app designed to monitor the different sensors stablishing a Bluetooth LE communication and showing the data in a graphical environment.

2.2 BlueNRG-2 system-on-chip

The STEVAL-BCN002V1B has a BlueNRG-2 system-on-chip (SoC) that is the processor based on a 32-bit ARM Cortex-M0 core used to coordinate all actions as sensors acquisition and transmission data processes; it is represented in Figure 2.2.1. This chip contains a Bluetooth Low Energy module to stablish a connection to an external device and can be programmed by the user to develop specific applications by using the different sensors on the board. This chip communicates to the different sensors using different communication protocols as I2C, UART or SPI and has a 10-bit analogue to digital converter (ADC). The BlueNRG-2 is usually powered with a supply voltage between 1.7V to 3.6V. The typical current consumption values when it is powered with a 3.0V input voltage according to the datasheet [14] are presented in Table 2.2.1.

Figure 2.2.1 – ST's BlueNRG-2 system-on-chip representation.

Table 2.2.1. – BlueNRG-2 supply current.

Test condition	Supply current typical value
Active mode: CPU, Flash and RAM on	1.9 mA
RX	7.7 mA
TX -2 dBm	8.3 mA

2.3 Board's power supply

The CR2032 is a coin-type lithium battery normally use to power supply low power systems such as real time clocks or oscillators. Its shape and physical dimensions are clearly indicated in Figure 2.3.1.

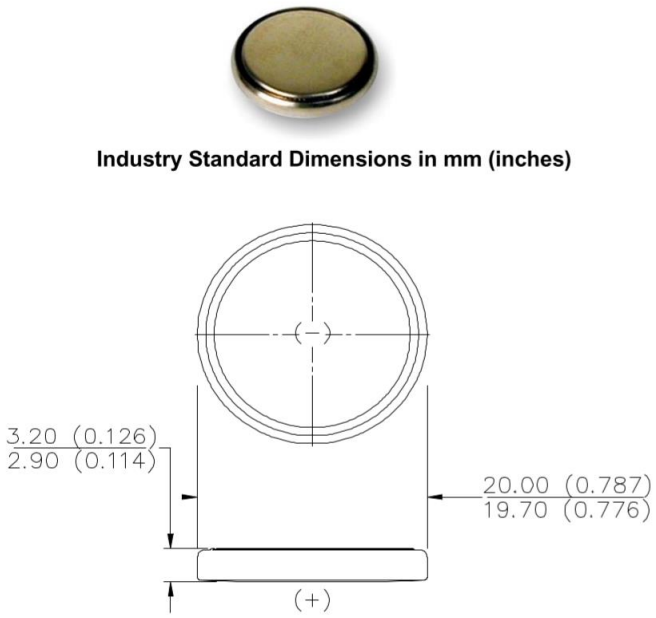

Figure 2.3.1 – CR2032 battery standard dimensions.

Figure 2.3.2 shows a graph taken from to the datasheet provided by the company Energizer [11] that shows the battery can supply a 3 V constant voltage with a lifetime of approximately 2500 hours of continuous work; depending on the fabricant this value can be different. The typical drain current value is around 295 mA working at 21 ºC.

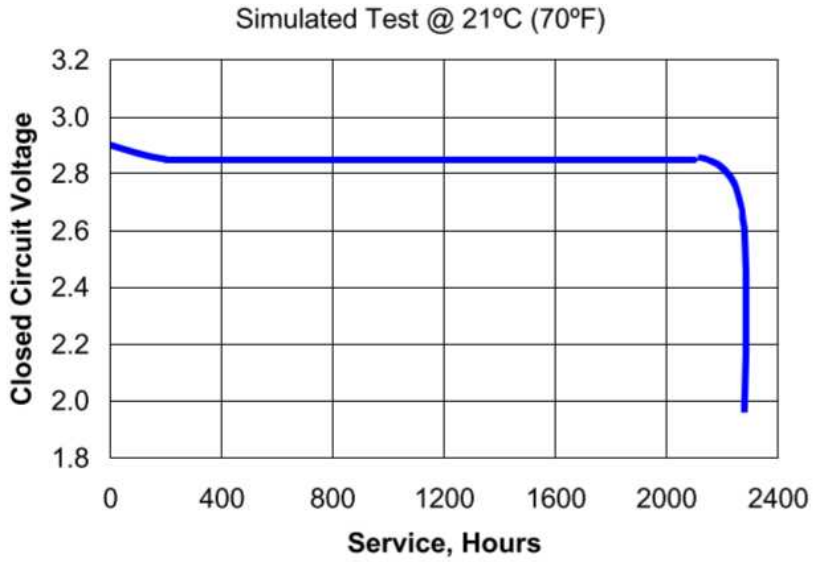

Figure 2.3.2 – Typical discharge curve of an Energizer CR2032 battery.

2.4 Board's typical power consumption

Some characteristics of power consumption of the sensor board taken from documentation [2] are presented in Table 2.4.1 showing the amount of average current consumed depending on the state, event or active sensor, if the device is powered by a CR2032 battery and its corresponding lifetime.

Table 2.4.1. – Battery lifetime and average consumption.

Event	Average current consumption	Battery lifetime
Stand-by	25µA	8800 hrs / 367 days
Environmental / AccEvents / LED control	0.3mA	733 hrs / 30 days
Motion FX (Inertial)	1.4mA	157 hrs / 6.5 days
BlueVoice	3.6mA	61.1 hrs/ 2.5 days

These values do not contemplate the use Bluetooth data transmission but just the active sensors and the BlueNRG-2 system-on-chip powered.

2.5 Bluetooth Low-Energy protocol

The Bluetooth Low Energy (BLE) protocol is a relatively new evolution of the classic Bluetooth communication and is highly oriented to connect to portable devices. Works in a 2.4GHz industrial, scientific and medical (ISM) radio frequency band divided in forty channels with a separation of 2MHz one from each other along the entire band, 37 of these channels are used to transmit information and the remaining 3 to stablish and advertising mode of the device. This protocol is implemented with what is known as stack, an application that manages all the services, that is built in different layers as are enlisted and described in Table 2.5.1.

Table 2.5.1 – Bluetooth LE stack layers.

Layer name	Function description
General access profile (GAP)	How the device discovers and connects with others
General attribute profile (GATT)	How the services and characteristics can be discovered and used
Attribute protocol (ATT)	Protocol for discovering attributes, writing and reading
Security manager (SM)	Communication security
L2CAP	Multiplexor, segmentation and rebuilt of packages
Host controller interface	Standardized communication between the host stack and the Bluetooth integrated circuit
Link layer	Digital microphone
Physical layer (PHY)	Handle packages, channels, advertisings, scanning and connections

The GAP profile is the one who controls the network. It defines four roles: broadcaster, observer, peripheral and central. Figure 2.5.1 shows a representation of the interaction between devices depending on its role.

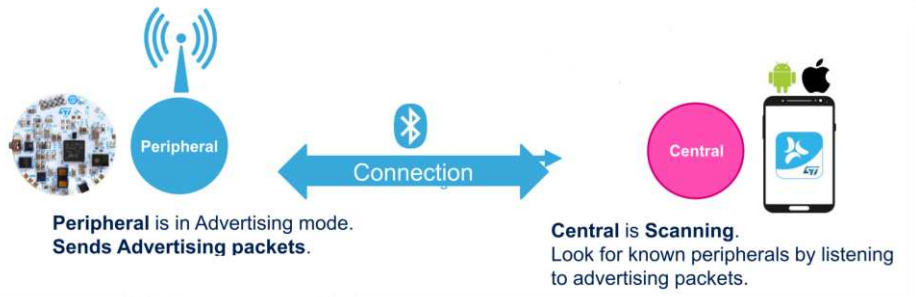

Figure 2.5.1 – GAP defining roles.

The GATT controls the flow of information and defines two roles: server and client. The server contains the information, receives requests, executes and responds, can indicate a value as represented in Figure 2.5.2. The client talks to the server and send requests and waits for and answer.

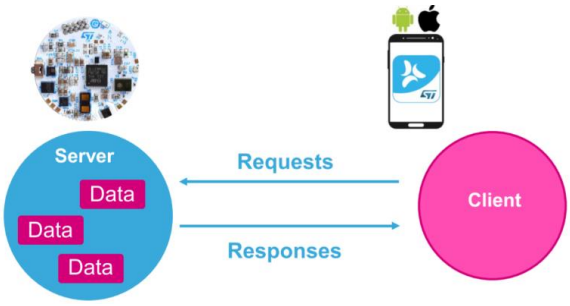

Figure 2.5.2 – GATT description.

The information is presented as attributes with a handle, a type and a value. Some examples of attributes are presented in Table 2.5.2.

Table 2.5.2 – Example of attributes.

Handle	Type	Value
0x0009	“Device name”	“Temperature sensor”
0x0022	“Battery status”	0x04
0x0098	“Temperature”	0x0802

Attributes are organized in services and characteristics. For example:

Service: “ARG” (Angular Rate and Gravity)
Characteristics: “Gyro”, “Acc”
Values: [0, -1, +2], [-10, +15, -900]

The multi-sensor board is always sending data from the sensors and the way this data is collected by the client is accessing to the services and characteristics.

3. Inertial sensor LSM6DSO

3.1 IMU's general description and characteristics

The LSM6DSO is an inertial motion unit (IMU) featuring a 3D digital accelerometer and a 3D digital gyroscope. It has a full-scale acceleration range of ±2/±4/±8/±16 g and an angular range of ±125/±250/±500/±1000/±2000 degrees per second (dps). The IMU connects to the BlueNRG-2 SoC using I2C protocol. It comes in a small land grid array package of 2.5 x 3.0 x 0.83 mm mounted on the top of the multi-sensor board. The axes on the device are oriented as can be seen in Figure 3.1.1 while the description of the orientation of those axes on the STEVAL-BCN002V1 is represented in Figure 3.1.2.

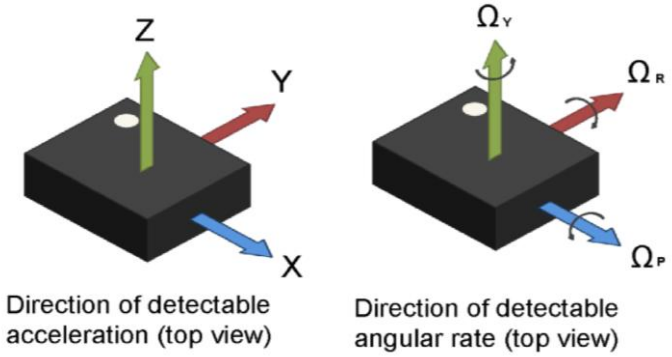

Figure 3.1.1 – LSM6DSO accelerometer and gyroscope axes orientation.

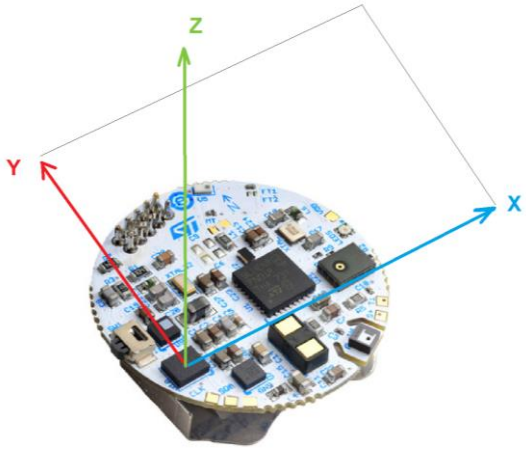

Figure 3.1.2 – LSM6DSO axes orientation on STEVAL-BCN002V1.

The accelerometer sensor can be set to different linear acceleration measurement range configurations and depending on the one selected gives a different output value per bit that is later read by the BlueNRG-2. Table 3.1.1 shows the main mechanical characteristics of the sensor. With respect to the sensitivity value, the less significant bit (LSB) corresponds to a 16-bit float type output value given by the sensor when communicating via I2C protocol with the BlueNRG-2 processor for its interpretation.

Table 3.1.1. – LDS6MDSO characteristics.

Parameter	Test conditions	Typical value	Unit
Linear acceleration sensitivity	±2 g	0.061	mg/LSB
	±4 g	0.122	
	±8 g	0.244	
	±16 g	0.488	
Linear acceleration sensitivity tolerance	At component level	±1	%
Linear acceleration output data rate		1.6 12.5 26 52 104 208 416 833 1666 3332 6664	Hz
Supply voltage		1.71 to 3.6	V
Input current		0.55	mA

To know more about the electrical power consumption of the board it is necessary to perform certain test to obtain the values of the electrical tension feeding the device and the current demanded from the power source.

3.2 Comparison with an analogue accelerometer

The correct selection of a device for a specific application should involve the evaluation of different characteristics including size, materials, electrical consumption, etc. Table 3.2.1 shows the main mechanical characteristics of the 356A15 analogue accelerometer, shown in Figure 3.2.1, as an example of devices used for different purposes to compare both sensors. In this case as the sensor is analogue the output is given by a voltage signal corresponding to acceleration value measured.

Figure 3.2.1 – 356A15 analogue accelerometer.

Table 3.2.1. –Analogue and digital accelerometers detailed comparison.

Parameter	LDS6MDSO (Digital)	PCB-356A15 (Analogue)
Measurement Range	±2g, ±4g, ±8g, ±16g	±50g
Sensitivity	0.2013 mV/g (±2g) 0.4026 mV/g (±4g) 0.8052 mV/g (±8g) 1.6104 mV/g (±16g)	100 mV/g
Resolution	16 bits	Continuous
Linear acceleration output data rate	1.6 Hz to 6.6 kHz	1.4 Hz to 6.5 kHz
Supply voltage	From 1.71V to 3.6V	Requires 20-30 VDC
Input current	0.55 mA	From 2 to 20 mA
Linear acceleration sensitivity tolerance	±1%	±1%
Operating Temperature	-40°C to 85°C	-54°C to 121°C
Dimensions	2.5 mm x 2.5 mm x 0.86 mm	10.2 mm x 10.2 mm x 10.2 mm
Interface	I²C, SPI	Analog voltage output

4. Software configuration and description

4.1 µVision IDE configuration

The first step is to install the integrated development environment (IDE) needed to initiate the analysis and manipulation of the SensorDemo source code. There are three software alternatives to choose: IAR's EWArm, Atollic's TrueStudio and Keil's µVision but since there is more information about working with Keil's IDE this is the one that is been selected. It is possible to obtain it by downloading the microcontroller development kit visiting Keil's website [5], seen in Figure 4.1.1, then opening and proceeding to install it following the installation assistant. When the process is complete the µVision IDE will be installed on the user's computer.

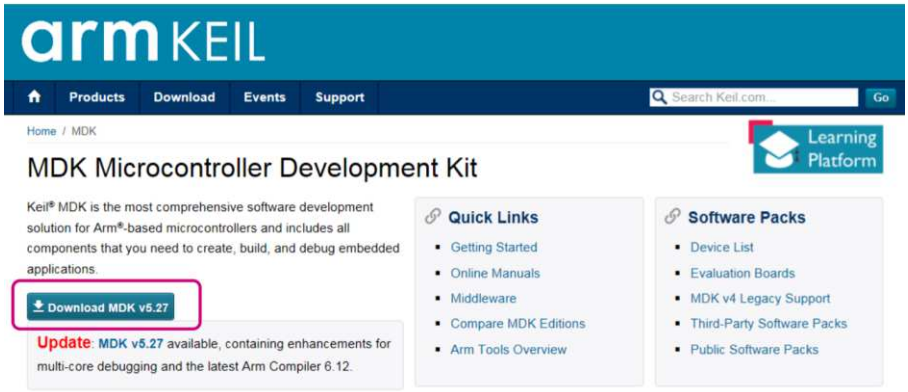

Figure 4.1.1 – Keil's website to download the IDE.

Then, it is necessary to configure the IDE to work with the STEVAL-BCN002V1. To do this, a device family package needs to be downloaded by visiting Keil's specific website [6], observed in Figure 4.1.2, obtaining a .zip file which allows the IDE to work with BlueNRG-2 based devices.

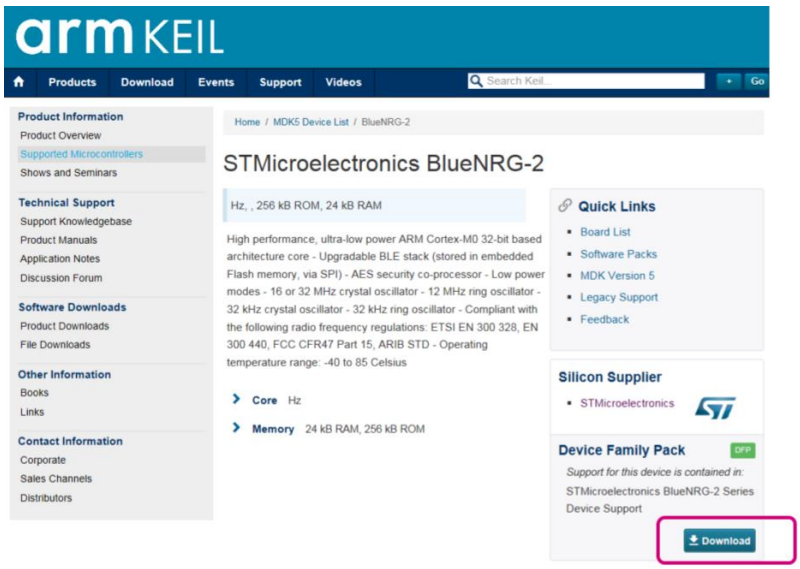

Figure 4.1.2 – Keil's BlueNRG-2 package website.

To start the configuration the µVision IDE needs to be executed, then the user must go to: Project>>Manage as is clearly shown in Figure 4.1.3; then a new window will open.

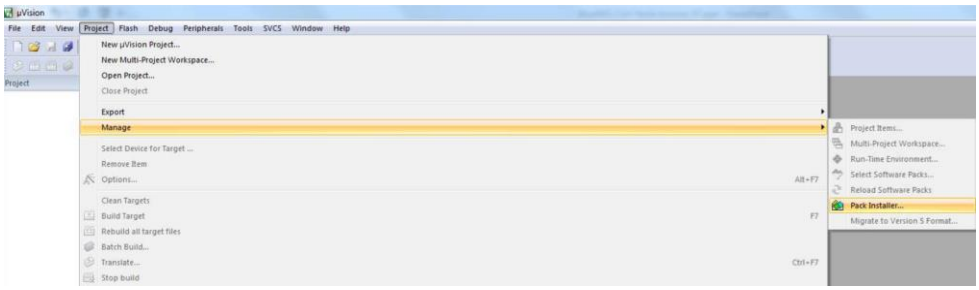

Figure 4.1.3 – Access to package installer on µVision IDE.

The user must select: File>>Import, then look for the .zip package file previously downloaded and select it as Figure 4.1.4 shows. The installation of this package will start.

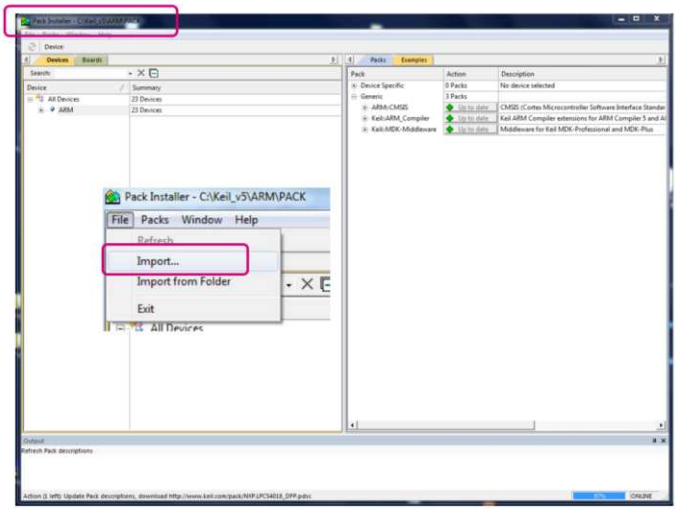

Figure 4.1.4 – Installing the device family package in µVision.

Once the process is completed it is possible to verify if the device package is correctly installed by looking at the devices list on the left column of the new window and selecting STMicroelectronics>>STBlueNRG-2 Series>>BlueNRG-2 to open a window like in Figure 4.1.5. In the right column will be shown in green 'up to date'. Now it is possible to close the window.

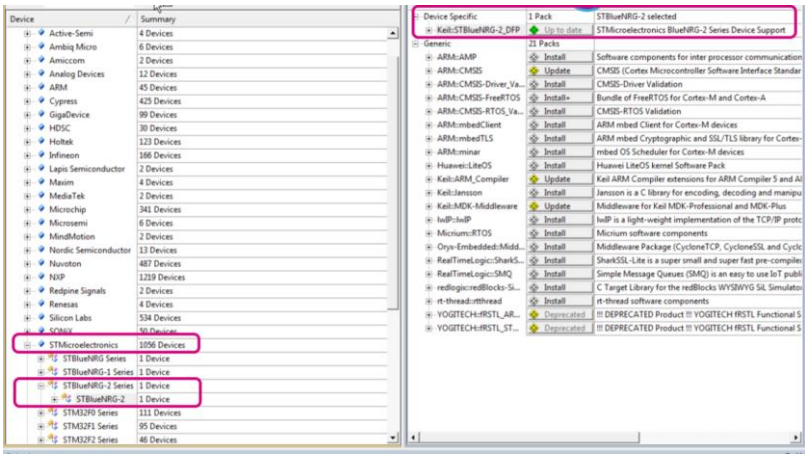

Figure 4.1.5 – Verifying the installation of device package.

The activation of the IDE is needed before starting to work so the user must go to the activation website [7] and locate the product serial number. After this, µVision must be executed as administrator and when the IDE opens the user has to go to: File>>License Management and a new window like the one shown in Figure 4.1.6 will open. In the Single-User License section the user must select 'Get LIC via Internet'.

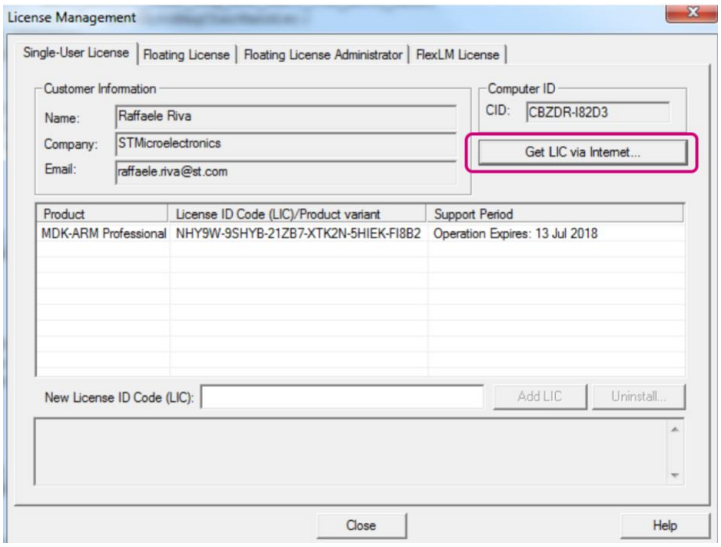

Figure 4.1.6 – License management on µVision.

When a new window appears, click on Ok button. This will open the license management page on Keil's website. Here, the product serial number previously identified has to be set and the information required, including an e-mail address, has to be fulfilled. To the given e-mail address license activation code will be send. When received, the user has to introduce this code in the box called 'New License ID Code (LIC)' located at the bottom of the license management window Finally, click the 'Add LIC' button. Now it is possible to close the window, and it concludes the configuration of µVision IDE. The other required software is the RF Flasher Utility that can be downloaded from the ST dedicated website [8] and install following its installation assistant. It does not need any special configuration. By last, Tera Term virtual serial port must be downloaded directly from its website [9] for free because it is an open-source project. To install the downloaded file the user must follow its installing assistant. Once done, the software must be configured. Figure 4.1.7 shows the Tera Term window where serial option should be chosen as well as the corresponding virtual COM appearing when the STEVAL-BCN002V1is connected to the computer though a USB cable.

Figure 4.1.7 – Selecting serial communication in Tera Term.

In the black window appearing go to: Setup>>Serial Port and set the parameters of window presented in Figure 4.1.8. Close the window.

Figure 4.1.8 – Serial port configuration.

Next, go to Setup>>Terminal and set the configuration as shown in Figure 4.1.9, then close the window.

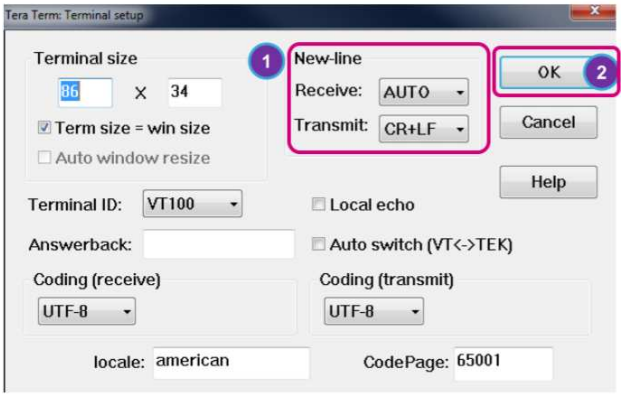

Figure 4.1.9 – Terminal configuration.

Finally, go to Setup tab and save the setup with the predefined name.

4.2 BLE_SensorDemo project

There is a pre-loaded application on the STEVAL-BCN002V1 capable of obtaining the different sensor data called BLE Sensor Demo, its code can be found inside the software development kit (SDK), a .zip file downloaded from the ST website [4], following the path: Project>>BLE_Examples>>BLE_SensorDemo and it is presented in three different projects to execute depending on the integrated development environment (IDE) software chosen by the user: Atollic's TrueStudio, Keil's µVision or IAR's EWARM The project will be worked on Keil's µVision IDE. To open it on the IDE is necessary to go on Project>>Open Project and select its location.

4.2.1 BLE SensorDemo general overview

The BLE SensorDemo project is organized in many folders containing .c files with different specific parts of the entire code organized as presented in Figure 4.2.1.1 and a briefly description of each folder purpose is described in Table 4.2.1.1.

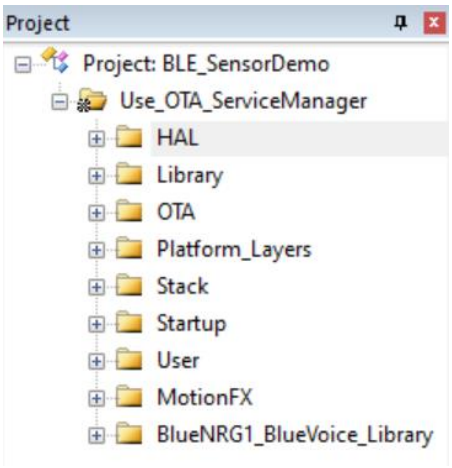

Figure 4.2.1.1 – BLE SensorDemo project content.

Table 4.2.1.1 – BLE SensorDemo folders.

Layer name	Folder purpose description
Hardware abstraction layer (HAL)	Configures some physical parameters
Library	Contains the library files that the BlueNRG-2 processor needs to work
Over-the-air services (OTA)	Code that controls the wireless communication of the device
Platform_Layers	Contains the sensors libraries
Stack	Defines the BLE protocol
Startup	Has the BlueNRG-2 main application
User	Has the files about the specific SensorDemo application
MotionFX	Contains the files to set up the Motion FX sensor
BlueNRG1_Bluevoice_Library	Contains the files to set up the microphone

Most of all the files in the project cannot be modify because they are libraries, define protocols or are main codes of certain elements of the board but there is a particular section in which the user can work by modifying code lines and transform the SensorDemo general application to its own specific one, this includes the enable or disable of sensors or configuration of certain parameters of the board. To start to work on the source code it is previously necessary the installation and configuration of the IDE software.

4.2.2 Project modifications

`Sensor.c` is a file where the multi-sensor board connection properties are set, and the many sensors are configured for a specific application. All those actions are organized along the code in functions that can be related to some others located in different files of the project such as libraries. Figure 4.2.2.1 shows the first lines of the file which are dedicated to defining the device name, originally set as 'BCN-002'. This is the name that the device takes when is in advertising mode, or how the other devices identify it.

```
50  /* Define default BlueNRG-2 name; must be 7 char long */
51
52  #define DEFAULT_NAME_ALLMEMS    'B','C','N','-','0','0','2'
53
54  #define DEVICE_NAME_PAGE      (125)         // Board name position
55  #define DEVICE_NAME_ADDR      (uint32_t)0x1007E800  // Board name address
56
```

Figure 4.2.2.1 – Multi-sensor board's name.

Figure 4.2.2.2 shows a specific section of the code is dedicated to set initializing functions for each one of the sensors, here some parameter values are set using specific functions from the sensor's libraries. Due to a particular interest in the accelerometer sensor, its initializing function called `Init_Accelerometer_Gyroscope()`.

```
150 /*******************************************************************************
151  * Function Name  : Init_Accelerometer_Gyroscope.
152  * Description    : Init LSM6DSO accelerometer/gyroscope.
153  * Input          : None.
154  * Output         : None.
155  * Return         : None.
156  *******************************************************************************/
157 void Init_Accelerometer_Gyroscope(void) {
158
159   uint8_t rst;
160
161   lsm6dso_i3c_disable_set(0, LSM6DSO_I3C_DISABLE);
162
163   rst = lsm6dso_reset_set(0, PROPERTY_ENABLE);
164   do {
165     lsm6dso_reset_get(0, &rst);
166   } while (rst);
167
168   lsm6dso_pin_mode_set(0, LSM6DSO_PUSH_PULL);
169   lsm6dso_pin_polarity_set(0, LSM6DSO_ACTIVE_LOW);
170   lsm6dso_all_on_int1_set(0, PROPERTY_ENABLE);
171   lsm6dso_int_notification_set(0, LSM6DSO_ALL_INT_LATCHED);
172
173   lsm6dso_block_data_update_set(0, PROPERTY_ENABLE);
174   lsm6dso_xl_power_mode_set(0, LSM6DSO_LOW_NORMAL_POWER_MD);
175   lsm6dso_gy_power_mode_set(0, LSM6DSO_GY_NORMAL);
176   lsm6dso_xl_data_rate_set(0, LSM6DSO_XL_ODR_52Hz);
177   lsm6dso_gy_data_rate_set(0, LSM6DSO_GY_ODR_52Hz);
178   lsm6dso_xl_full_scale_set(0, LSM6DSO_2g);
179   lsm6dso_gy_full_scale_set(0, LSM6DSO_2000dps);
180
181   lsm6dso_auto_increment_set(0, PROPERTY_ENABLE);
182
183   InitHWFeatures();
184
185 }
```

Figure 4.2.2.2 – Init_Accelerometer_Gyroscope() function code.

Inside this function, parameters for the LSM6DSU IMU correct working are set. There is special interest in lines 176 and 177 because here is where the rate acquisition frequency for the accelerometer and gyroscope is defined, originally set at 52 Hz.

```
lsm6dso_xl_data_rate_set(0, LSM6DSO_XL_ODR_52Hz);
lsm6dso_gy_data_rate_set(0, LSM6DSO_GY_ODR_52Hz);
```

Another interest function in this file is the one shown in Figure 4.2.2.3 which sets the sensor in active or low-power mode called `SensorsScan()` located on the line 943. Here, the variable `who_am_I_8` is compared to the identifier of each one of the sensors to select them one by one, then the selected sensor is set as enabled or disabled through a Boolean value, true or false, associated to an object created in the function `XFeaturePresence()` defined in the file `Sensor.h`.

```
937 /*******************************************************************************
938  * Function Name  : SensorsScan
939  * Description    : Configure the sensors in active or low-power mode.
940  * Input          : None
941  * Return         : None
942  *******************************************************************************/
943 void SensorsScan(void) {
944   uint8_t who_am_I_8 = 0x00;
945   uint16_t ModelID;
946
947   PRINTF("Scan for sensors:\n\r");
948
949   lsm6dso_device_id_get(0, &who_am_I_8);
950   if (who_am_I_8 == LSM6DSO_ID) {
951     PRINTF("- Accelerometer and Gyroscope: OK\n\r");
952     xFeaturePresence.AccelerometerGyroscopePresence = true;
953     xFeaturePresence.Pedometer = true;
954
955   } else {
956     PRINTF("- Accelerometer and Gyroscope: FAIL\n\r");
957     xFeaturePresence.AccelerometerGyroscopePresence = false;
958     xFeaturePresence.Pedometer = false;
959   }
960
961   lps22hh_device_id_get(0, &who_am_I_8);
962   if (who_am_I_8 == LPS22HH_ID) {
963     PRINTF("- Pressure and Temperature: OK\n\r");
964     xFeaturePresence.PressurePresence = true;
965
966   } else {
```

Figure 4.2.2.3 – SensorsScan() function code.

Another interesting function is the one named `Sensor_DeviceInit()` that coordinates some initialization procedures such as connection or sensors detection. This is called in the `SensorDemo_main.c` file, stablishing its importance in the main application structure. To start with the modifications the user must be aware that in the select target box located on the top part of the window, the option 'Use_OTA_ServiceManager' must be selected to correctly link the OTA services to the main code. Figure 4.2.2.4 clearly shows the µVision's box where the user must set this configuration.

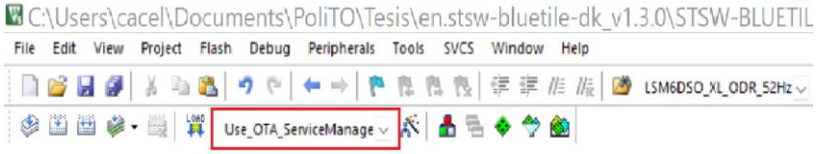

Figure 4.2.2.4 – Select target box.

The first modification applied to the code, as a test, is changing the device name in line 52 always respecting a length of seven characters. The new name proposed is defined as 'POLITO1', the modification is presented below.

```
#define DEFAULT_NAME_ALLMEMS       'P','O','L','I','T','O','1'
```

The second change made is done in the `SensorsScan()` function to disable all the sensors but the LSM6DSO IMU. The changes are done to the Boolean values originally set as ‘true’ in all the non-desired sensors changing them to ‘false’. The modified `SensorsScan()` function stays as follows.

```
void SensorsScan(void) {
     uint8_t who_am_I_8 = 0x00;
     uint16_t ModelID;

     PRINTF("Scan for sensors:\n\r");

     lsm6dso_device_id_get(0, &who_am_I_8);
     if (who_am_I_8 == LSM6DSO_ID) {
          PRINTF("- Accelerometer and Gyroscope: OK\n\r");
          xFeaturePresence.AccelerometerGyroscopePresence = true;
          xFeaturePresence.Pedometer = true;
          xFeaturePresence.Pedometer = false;//Pedometer Sensor OFF

     } else {
          PRINTF("- Accelerometer and Gyroscope: FAIL\n\r");
          xFeaturePresence.AccelerometerGyroscopePresence = false;
          xFeaturePresence.Pedometer = false;
     }

     lps22hh_device_id_get(0, &who_am_I_8);
     if (who_am_I_8 == LPS22HH_ID) {
          //PRINTF("- Pressure and Temperature: OK\n\r");
          //xFeaturePresence.PressurePresence = true;

          PRINTF("-    Pressure    and    Temperature    OFF\n\r");
     //Pressure and Temperature Sensors OFF
                    xFeaturePresence.PressurePresence = false;
     } else {
          PRINTF("- Pressure and Temperature: FAIL\n\r");
          xFeaturePresence.PressurePresence = false;
     }

     HTS221_Get_DeviceID(0, &who_am_I_8);
     if (who_am_I_8 == 0xBC) {
          //PRINTF("- Humidity and Temperature: OK\n\r");
          //xFeaturePresence.HumidityTemperaturePresence = true;

          PRINTF("-    Humidity    and    Temperature:    OFF\n\r");
     //Humidity and Temperature Sensors OFF
               xFeaturePresence.HumidityTemperaturePresence       =
false;
     } else {
          PRINTF("- Humidity and Temperature: FAIL\n\r");
          xFeaturePresence.HumidityTemperaturePresence = false;
     }
```

```
    lis2mdl_device_id_get(0, &who_am_I_8);
    if (who_am_I_8 == LIS2MDL_ID) {
        //xFeaturePresence.MagnetometerPresence = true;
        //PRINTF("- Magnetometer: OK\n\r- Proximity Sensor: ");

        xFeaturePresence.MagnetometerPresence      =      false;
    //Magnetometer Sensor OFF
        PRINTF("- Magnetometer: OFF\n\r- Proximity Sensor: ");
    } else {
        PRINTF("- Magnetometer: FAIL\n\r- Proximity Sensor: ");
        xFeaturePresence.MagnetometerPresence = false;
    }
    GPIO_WriteBit(GPIO_Pin_7, Bit_RESET);
    VL53L1_WaitMs(VL53L1_I2C_SLAVE_ADDR, 10);
    GPIO_WriteBit(GPIO_Pin_7, Bit_SET);

    for (uint8_t var = 0; var < 100; ++var) {
        VL53L1_WaitMs(VL53L1_I2C_SLAVE_ADDR, 10);

        VL53L1X_GetSensorId(VL53L1_I2C_SLAVE_ADDR, &ModelID);
        if (ModelID == 0xEACC)
            break;
    }

    GPIO_WriteBit(GPIO_Pin_7, Bit_RESET);
    if (ModelID == 0xEACC) {
        //PRINTF("OK\n\r");
        //xFeaturePresence.ProximityLightPresence = true;

        PRINTF(" OFF\n\r");      //Proximity Sensor OFF
        xFeaturePresence.ProximityLightPresence = false;
    } else {
        PRINTF("FAIL\n\r");
        xFeaturePresence.ProximityLightPresence = false;
    }

}
```

`Sensor.h` corresponds to a library file where many parameter values are set such as the milliseconds used by a timer function called which triggers the data acquisition process from the sensors. Figure 4.2.2.5 presents the part of the code where the numerical values of the timers are defined being SENSOR_TIMER, ADVERTISING TIMER and RESET_TIMER setting identifier values for each different timer and BATTERY_UPDATE_RATE, ENV_SENSOR_UPDATE_RATE and MOTION_SENSOR_UPDATE_RATE the numerical values in milliseconds of the timers to execute the data acquisition from the sensors; this values must match the output data rates of each sensor set in initializing functions; for accelerometer sensor `Init_Accelerometer_Gyroscope()` function is where the output data rate is defined.

```
/* W2ST command for resetting the calibration */
#define W2ST_COMMAND_CAL_RESET  0x00
/* W2ST command for stopping the calibration process */
#define W2ST_COMMAND_CAL_STOP   0x01

#define W2ST_CHECK_CONNECTION(BleChar) ((ConnectionBleStatus&(BleChar)) ? 1 : 0)
#define W2ST_ON_CONNECTION(BleChar)    (ConnectionBleStatus|=(BleChar))
#define W2ST_OFF_CONNECTION(BleChar)   (ConnectionBleStatus&=(~BleChar))

#define SENSOR_TIMER     0   // Fixed ODR @ 25 Hz
#define ADVERTISING_TIMER   1   // Fixed @ 20 seconds
#define RESET_TIMER      2   // Fixed 5 seconds

#define ADVERTISING_TIME  20000 // Time to advertise before enter standby [ms]
#define RESET_TIME       5000  // Time to wait before reset [ms]

#define BATTERY_UPDATE_RATE     1000    // Fixed ODR @  1 Hz
#define ENV_SENSOR_UPDATE_RATE    100     // Fixed ODR @  10 Hz
#define MOTION_SENSOR_UPDATE_RATE   2   // Fixed ODR @ 25 Hz

void User_Process(void);
void Set_DeviceConnectable(void);

void Init_SensorFusion(bool onOff);
void Init_BlueNRG_Custom_Services(void);
void Init_Accelerometer_Gyroscope(void);
void Init_Pressure_Temperature_Sensor(void);
void Init_Humidity_Sensor(void);
void Init_Magnetometer(void);
void SensorsScan(void);
void SensorsLowPower(void);
uint32_t ConfigCommandParsing(uint8_t * att_data, uint8_t data_length);
uint32_t DebugConsoleCommandParsing(uint8_t * att_data, uint8_t data_length);
void MEMSCallback(void);

#if ENABLE_BLUEVOICE
BV_APP_Status BVL_APP_PER_Init_BLE(void);
BV_APP_Status BV_APP_PER_ProfileInit(void);
void TC_IT_Callback(void);
```

Figure 4.2.2.5 – Sensor.h modifications.

4.3 Flashing STEVAL-BCN002V1B multi-sensor board

Once all the modifications on the BLE_SensorDemo project are done it is possible to load this application to the sensor board. To do this, in the µVision IDE the build button located on the left top corner of the window must be clicked. This process leads to obtain a .bin file created in a new folder in the Keil's project folder named 'Use_OTA_ServiceManager' shown in Figure 4.3.1 where two more folders are created: listings and objects, in the las one is where the .bin file created is located.

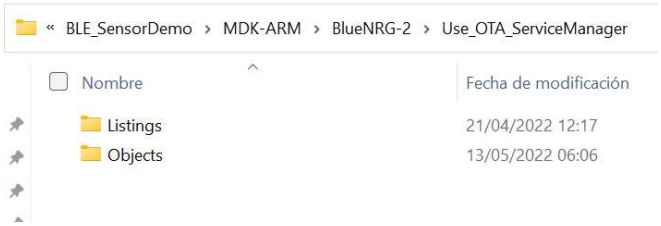

Figure 4.3.1 – Generated flashing file location.

Figure 4.3.2 shows the RF flasher utility window when the device is set to be flashed. Once the sensor board is connected to the computer using the flashing board, it will be identified with a COM port number which must be selected.

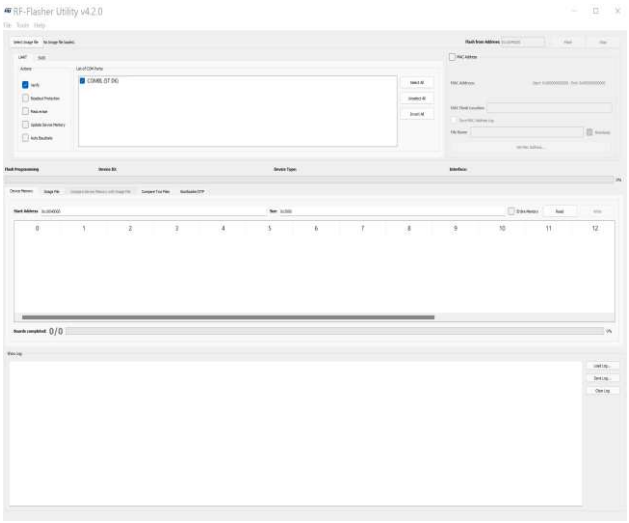

Figure 4.3.2 – RF flasher utility window.

To load the .bin file the user must click the 'Select Image file' button and locate the file named `BLE_SensorDemo_Use_OTA_ServiceManager.bin` and select it, then type the address 0x10051800 on the top right corner of the utility window. Finally press the button 'Flash' to initiate the flashing process. It is crucial to know that the memory of the multi-sensor board is divided in two parts for its use with the reference codes. The top part going from address 0x10040000 to 0x0x10051799 is reserved to contain the OTA service manager code and the second part starting from 0x10051800 to 0x1007F000 is reserved for the application without OTA service, this type of application is created since in the µVision IDE during the selection of the target as explained at beginning of this section. Figure 4.3.3 shows a representation of the memory distribution on the board and where the programs are located.

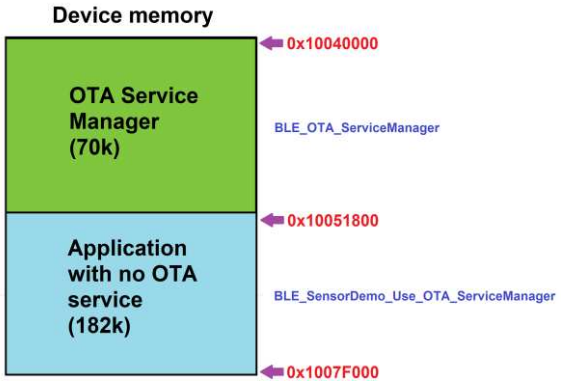

Figure 4.3.3 – Memory distribution of the BLE Sensor demo code.

During the flashing procedure, the LED indicator on the sensor board will light green and if the flashing was successfully completed the LED will turn to light blue as showing in Figure 4.3.4.

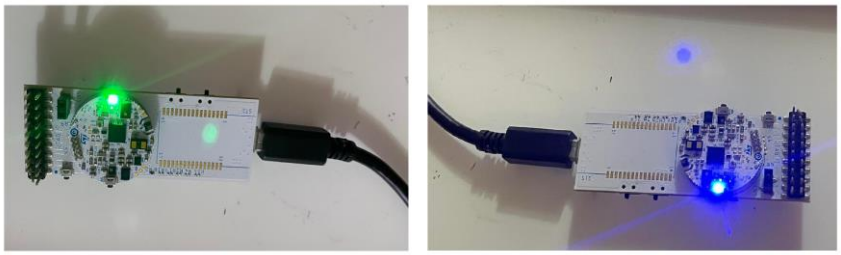

Figure 4.3.4 – LED indicator during flashing procedure.

To verify if all the modifications we use the ST BLE Sensor mobile application previously installed on a mobile phone from the corresponding applications for iOS [X] or Android[X]. When the sensor board is paired without any modification is possible to observe that the mobile app identifies the device with the name 'BCN-002' as was defined from fabrics. After the flashing with the new code the name changes to 'POLITO1'. A screenshot of the mobile application of both tests is presented in Figure 4.3.5.

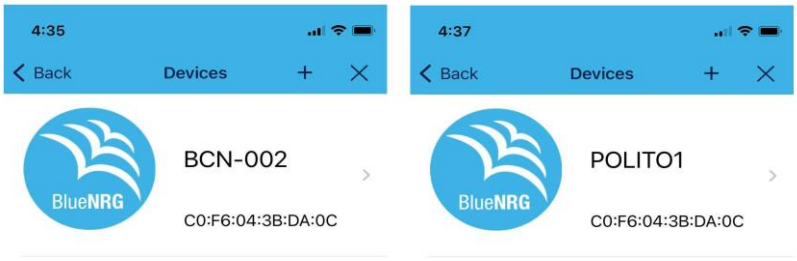

Figure 4.3.5 – Device name detected before and after modifications.

To verify the status of the sensors, enabled or disabled, the use of Tera Term virtual serial port is required. Once the board is connected to the computer, on the Tera Term main window is possible to observe the information arriving from the device about the status of every sensor. The values obtained before any modification on the code are shown in the Figure 4.3.6, where all sensors are set as active according to the 'OK' string appearing next to each one.

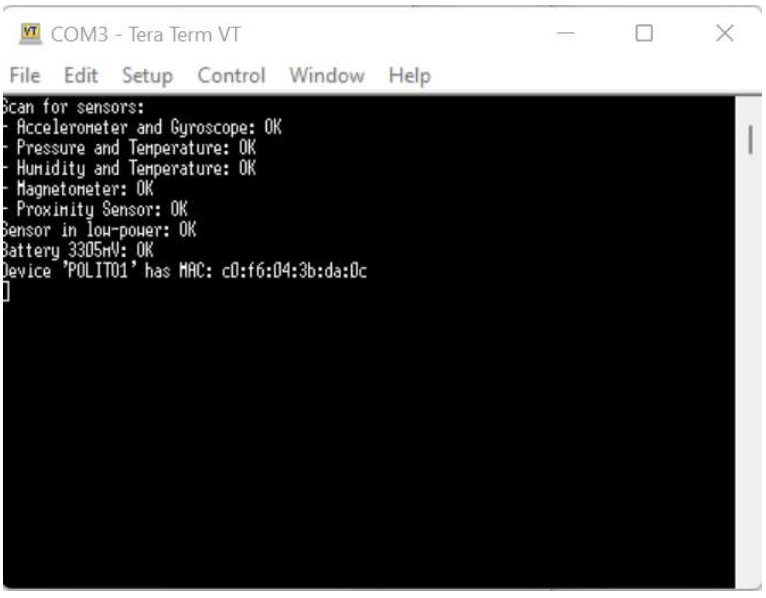

Figure 4.3.6 – Status of the sensors before code modifications.

When the modified code is flashed on the device the same test is repeated obtaining the new status of the sensors on the screen indicating ‘OFF’ next to the sensors that were set as disabled in the new code. Figure 4.3.7 shows how all sensors except from the accelerometer and gyroscope IMU were disable.

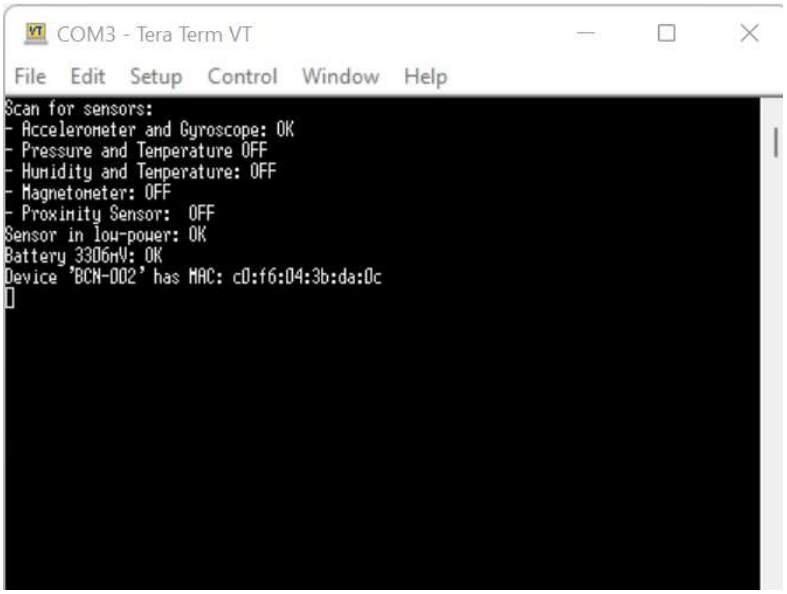

Figure 4.3.7 – Status of each sensor after code modifications.

Another way to verify that these sensors are truly disabled is using the ST BLE Sensor mobile app for mobile phones. The app provides the lectures of all the sensors, and it is quite easy to observe if it is receiving any data from them. Figure 4.3.8 shows how the values from the temperature, humidity, and pressure sensors before and after changing the code, where the quantity obtained moved from a certain measured value to cero.

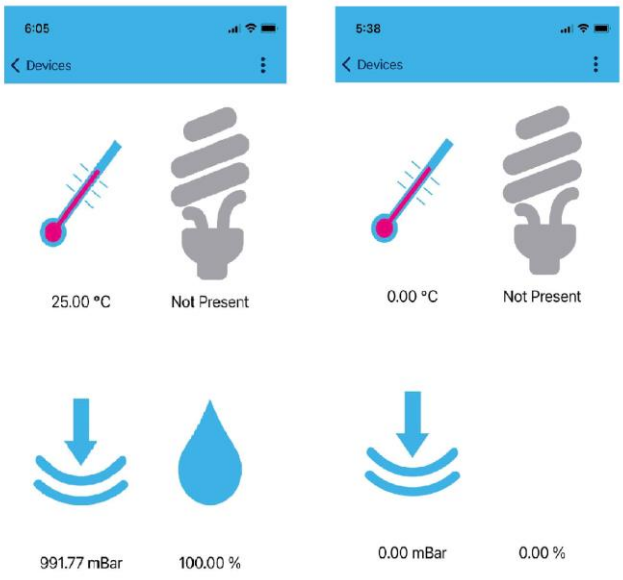

Figure 4.3.8 – Sensors measures on mobile app before and after modifications.

5. Accelerometer data acquisition

5.1 Wireless connection using a mobile phone

To acquire the data from the sensor board, the ST BLE Sensor app for mobile phones is used. The first step is to open the mobile app on a mobile phone (iOS or Android) and an interface will give the user the option to connect to a device, as shown in Figure 5.1.1. Tapping on “Search” will show the devices to connect to as in Figure 5.1.2 and tapping on the corresponding sensor board will take the user to the main application window. Once the user is in the main app window, they must select at the bottom of the app an option called ‘Plot Data’ that opens a graphical environment that shows the selected sensor data in form of a plot. Tapping on “Select Feature” on the top of the screen the user should select the accelerometer.

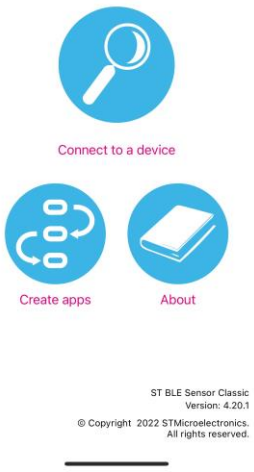

Figure 5.1.1 – ST mobile app initial window.

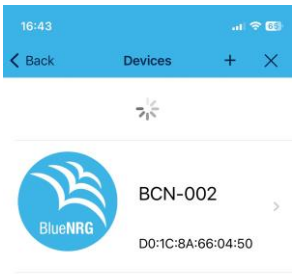

Figure 5.1.2 –List of devices abled to pair.

Immediately after, on the mobile’s screen, three lines of different colours appear corresponding to the acceleration each one of the axes X, Y, Z of the LSM6DSO, as presented in Figure 5.1.3.

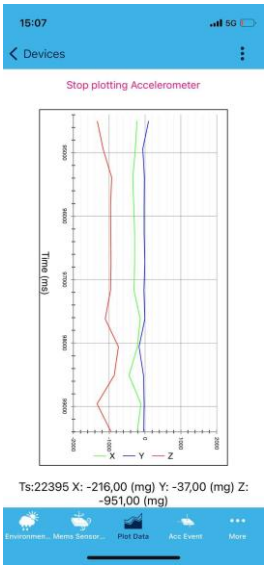

Figure 5.1.3 – Accelerometer data on ST BLE sensor app.

To start saving the data the user must go to the top right corner of the screen and locate a menu indicated with three vertical points, tap and select the option 'Start Logging' to start the recording of data. To end the data acquisition, in the same menu, the user must select 'Stop Logging' and after this a new window will appear showing the possibility of sending three different .csv files corresponding to the accelerometer, gyroscope and magnetometer data acquired during the performed test as can be seen in Figure 5.1.4.

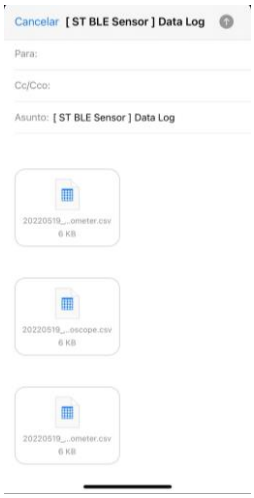

Figure 5.1.4 – Sending data to a mail address.

Once the file corresponding to the accelerometer measurements is obtained from the mailbox there is possible to be opened using MATLAB to see its content. First, the file must be moved to the MATLAB folder, then data can be imported using command `importdata()` and it is possible to observe that the file contains a structure array with two elements named "data" and "textdata". The element "data" corresponds just to the acceleration on each axis x, y, z organized in three corresponding columns with the values on mg (thousandths of the gravitational acceleration) while the "textdata" element corresponds to a bigger description of the test including interesting information as the time each sample was acquired.

5.2 Wireless connection using a PC

Another option to get the accelerometer data to a computer is obtaining the data directly from the sensor using the Bluetooth connection. Until this point a computer with Windows operative system has been used to work with the software mentioned in previous sections but now a Linux operative system is going to be used. The approach to install it is using a virtual machine to work on both operative systems in the same computer if needed. The virtual machine software use for this task is VirtualBox that can be downloaded free from its website [12] seen in Figure 5.2.1. Once the installer is downloaded it should be open and follow the instructions normally.

Figure 5.2.1 – VirtualBox .exe download website.

The Linux operative system chosen to use is Ubuntu 22.04 Jellyfish. An optical disc image (.iso) file of the operative system can be downloaded directly from their website [13] shown in Figure 5.2.2. The intention to have a Linux operating system is the possibility to use Python to get the accelerometer data because normally there are less restrictions than using it on Windows and exist more documentation.

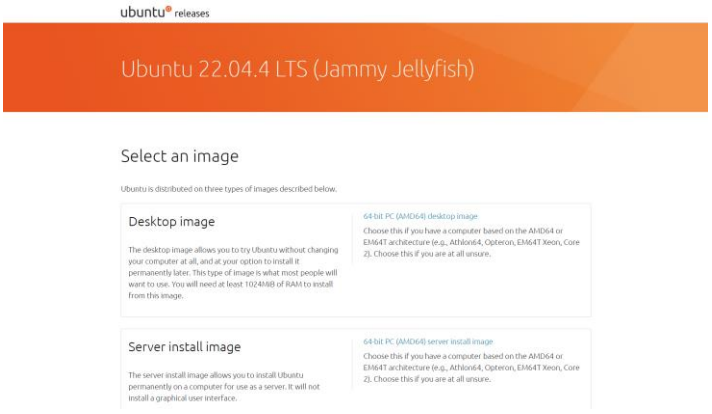

Figure 5.2.2 – Ubuntu 22.04 .iso download website.

To install Ubuntu the user must open VirtualBox and go on the top bar to Machine >> New and a new window will open as seen in Figure 5.2.3 where it is possible to stablish the name of the virtual machine and the .iso file previously downloaded is needed to be selected. It is important to select the option “Skip Unattended Installation” because sometimes when it is omitted the Terminal cannot be opened.

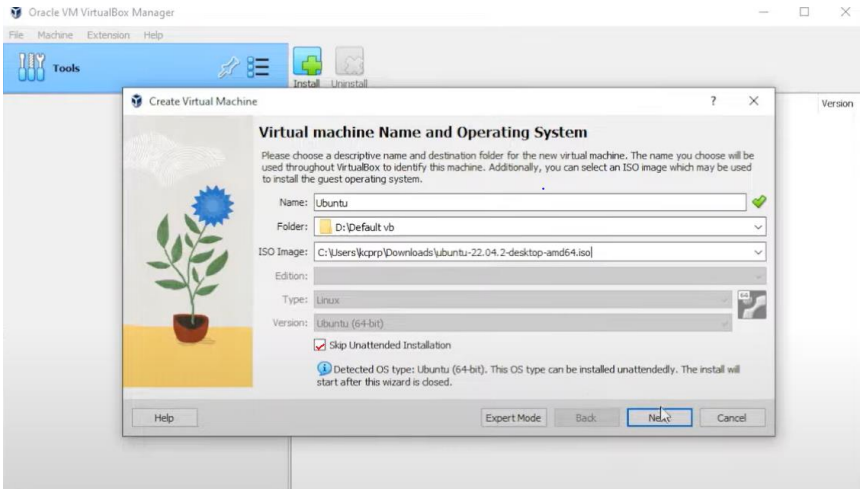

Figure 5.2.3 – New virtual machine installation.

To install Ubuntu the user must open VirtualBox and go on the top bar to Machine >> New and a new window will open as seen in Figure 5.2.3 where it is possible to stablish the name of the virtual machine and the .iso file previously downloaded is needed to be selected. It is important to select the option “Skip Unattended Installation” because sometimes when it is omitted the Terminal cannot be opened. After clicking “Next” new windows are showed asking the user to stablish the amount of RAM and virtual hard disc space is going to be reserved for the virtual machine according to the user’s necessities. When this operation is concluded the installation of Ubuntu will start and the user can normally follow the instructions from the installer and by the end a window with the operating system will show as in Figure 5.2.4.

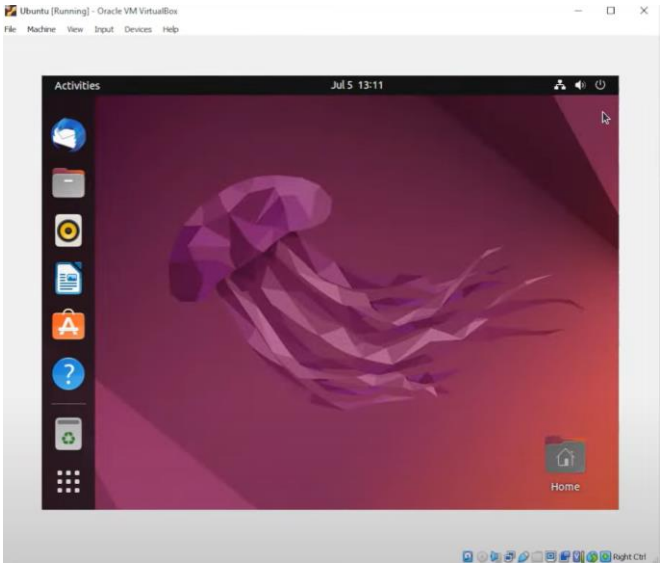

Figure 5.2.4 – Ubuntu 22.04 on VirtualBox.

Searching for solutions for obtaining the sensors data from the sensors board, a previously developed work has been found on a repository in GitHub website [14], as can be seen in Figure 5.2.5, and used as a reference for creating a python program able to collect the accelerometer data. The program in the repository can connect the computer to the board using a Bluetooth protocol and can obtain many sensors measurement during a certain amount of time defined by the user and collect it in a .csv file.

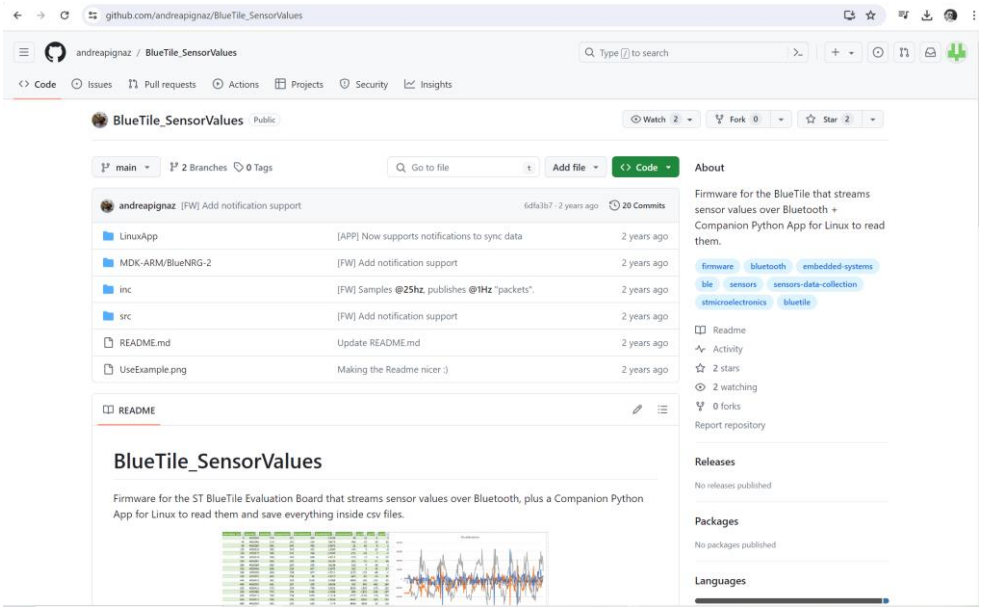

Figure 5.2.5 – Data acquisition program GitHub website.

Now phyton needs to be set up to start developing the new app so some libraries and additional software need be installed. The first step is to open a terminal and verify that Python is installed typing python3 –version, this will return a message with the version installed in the operating system. Next step is typing `sudo apt update` to start downloading and refreshing the local package index. To install the last version of the packages now it is needed to enter `sudo atp upgrade` in the terminal window as Figure 5.2.6 presents.

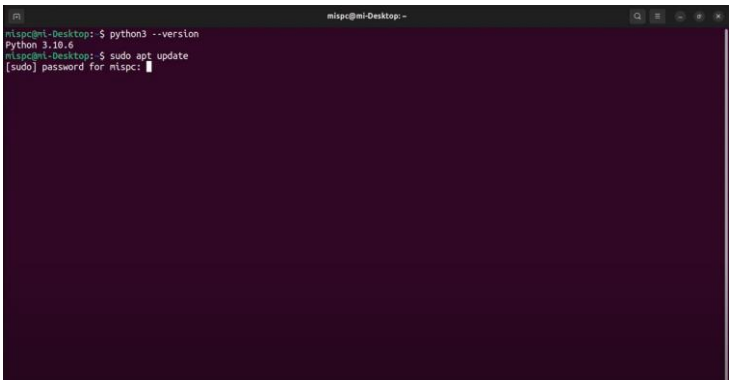

Figure 5.2.6 – Updating local package index using the terminal.

After this, some python libraries are needed to be installed. The first one is NumPy that works with arrays and can be installed typing `sudo pip3 install numpy` in the terminal. The second is BLE_GATT library that works with Bluetooth connectivity and can be installed typing `sudo pip3 install BLE_GATT`.

To stablish a Bluetooth connection to a device using VirtualBox the use of a USB dongle Bluetooth adapter like the one seen in Figure 5.2.7 or using the one integrated in the laptop. If the dongle is used, it must be selected for using with the VirtualBox going to the top bar of the window and selecting Devices >> USB and choosing the device's name. This will enable Ubuntu to use Bluetooth functions.

Figure 5.2.7 – USB dongle Bluetooth 5.1.

To verify the possible devices to connect an additional app should be installed. Blueman Bluetooth manager is the app that can allow the user to see the devices near the PC to connect with. To install it a terminal is needed to be opened then the user must type `sudo apt-get install -y blueman` and this will do it.

The original code from the GitHub repository [14] stablish sets the sensors board to stream the data from the sensors by using three services and enables the board to connect to other devices apart from a mobile phone. The µVision project included there is build and the generated .bin file is loaded to the board using the RF Flasher Utility considering again the 0x10051800 location as the initial flashing address. To verify that the flashing has been well done a blue led on the board should be seen always on.

The original python app `ReadValuesApp.py` in the repository stablishes the connection to the board using its MAC address and saves the data sent by the board reading the three services and the characteristics as a chain where the value of the data can be obtained. These data are collected in an array for a time between 1 and 254 seconds defined by the user with sampling frequency of 25Hz. After the data is collected it is written in a .csv file that when the test is finished can be found in the same folder the application is saved.

To test this app the first thing is to verify that the device is detectable by opening the Bluetooth manager and clicking on search. The board should be seen in the list of near devices as seen in Figure 5.2.8.

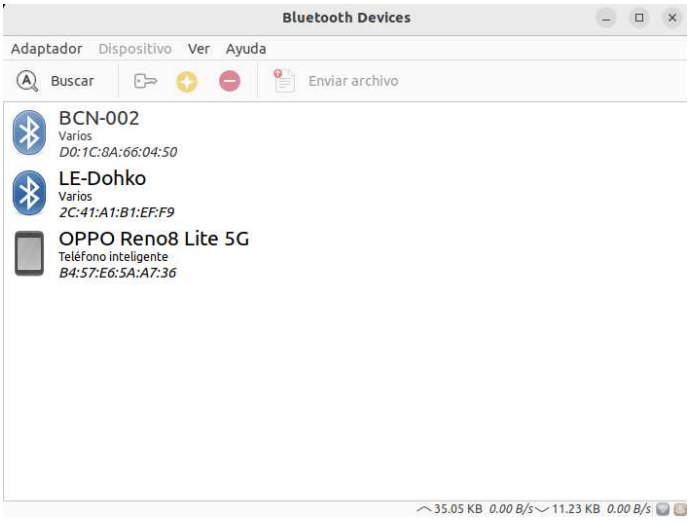

Figure 5.2.8 – Blueman Bluetooth manager.

Now, the user must go to the folder the file is saved and right click in the window to open a terminal set to that directory and type `python3 ReadValuesApp.py` to start the app. The terminal will show a message, seen in Figure 5.2.9, asking the user to define the time of the test and after five seconds the app will start to get the information form the board. When the time ins finished the .csv file will be created, and the data can be processed.

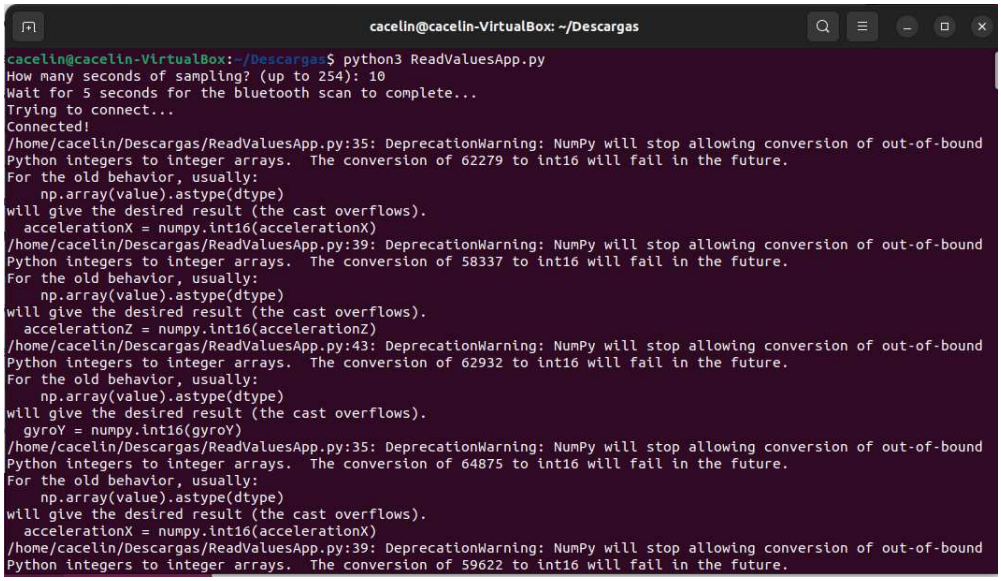

Figure 5.2.9 –ReadValuesApp.py program execution.

The .csv file contains the measures of the acceleration axes in mg organized in three columns, the same format as the file produced by the mobile app sends to the email, the first column corresponds to acceleration in X axis, the second column to acceleration in Y axis and finally the third column to the acceleration in Z-axis.

5.3 Accelerometer data analysis using MATLAB

To process the data obtained with the mobile phone of the acceleration values a MATLAB program named `Acceleration_data_analysis.mat` was developed. This program starts asking the user to write the .csv file's name on a box to load the data as shown in Figure 5.3.1; this file must be previously saved in the MATLAB folder.

Figure 5.3.1 – Box to write the .csv file's name.

Two windows pops-up showing the acceleration data obtained, the first one with independent graphs of the acceleration values measured in each axis as shown in Figure 5.3.2 and the second showing a plot of the combination of all of three axes as it could be seen in the mobile phone as can be seen in Figure 5.3.3.

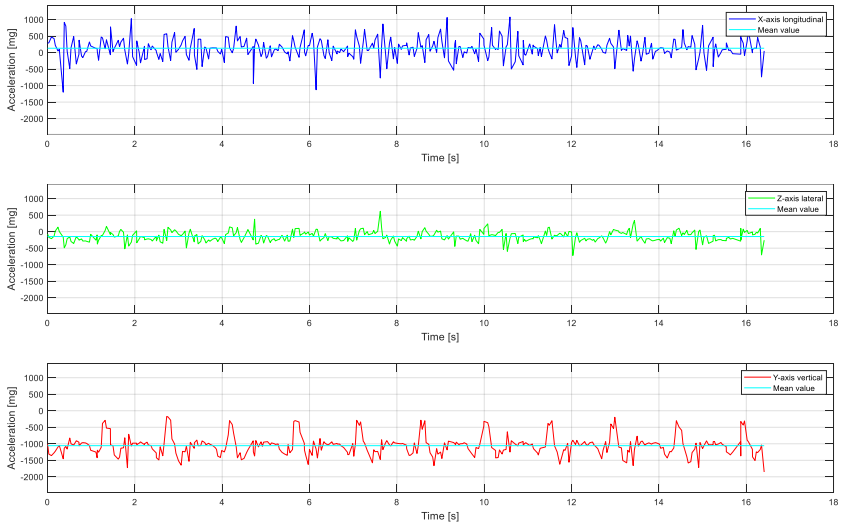

Figure 5.3.2 – Accelerometer data by axis.

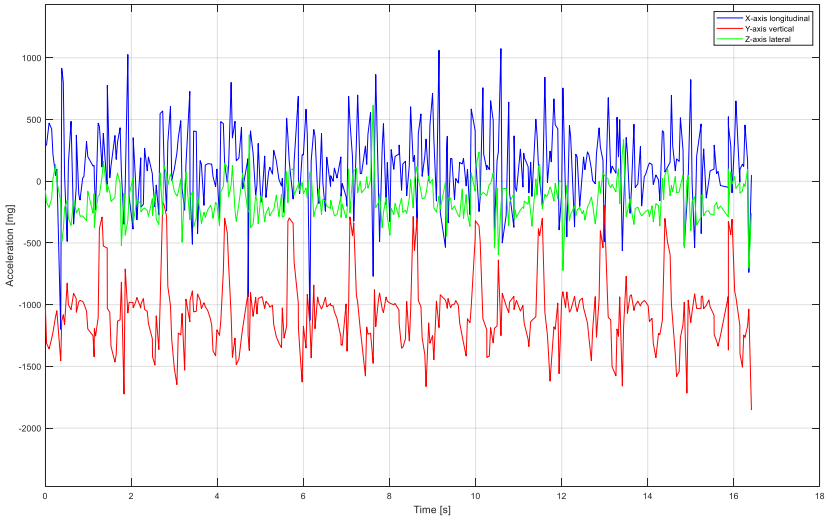

Figure 5.3.3 – Simultaneous axes accelerations plot.

The flowchart corresponding to the `Acceleration_data_analysis.mat` code is shown in Figure 5.3.4.

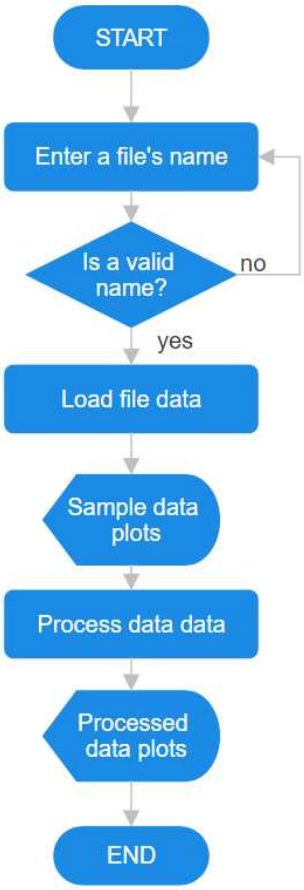

Figure 5.3.4 – Acceleration data analysis code flowchart.

6. Electrical power measurement

6.1 Electric circuit design

To do the physical connection between the CR2032 and the electronic circuit a 3D printed device was developed, shown in Figure 6.1.1. This device has on each side an independent wire that carries the energy from the battery to the STEVAL-BCN002V1 sensor board when while allows it to be easier connected to other electronic devices.

Figure 6.1.1 – 3D printed battery adapter device.

An electronic circuit has been proposed to build using a current sensor and an Arduino UNO to process and collect measuring data of voltage and current demanded by STEVAL-BCN002V1 when used. Figure 6.1.2 shows an INA219 current sensor module selected to perform the measurements. The INA219 integrated circuit has a precision amplifier that measures the voltage across a 0,1 Ω shunt resistor and a 12-bit analogue to digital converter (ADC) to obtain a digital value of this measurement. It is originally configured to measure electrical tension values in a range under 32 V and 1 A, this allows to have a precision of 0.8 mA per bit in the ADC, but it can be modified to work under 16 V and 400 mA which gives a better precision of 0.1 mA per bit. This current sensor needs to be powered with a source between 2.7 V and 5,5 V.

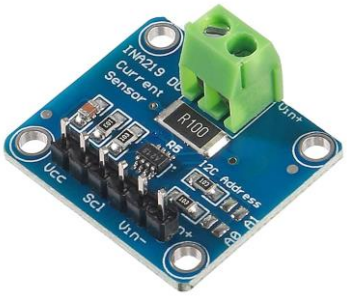

Figure 6.1.2 – INA219 current sensor module.

The INA219 module, STEVAL-BCN002V sensor board and CR2032 battery are connected using a protoboard as Figure 6.1.3 clearly shows allowing the user to collect data using a computer while Figure 6.1.4 shows a picture of the physical circuit built.

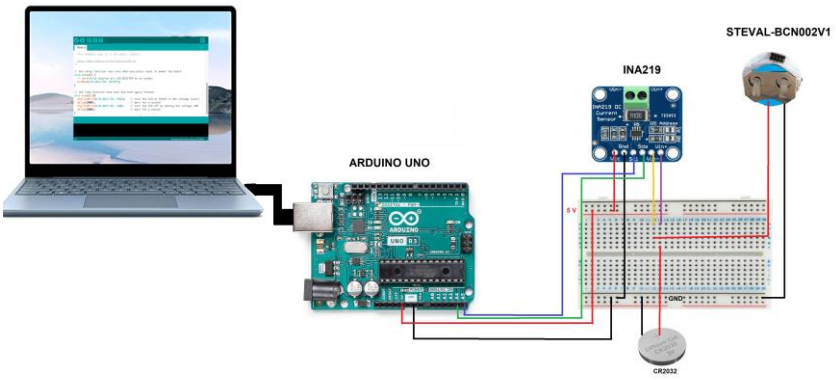

Figure 6.1.3 – INA219 to Arduino UNO connections diagram.

Figure 6.1.4 is a photo of the physical circuit built on a protoboard using cables to make the connections between elements.

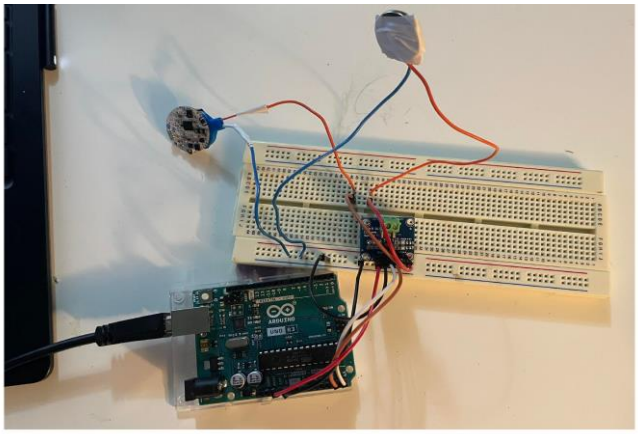

Figure 6.1.4 – Electrical measurement arrangement.

6.2 First voltage and current measurements test

An Arduino code that prints the measured values on a serial monitor of the current, the input voltage, the shunt resistor's voltage and the power has been created using a specific library developed by Adafruit called `Adafruit_INA219.h` possible to install to the Arduino IDE, previously downloaded from Arduino's website [10], using the library manager and searching for Adafruit INA219 library. The developed code presented below, corresponding to the file `INA219_test_1.ino`, is uploaded to the Arduino UNO board and then a serial terminal window is open to verify the measurements.

```
#include <Wire.h>
#include <Adafruit_INA219.h>

Adafruit_INA219 ina219;

void setup(void)
{
  Serial.begin(115200);
  while (!Serial) {
```

```
      // will pause Zero, Leonardo, etc until serial console opens
      delay(1);
  }
  uint32_t currentFrequency;
  Serial.println("Hello!");
  // Initialize the INA219.
  // By default the initialization will use the largest range
(32V, 2A).  However
  // you can call a setCalibration function to change this range
(see comments).
  if (! ina219.begin()) {
    Serial.println("Failed to find INA219 chip");
    while (1) { delay(10); }
  }
  // To use a slightly lower 32V, 1A range (higher precision on
amps):
  //ina219.setCalibration_32V_1A();
  // Or to use a lower 16V, 400mA range (higher precision on volts
and amps):
  //ina219.setCalibration_16V_400mA();
  ina219.setCalibration_16V_400mA();
  Serial.println("Measuring voltage and current with INA219 ...");
  }

void loop(void)
{
  int n=10; //number of samples
  float shuntvoltage_array[n];
  float busvoltage_array[n];
  float current_mA_array[n];
  float loadvoltage_array[n];
  float power_mW_array[n];

  for(int i=0;i<n;i++){
    shuntvoltage_array[i] = ina219.getShuntVoltage_mV();
    busvoltage_array[i] = ina219.getBusVoltage_V();
    current_mA_array[i] = ina219.getCurrent_mA();
    power_mW_array[i] = ina219.getPower_mW();
    loadvoltage_array[i]       =       busvoltage_array[i]       +
(shuntvoltage_array[i] / 1000);
    delay(100);
    }
  for(int i=0;i<n;i++){
    Serial.print("Measure:                    ");Serial.print(i+1);
Serial.println("");
    Serial.print("Bus         Voltage:                          ");
Serial.print(busvoltage_array[i]); Serial.println(" V");
    Serial.print("Shunt               Voltage:                ");
Serial.print(shuntvoltage_array[i]); Serial.println(" mV");
    Serial.print("Load           Voltage:                       ");
Serial.print(loadvoltage_array[i]); Serial.println(" V");
```

```
    Serial.print("Current:                                                    ");
Serial.print(current_mA_array[i]); Serial.println(" mA");
    Serial.print("Power:                                                      ");
Serial.print(power_mW_array[i]); Serial.println(" mW");
    Serial.println("");
    }
  delay(500);
}
```

A test consisting in taking some measurements while the sensor board is connected using the ST BLE Sensor mobile application was performed considering each stage of the communication process: advertisement stage, connection stage and data transmission stage. During the advertising pairing process measurements showed a maximum current of 0.10mA and the battery supplies 3.23V as can be seen in Figure 6.2.1.

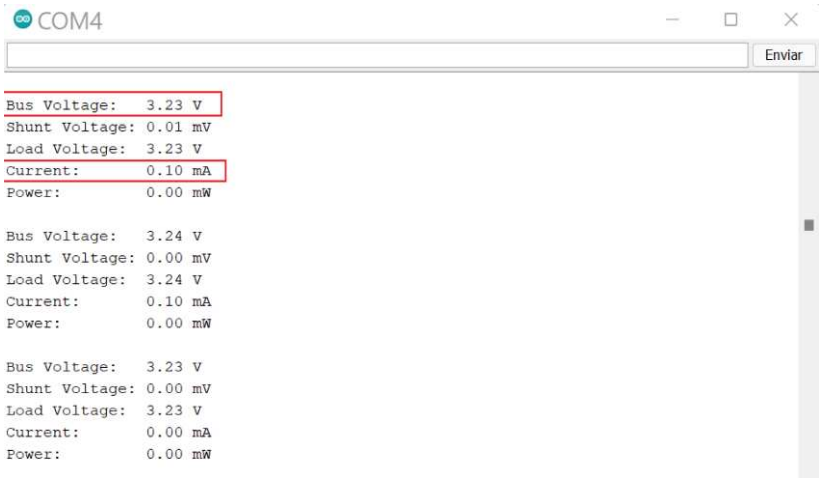

Figure 6.2.1 – Electrical values monitored during pairing process.

When connection between devices was correctly stablished measurements obtained with just the accelerometer sensor enabled showed a mean current value of 0.3 mA and an electrical power value of 2mW as can be seen in Figure 6.2.2.

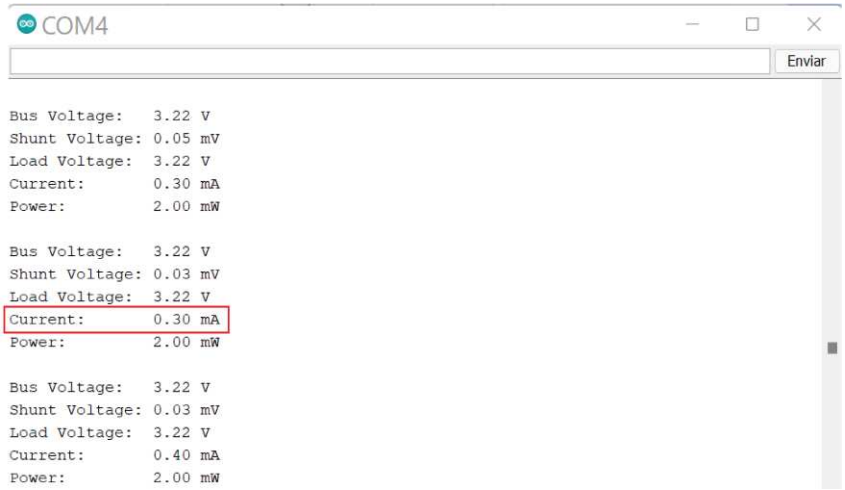

Figure 6.2.2 – Electrical values monitored while waiting for an action.

Finally, measurements were taken when the accelerometer data was been reading by the mobile application. Here many different lectures values were obtained. When the board was moved fast, the measurements detected were higher, obtaining around 0.3 mA when the device was relatively static and having a maximum current value of 7.3 mA and 21 mW of power as marked in blue in Figure 6.2.3.

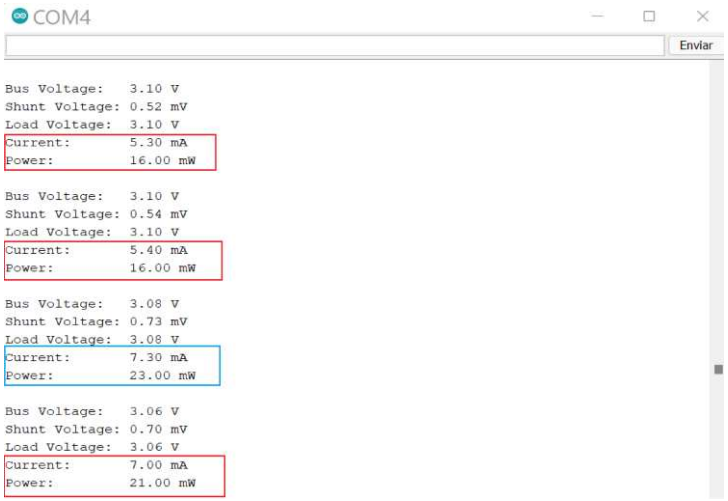

Figure 6.2.3 – Electrical values monitored while accelerometer was performing.

After this, a test consisting of setting the LSM6DSO and another sensor enabled, always in pairs, was realized to measure the maximum value of current obtained while the sensor is moved with aggressive motion applied directly by the user. The values of the measurements can be seen in the Table 6.2.1 noticing that there is no great variation on the maximum amount of current obtained between any pairs of sensors. These measures occur when data from the accelerometer is demanding by the mobile app even when the other sensor is enabled but not read.

Table 6.2.1 – Maximum current obtained with pair of sensors enabled.

Sensor 1	Sensor 2	Max current measured [mA]	Max power measured [mW]
Accelerometer + Gyroscope	-	8.10	25
Accelerometer + Gyroscope	Pedometer	7.5	23
Accelerometer + Gyroscope	Pressure/Temperature	7.8	24
Accelerometer + Gyroscope	Humidity/Temperature	7.1	20
Accelerometer + Gyroscope	Magnetometer	8.6	24
Accelerometer + Gyroscope	Proximity	7.4	21

Using this measurement approach there is possible to observe that there are no great variations between measurements having enable just the accelerometer or another one while the first one is in use so another method will be developed to obtain more samples of the energy values and make a better analysis.

6.3 Arduino limitations on data acquisition

To know better the capacities of the Arduino UNO board when working with the INA219 in terms of data acquisition frequency a new test that consist in minimizing the code lines and acquire a series of limited number of samples is designed. The code used is the one described in section 6.2 but adding a push button connected to digital input-output pin number 2 on the board to start the process of acquiring a hundred samples of the input voltage and the current flowing through the sensor board using the current sensor INA219. The results, after being collected, are displayed on the serial monitor window. The modified code is shown below and corresponds to the file named

INA219_limitations_test.ino.

```
#include <Wire.h>
#include "Adafruit_INA219.h"

Adafruit_INA219 ina219;
const int buttonPin=2;                          //Digital pin input 2
const int n=100;                                //number of samples
bool done=LOW;
float busvoltage_array[n];                      //Voltage array
float current_mA_array[n];                      //Current array
int timevector_array[n];                        //Time vector array

void setup(void)
{
  uint32_t currentFrequency;
  Serial.begin(2000000);
  ina219.begin();
  ina219.setCalibration_16V_400mA();   //Calibration of the INA219
  }

void loop(void)
{
if(digitalRead(buttonPin)==0)      //If the button is not pressed
{
  Serial.println("Push the button to start");
  done=LOW;
  delay(1000);
  }
else               //When the button is pressed starts recording
{
  if(done==0)
  {
    for(int i=0;i<n;i++)
    {
      timevector_array[i]=millis();
      busvoltage_array[i] = ina219.getBusVoltage_V();
      current_mA_array[i] = ina219.getCurrent_mA();
      }

    for(int i=0;i<n;i++)
```

```
    {
      Serial.print(timevector_array[i]);  Serial.print(",");
      Serial.print(busvoltage_array[i]); Serial.print(",");
      Serial.println(current_mA_array[i]);                    }
      }
  done=HIGH;
}
}
```

Some of the data displayed on the serial monitor can be seen in Figure 6.3.1. The first column corresponds to the time the data is displayed on the serial monitor while after the arrow the three numbers separated by a comma correspond to the time in milliseconds when the sample was acquired respect to the beginning of the execution of the program, then the value of the supply electrical tension in volts and finally the current measured in milliamperes.

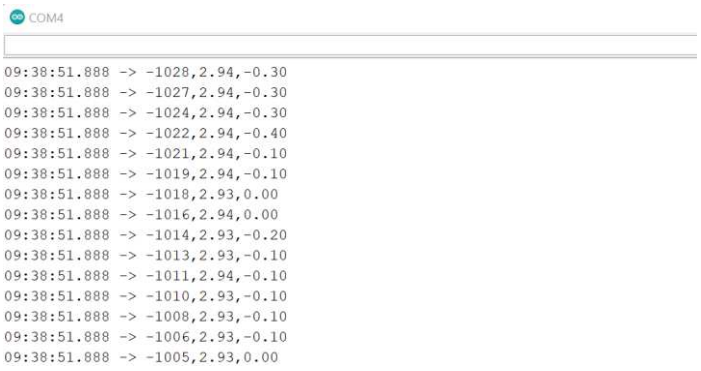

Figure 6.3.1 – Arduino data acquisition test results on serial monitor.

It can be seen that the time between each sample according to the code, using the command `millis()`, is about one or two milliseconds After this, another experiment is defined by just changing the number of samples that the Arduino can possibly store in its internal memory increasing the value of the variable n but from 109 samples an error message appears on the Arduino IDE indicating there is little memory space and it can cause instability problems while executing the program. These results give an idea of the limitations of using the Arduino and the INA219 configuration to acquire data. In case of needing a faster measurement or a bigger memory space to storage data it would be necessary to consider the use of a specialized data acquisition system.

6.4 PCB design and construction

Once the electronic circuit built on the protoboard has been tested and correctly works, it was decided to build a printed circuit board (PCB) to avoid disconnections and to be more comfortable for the user to work with it. The PCB was designed as an Arduino shield to optimize the space and transportation. The dimensions used were the ones recommended by Arduino on its website and are shown in Figure 6.4.1.

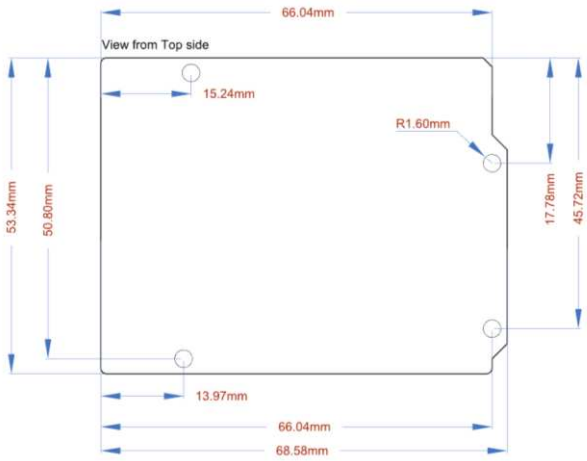

Figure 6.4.1 – Arduino shield dimensions.

For the PCB's electric circuit design Proteus 8 software was used considering all the components and connections as they were on the protoboard. Some of the elements like headers or INA219 current sensor module are not included in any library of the software so they should be created as a new element considering their pins and physical dimensions. Some minor additions to the original circuit in the protoboard were incorporated as a battery holder and an on/off button. Figure 6.4.2 shows the final electronic designed using Proteus 8.

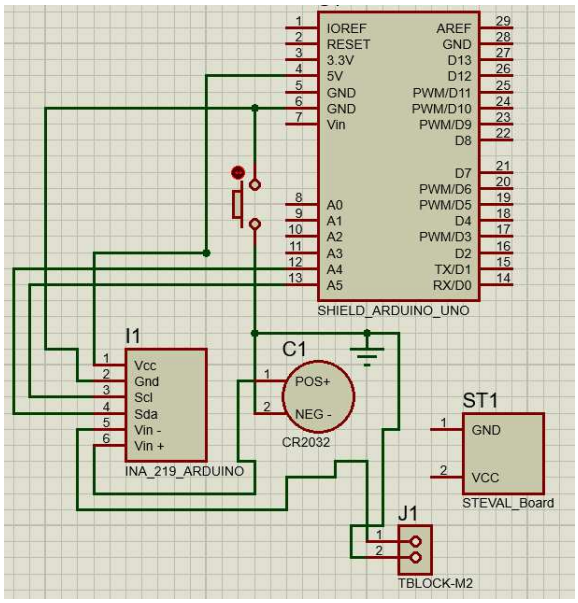

Figure 6.4.2 – Electric circuit designed using Proteus 8.

Using the same software, it is possible to obtain a PCB design of the circuit selecting different options depending on the project. For this specific purpose a single side copper board is used to build the shield and set all connection paths. Figure 6.4.3 presents the PCB designed in the software with all element's dimensions and positions in cyan, dark blue lines are the copper connection paths, and purple circles are the pins where the elements will be soldered.

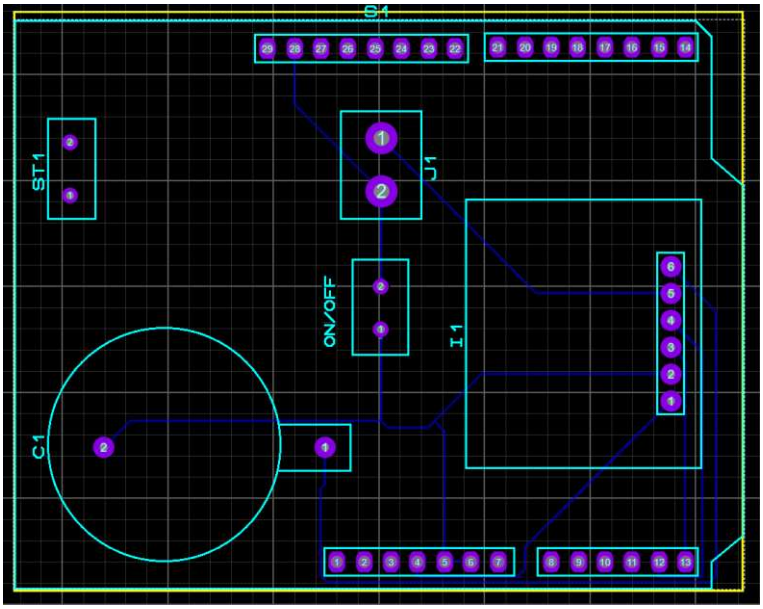

Figure – 6.4.3 – PCB designed using Proteus 8.

To get just the paths and pins and proceed to the physical construction of the PCB the design needs to be exported as a .pdf file selecting just the bottom copper layer obtaining the pattern shown in Figure 6.4.4.

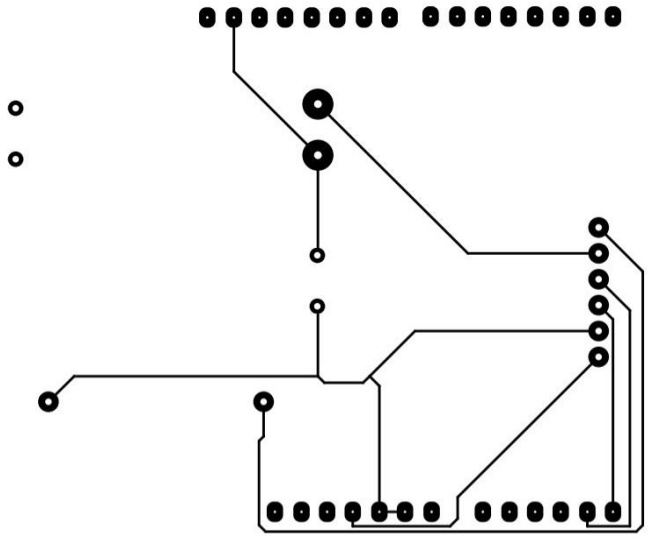

Figure 6.4.4 – PCB bottom copper layer.

It is possible to build a PCB using different techniques depending on the materials and instrumental that the user has available, in this case the toner transfer method is used. It consists of printing the pins and paths in real scale as shown in Figure 6.4.4, on an acetate sheet using a toner printer and then transferring the toner to a copper board using heat provided from an iron. The paths and pins transferred to the copper board can be seen in Figure 6.4.5.

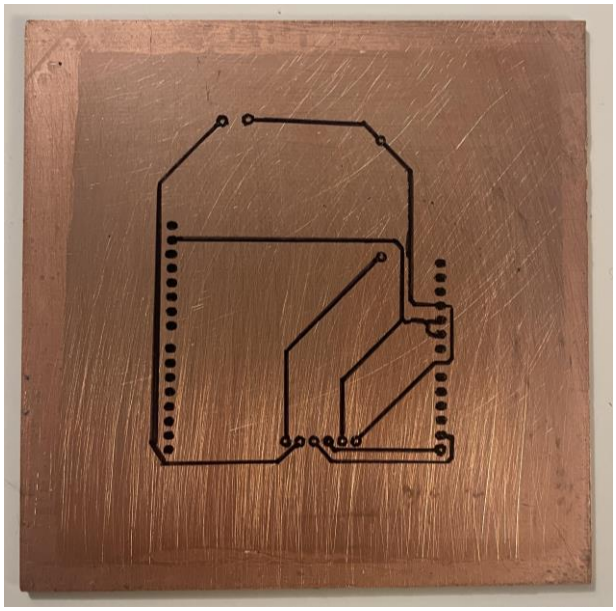

Figure 6.4.5 – Paths and pins transferred to copper board.

Now, to eliminate copper not covered by the toner the board must be submerged in a solution of 40% ferric chloride (FeCl3) and 60% water as can be seen in Figure 6.4.6; after some minutes the board with just the copper covered by the toner is obtained.

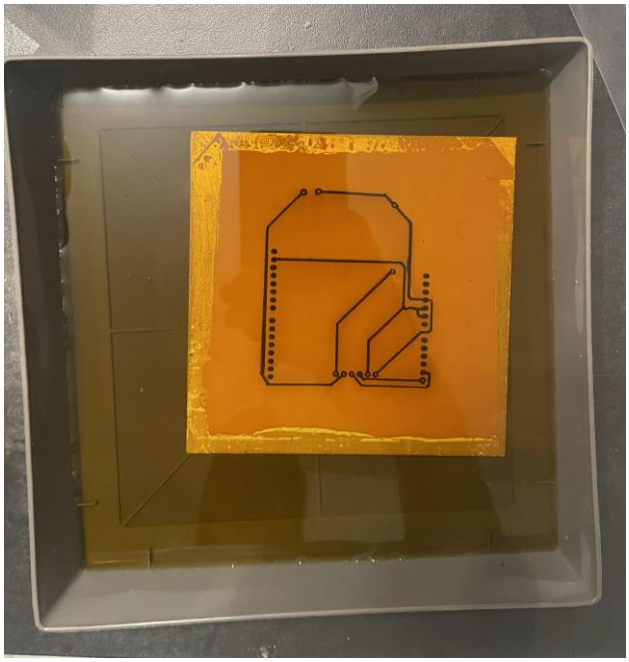

Figure 6.4.6 – Copper board submerged in ferric chloride and water solution.

The next step is to clean the tonner with acetone to discover the copper paths and perform a continuity test of them using a multimeter to verify every element is connected as shown in Figure 6.4.7.

Figure 6.4.7 – Paths continuity test.

After the continuity test a solder mask is applied on the board side that contains the paths and pins as a protection layer. To apply the solder mask, it is necessary to print a new .pdf file with just the component pins, as seen in Figure 6.4.8, on an acetate sheet.

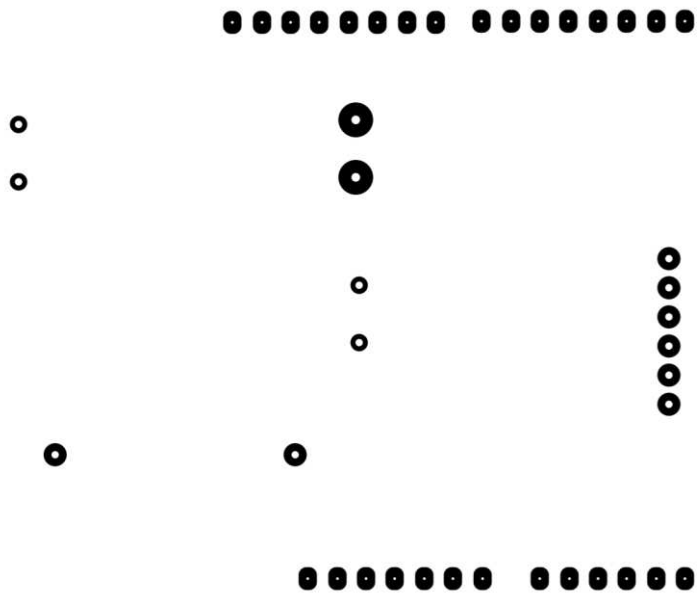

Figure 6.4.8 Pins pattern.

The solder mask is applied on the board the most homogeneous possible and over it the sheet with the pins is collocated making the physical pins be covered by the toner, then a UV light in a dark room is applied for about ten seconds to make the mask solidify on the board except on the pins. Figure 6.4.9 shows the board with the solder mask and the pins exposed.

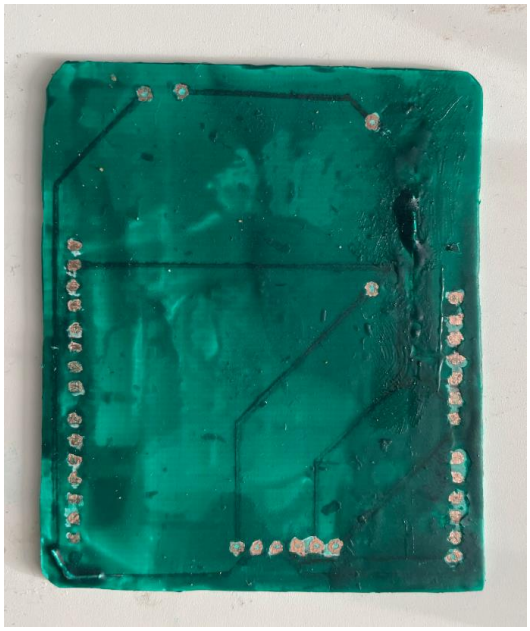

Figure 6.4.9 – Solder mask applied.

The next step is to use a drill to make the holes that let the components to be inserted using two drill bits. For all pins except from the ones corresponding to the sensor board 3D connector and the switch a 1/32-inch drill is used; for the rest of components a 1/16-inch one is used. can be seen in Figure 6.4.10 shows the drilling process performed with a Dremel drill tool.

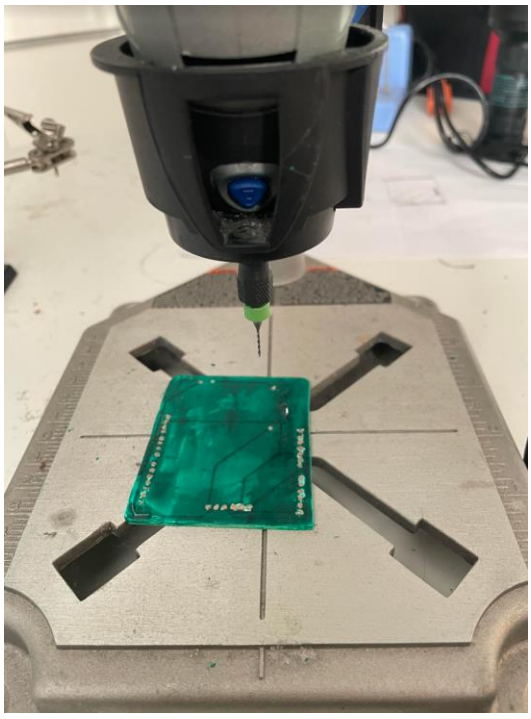

Figure 6.4.10 – Drilling the board pins.

Finally, the components are ready to be soldered to the board using a soldering iron and stained solder wire. The final PCB board with every component soldered is observed in Figure 6.4.11 and mounted on the Arduino UNO board in Figure 6.4.12.

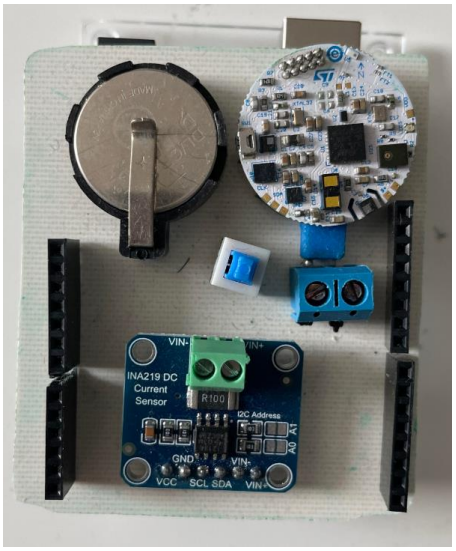

Figure 6.4.11 – ST mobile app initial window.

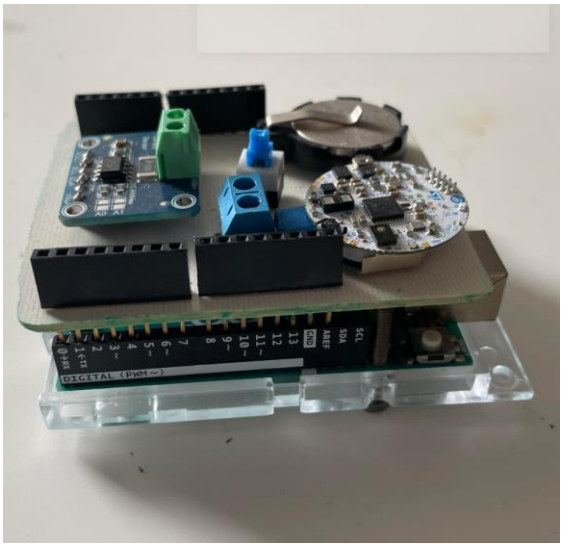

Figure 6.4.12 –List of devices abled to pair.

6.5 Power measurement using MATLAB

It is possible to make a connection between the Arduino UNO board and the computer to obtain data from the microcontroller's analogue to digital (ADC) structure measuring the electrical power values from the INA219 and manipulate them using MATLAB through serial communication. A program named `measurements_test_4.mat` has been developed to obtain the voltage and current values during a 60 second test divided in three stages. The first stage is when the sensor board is in advertising mode waiting to be paired to a device and defined to occur during the first 15 seconds, the second stage corresponds to when the connection to de device is stablished and waiting for the user to start the accelerometer data reading and the third and final stage is when the accelerometer data is been reading and saved always using the ST mobile app. The first feature appearing after running the code is an initial window asking the user to choose between perform a test or load a previous one using an existing `.mat` file, this window can be seen in Figure 6.5.1.

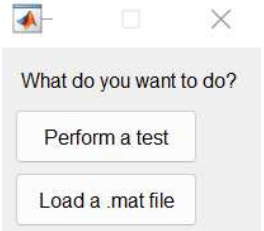

Figure 6.5.1 – Initial menu for measurement test.

Selecting to perform a test makes a box appear, like the one shown in Figure 6.5.2, letting the user know that to stop the continuous acquisition of data it is necessary to close the graphics window, shown in Figure 6.5.3, where the voltage and current values are showing up. To continue it is necessary to press 'OK' or close this box.

Figure 6.5.2 – Message to close the graphics.

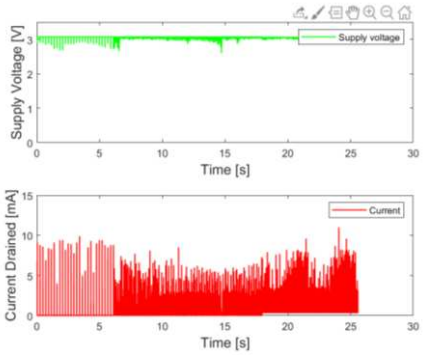

Figure 6.5.3 – Measurement graphics window.

As the data obtained is not corresponding to a constant sampling frequency, all the data is interpolated to obtain a constant sample frequency analysis. The program analyses just a portion of each stage defining their time limits, the first is when the board is in advertisement to be discovered by the phone and goes from 0 to 10 seconds, the second corresponds to when the connection is stablished between the sensor board and the mobile, from second 20 to 35, and the third one is when the phone is reading and saving accelerometer data, from second 45 to 60. The three stages can be identified on the current graph due to different behaviour and the analysed intervals are marked with boxes of different colours as can be seen in Figure 6.5.4, that also shows some values as the mean and standard deviation values of current and voltage.

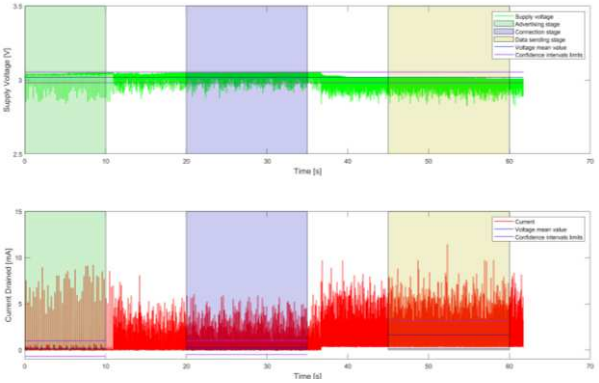

Figure 6.5.4 – Voltage and current data plot.

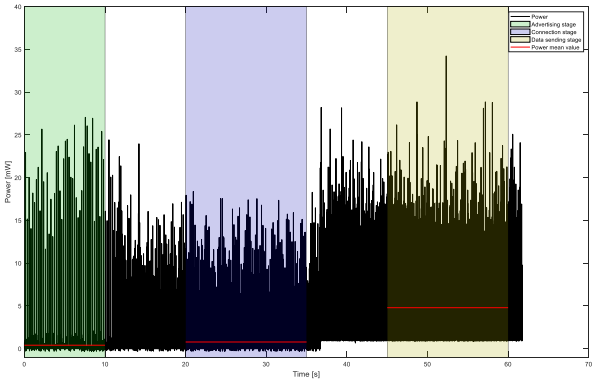

Figure 6.5.5 – Measurement graphics window.

The user has the option to save the test or not; if the test is saved two files are created a `.mat` and a `.csv` with a valid name chosen by the user. Otherwise, if the user decides to load a `.mat` file from a previous test the program validates its existence and immediately after shows the plots corresponding to the ones previous shown in Figure 6.5.4 and Figure 6.5.5. The flow diagram of the MATLAB program is shown in Figure 6.5.6.

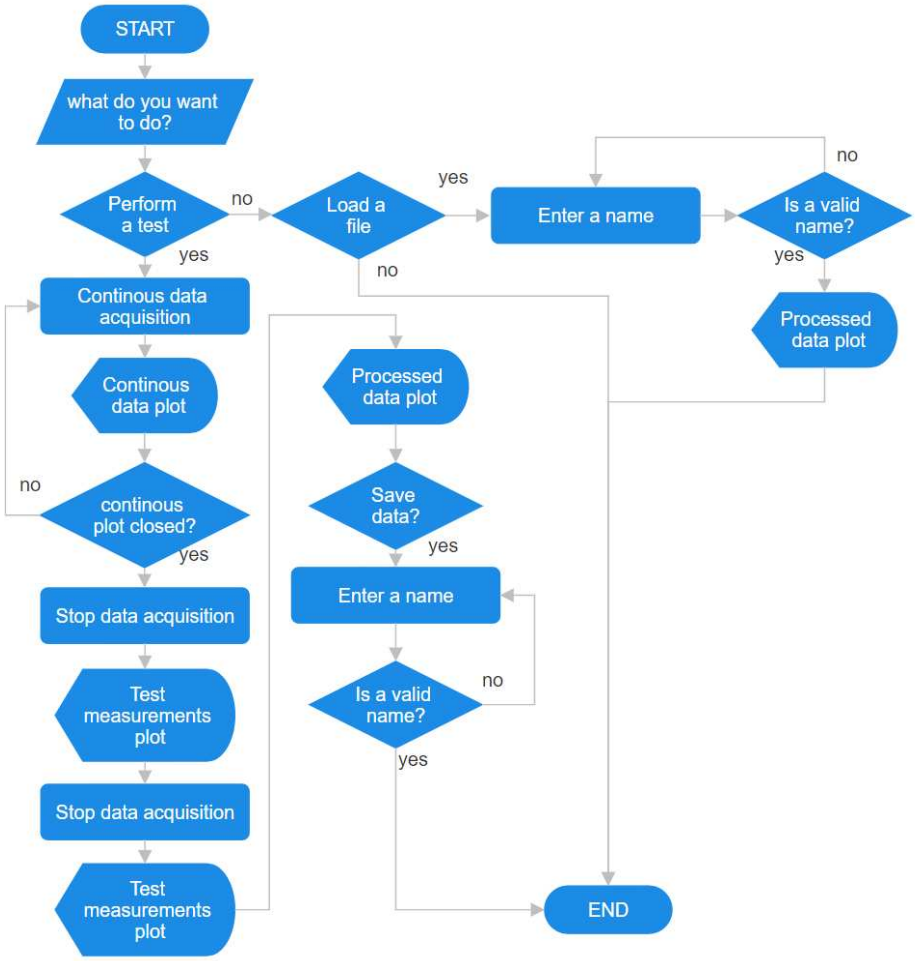

Figure 6.5.6 – Flow diagram of MATLAB's program for test 4.

6.6 Second voltage and current measurements test

It is convenient to stablish a test applied to the board with different configurations of active sensors to evaluate the maximum current consumption expected for different applications. The proposed configurations to evaluate are all sensors on, just the accelerometer sensor on, just accelerometer and pressure sensors on, just accelerometer and humidity sensors on, just accelerometer and magnetometer sensors on and just accelerometer and proximity sensors on. The condition of the test is needs to respect the way the MATLAB code will receive data from the different connection stages previously described in this same chapter. The test is performed five times for each configuration of active sensors for 60 seconds starting the measurements from advertisement stage, second 0 to 10, then manually the user stablishes the connection to the mobile using the ST mobile app before second 20 has occurred and waiting till second 35 to start acquiring data but just saving the last 15 seconds of accelerometer data to a .csv file. A small modification has been performed in the Arduino code of the section 6.3 to only send data voltage supply and current data to MATLAB though serial communication as is following showed.

```
#include <Wire.h>
#include "Adafruit_INA219.h"

Adafruit_INA219 ina219;
 float busvoltage = 0;
 float current_mA = 0;
```

```
void setup(void)
{
  uint32_t currentFrequency;

  Serial.begin(115200);

  ina219.begin();
  ina219.setCalibration_16V_400mA();
}

void loop(void)
{
  busvoltage = ina219.getBusVoltage_V();
  current_mA = ina219.getCurrent_mA();

  Serial.print(millis());  Serial.print(",");
  Serial.print(busvoltage); Serial.print(",");
  Serial.println(current_mA);
}
```

The condensed results data of the maximum current obtained from the plots is presented in the Table 6.6.1.

Table 6.6.1 – Current measurement results of different set of sensors configuration.

Sensors active	Maximum current on test 1 [mA]	Maximum current on test 2 [mA]	Maximum current on test 3 [mA]	Maximum current on test 4 [mA]	Maximum current on test 5 [mA]	Maximum current of all tests [mA]
All	10.4	10.8	11.1	10.9	9.8	11.1
Just the accelerometer	10.8	10.1	10.2	10.8	10.8	10.8
Just the accelerometer + pressure/temperature	10.6	10.2	10.6	11	10.2	11
Just the accelerometer + humidity/temperature	10.7	10.4	10.5	11.2	10.4	11.2
Just the accelerometer + magnetometer	11.4	11.4	11.7	11.8	10.6	11.8
Just the accelerometer + proximity	11.4	10	11	10.2	11.4	11.4

It can be observed that the current values oscillate in most of the cases between the 10 mA and the 11.8 mA with no great differences choosing one configuration or another. A more detailed test to obtain the mean values of the electrical parameters will be presented in the following chapter.

6.7 Power measurement test with different data acquisition rates

To conclude this section a final test was defined to search for significant differences on energy consumption from the board when the data acquisition rate, or sampling rate, is modified when programming the LSM6DSO modifies the registers that set this specification. The Sensor.h file of the BLE_SensorDemo project uses the library file LSM6DSO.h where the different configurations for the frequency rate is stablished. As seen previously, it is possible to modify the code in Sensor.c file to modify the sampling rate with the defined functions in the library by changing the value of the attribute in `lsm6dso_xl_data_rate_set(0, LSM6DSO_XL_ODR_52Hz)` according to the functions defined in the library file and the acquisition frequency desired by the user, this part of the code can be seen in Figure 6.7.1. For this testing the rates of 108 Hz, 833 Hz, and 1667 Hz were used, and the electrical measurements are taken using MATLAB.

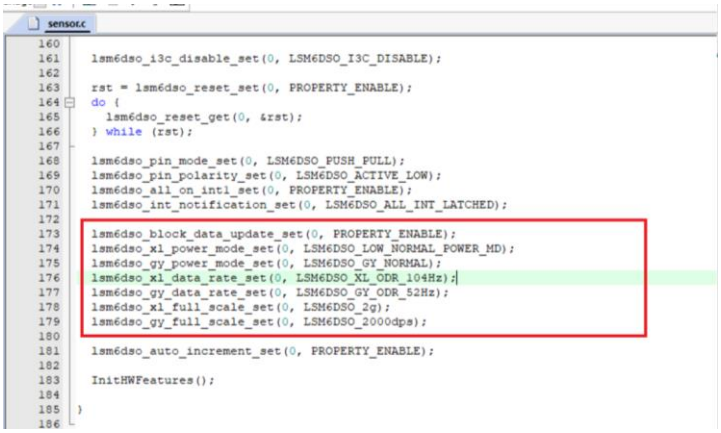

Figure 6.7.1 – Data rate configuration in Sensor.c.

After this, the user must go to the file Sensor.h and modify the timers according to the frequency in which the data acquisition wants to be performed. Originally is set to work at 40ms equivalent to work at 25Hz as can be seen in Figure 6.7.2. A test using three different acquisition frequencies is performed and the obtained data of the electrical consumption are presented from Table 6.7.1 to Table 6.7.3 to compare the behaviour of using three different rates. For each rate the test was performed three times.

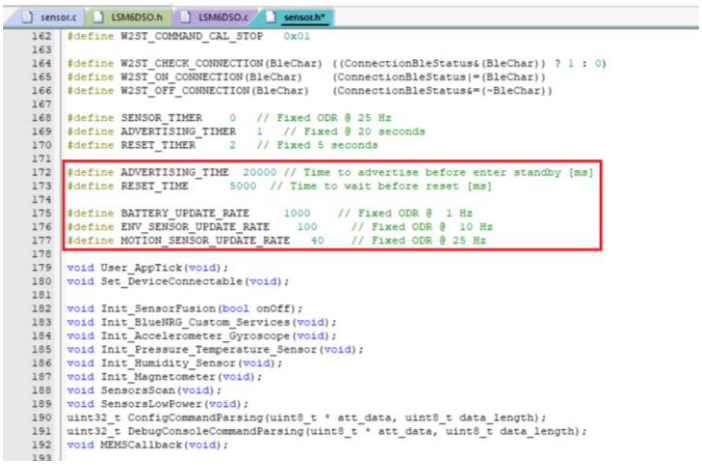

Figure 6.7.2 – Data rate configuration in Sensor.c.

Table 6.7.1 – Electrical values with accelerometer data rate set at 25Hz.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.137	9.385	3.24	0.266	7.553	3.24	2.509	9.856	3.15
2	0.150	8.944	3.14	0.286	5.983	3.14	2.527	10.928	3.07
3	0.152	9.557	3.08	0.288	6.73	3.09	2.512	11.570	3.03

Table 6.7.2 – Electrical values with accelerometer data rate set at 50 Hz.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.151	9.363	3.08	0.295	6.292	3.08	2.816	12.495	3.00
2	0.159	9.551	3.02	0.294	6.438	3.02	2.809	11.665	2.97
3	0.133	9.521	3.00	0.283	6.497	3.00	2.820	11.382	2.94

Table 6.7.3 – Electrical values with accelerometer data rate set at 120Hz.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.147	9.231	3.04	0.289	6.061	3.03	3.864	12.069	2.94
2	0.140	9.135	2.97	0.404	7.528	2.98	3.829	12.963	2.90
3	0.143	9.145	2.94	0.293	6.301	2.95	3.810	11.738	2.89

Finally, a power analysis is done by obtaining the mean power value for every configuration and seeing the consumption in every stage due to the sampling rate changes. The condensed values are presented in Table 6.7.4.

Table 6.7.4 – Mean power analysis with different data rate values

Data rate [Hz]	Test1	Test2	Test3	Transmission stage mean power [mW]
25	7.69	7.57	7.45	7.57
50	8.26	8.15	8.12	8.17
150	11.03	10.80	10.69	10.83

7. Electrical power testing enabling different board sensors

7.1. Tests with data acquisition at 25Hz

The experiment is performed again with the same sensor configurations and respecting the times the program previously defined in section 6.5 to analyse in each stage and that are described in the same section. The accelerometer sensor is originally configured to work at 52 Hz and with an acceleration measurement range of ±16 g. The time that triggers the data acquisition of the accelerometer is set to work at 25Hz or each 40ms. Each configuration is considered a test that will be repeated 5 times.

7.1.1 All sensors active power test

For repetition number 1 when all sensors are active voltage and current measured data is shown in Figure 7.1.1.1 and Figure 7.1.1.2 shows a second of the data transmission interval while Figure 7.1.1.3 shows the power calculated and Figure 7.1.1.4 shows a second of the power calculated in the same second of data transmission interval.

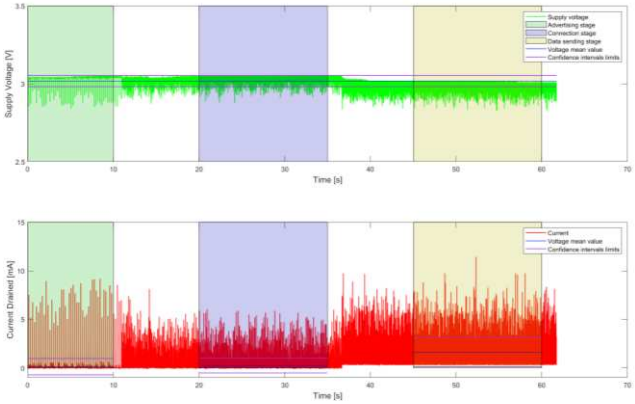

Figure 7.1.1.1 – Voltage and current plot.

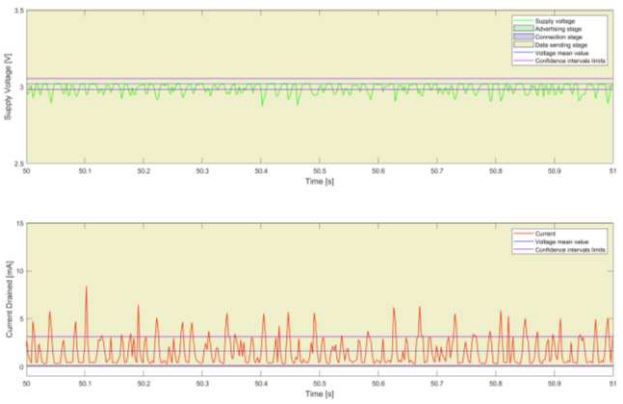

Figure 7.1.1.2 – Current and voltage 1s plot.

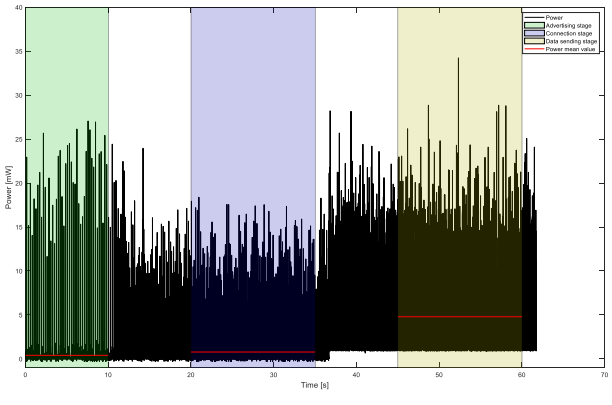

Figure 7.1.1.3 – Calculated power plot.

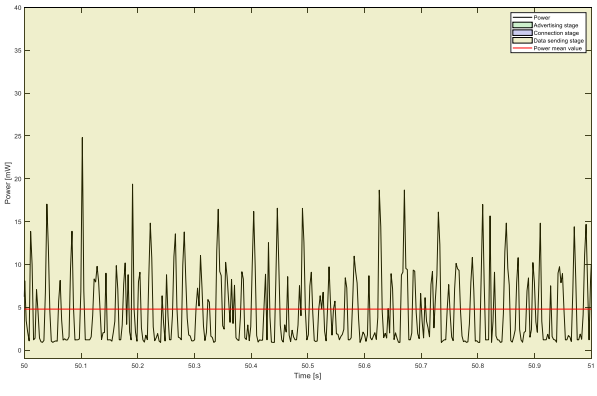

Figure 7.1.1.4 – Power data 1s plot.

For repetition number 2 when all sensors are active voltage and current measured data is shown in Figure 7.1.1.5 and Figure 7.1.1.6 shows a second of the data transmission interval while Figure 7.1.1.7 shows the power calculated and Figure 7.1.1.8 shows a second of the power calculated in the same second of data transmission interval.

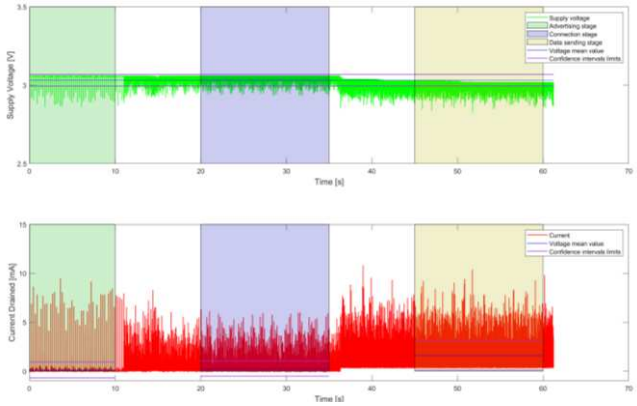

Figure 7.1.1.5 – Voltage and current plot.

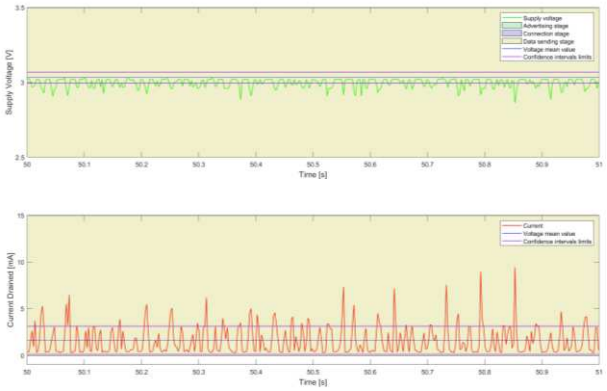

Figure 7.1.1.6 – Current and voltage 1s plot.

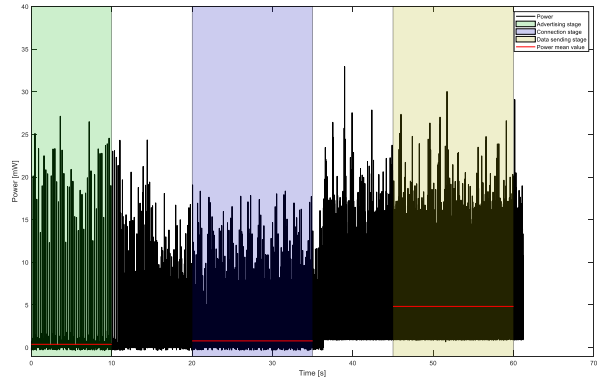

Figure 7.1.1.7 – Calculated power plot.

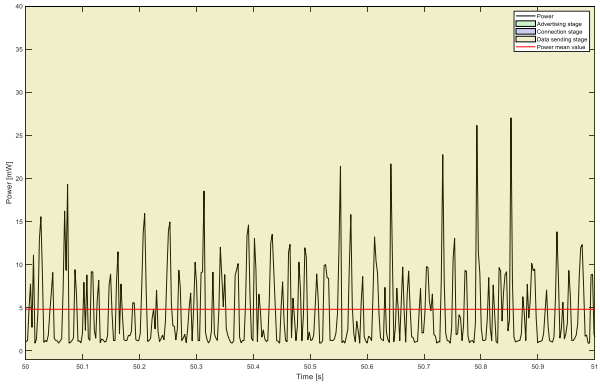

Figure 7.1.1.8 – Power data 1s plot.

For repetition number 3 when all sensors are active voltage and current measured data is shown in Figure 7.1.1.9 and Figure 7.1.1.10 shows a second of the data transmission interval while Figure 7.1.1.11 shows the power calculated and Figure 7.1.1,12 shows a second of the power calculated in the same second of data transmission interval.

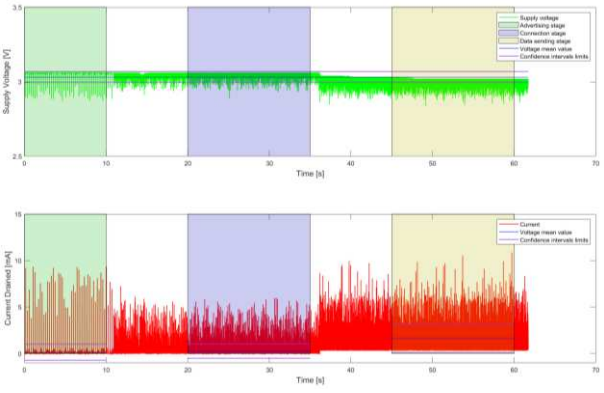

Figure 7.1.1.9 – Voltage and current plot.

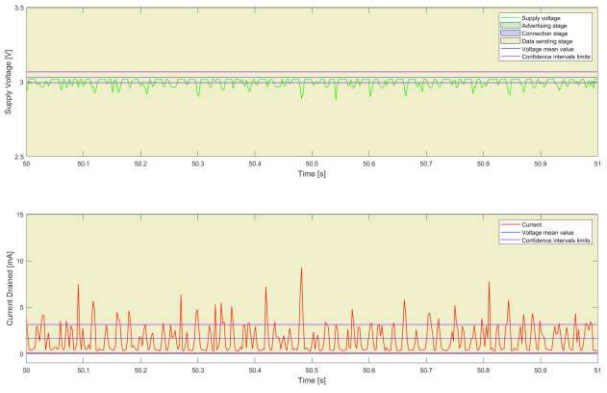

Figure 7.1.1.10 – Current and voltage 1s plot.

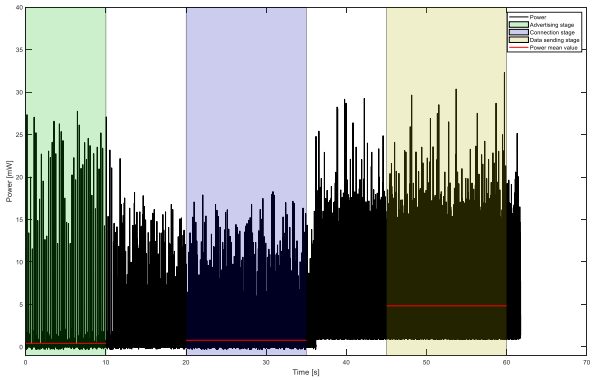

Figure 7.1.1.11 – Calculated power data plot.

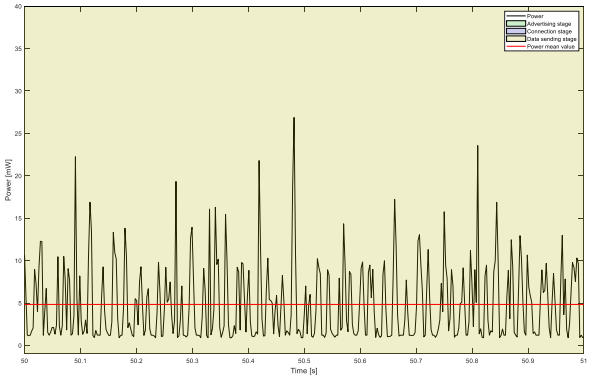

Figure 7.1.1.12 – Power data 1s plot.

For repetition number 4 when all sensors are active voltage and current measured data is shown in Figure 7.1.1.13 and Figure 7.1.1.14 shows a second of the data transmission interval while Figure 7.1.1.15 shows the power calculated and Figure 7.1.1.16 shows a second of the power calculated in the same second of data transmission interval.

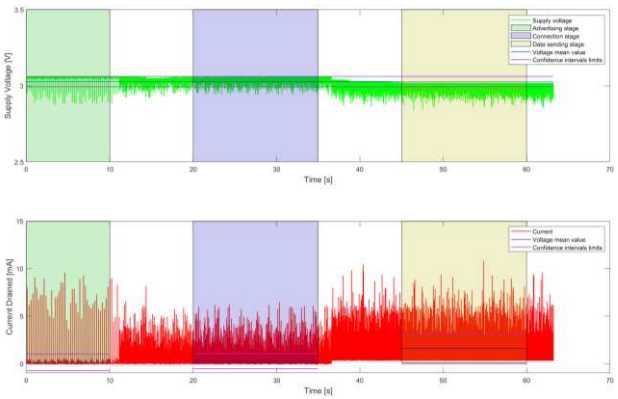

Figure 7.1.1.13 – Voltage and current plot.

Figure 7.1.1.14 – Current and voltage 1s plot.

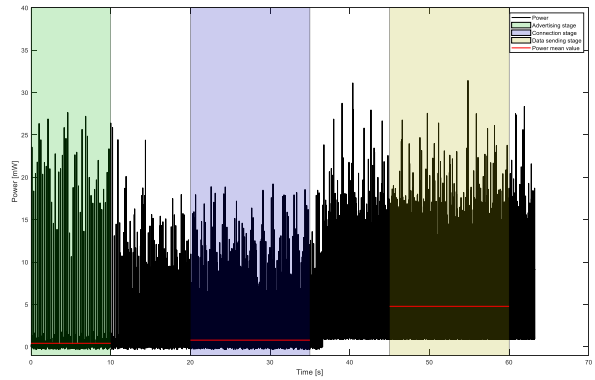

Figure 7.1.1.15 – Calculated power data plot.

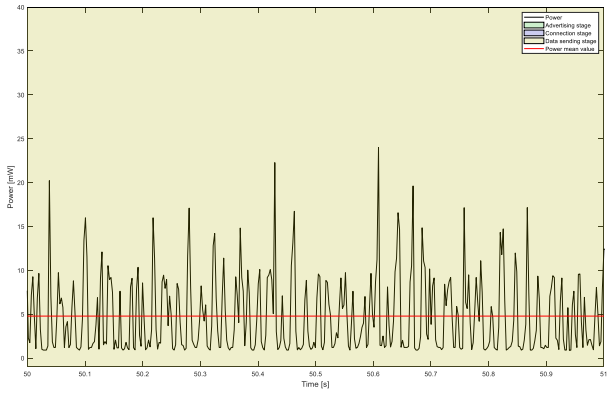

Figure 7.1.1.16 – Power data 1s plot.

For repetition number 5 when all sensors are active voltage and current measured data is shown in Figure 7.1.1.17 and Figure 7.1.1.18 shows a second of the data transmission interval while Figure 7.1.1.19 shows the power calculated and Figure 7.1.1.20 shows a second of the power calculated in the same second of data transmission interval.

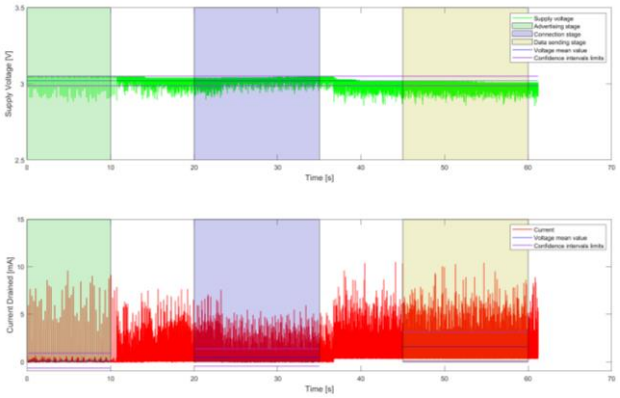

Figure 7.1.1.17 – Voltage and current plot.

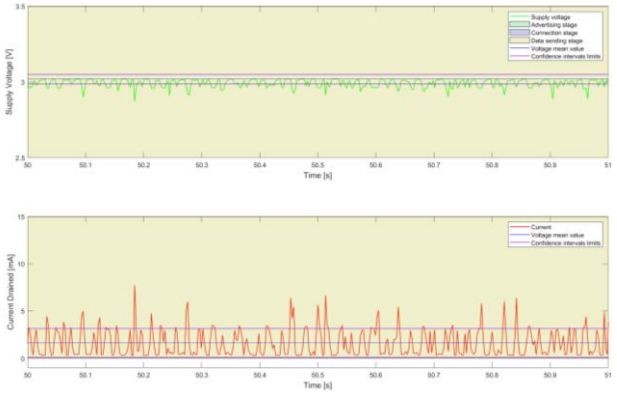

Figure 7.1.1.18 – Current and voltage 1s plot.

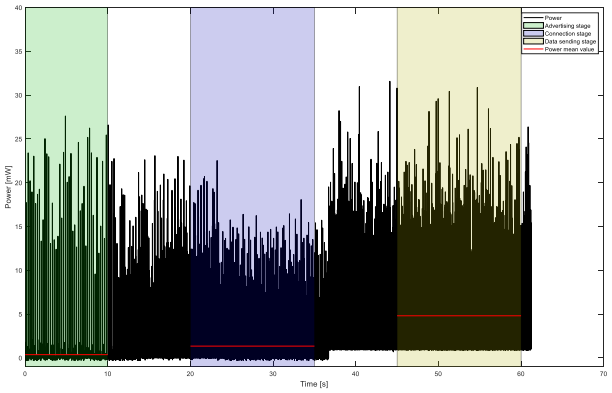

Figure 7.1.1.19 – Calculated power data plot.

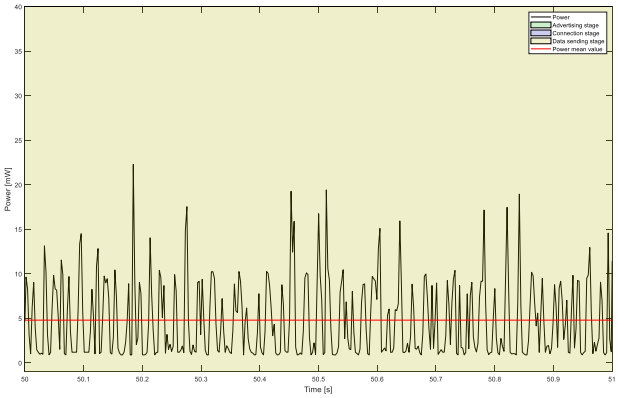

Figure 7.1.1.20 – Power data 1s plot.

Table 7.1.1.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.1.1.1 – Electrical values with all sensors active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.136	9.198	3.05	0.258	6.048	3.05	1.615	11.450	3.02
2	0.129	9.473	3.06	0.259	6.335	3.06	1.622	10.405	3.03
3	0.140	9.351	3.06	0.256	5.974	3.06	1.623	10.873	3.03
4	0.141	9.593	3.06	0.260	6.448	3.06	1.605	10.830	3.03
5	0.124	9.582	3.05	0.446	7.575	3.05	1.616	10.422	3.02

7.1.2 Accelerometer and pressure sensors active power test

For repetition number 1 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.1.2.1 and Figure 7.1.2.2 shows a second of the data transmission interval while Figure 7.1.2.3 shows the power calculated and Figure 7.1.2.4 shows a second of the power calculated in the same second of data transmission interval.

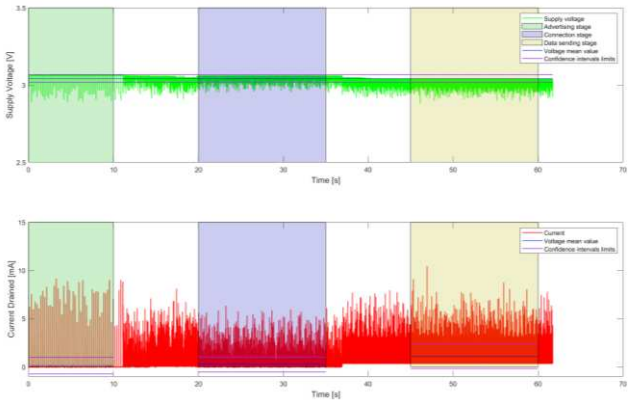

Figure 7.1.2.1 – Voltage and current plot.

Figure 7.1.2.2 – Current and voltage 1s plot.

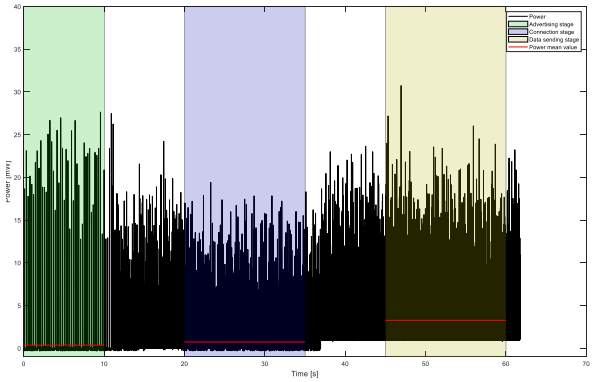

Figure 7.1.2.3 – Calculated power plot.

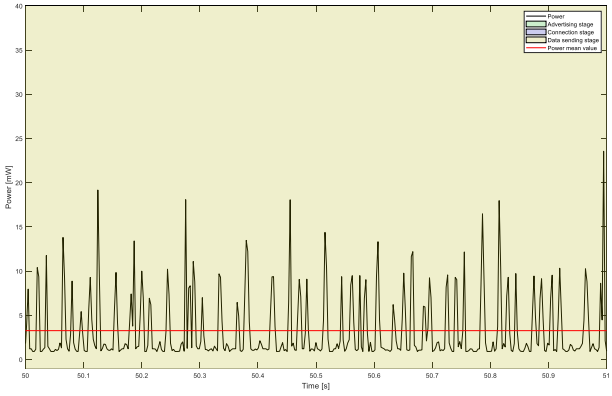

Figure 7.1.2.4 – Power data 1s plot.

For repetition number 2 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.1.2.5 and Figure 7.1.2.6 shows a second of the data transmission interval while Figure 7.1.2.7 shows the power calculated and Figure 7.1.2.8 shows a second of the power calculated in the same second of data transmission interval.

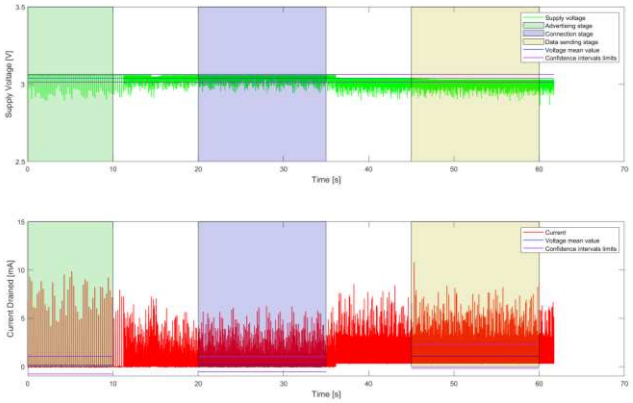

Figure 7.1.2.5 – Voltage and current plot.

Figure 7.1.2.6 – Current and voltage 1s plot.

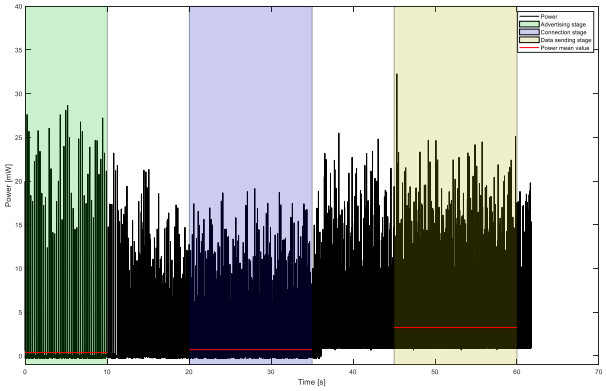

Figure 7.1.2.7 – Calculated power plot.

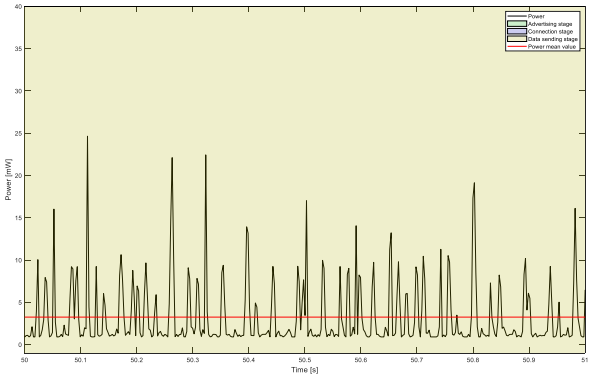

Figure 7.1.2.8 – Power data 1s plot.

For repetition number 3 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.1.2.9 and Figure 7.1.2.10 shows a second of the data transmission interval while Figure 7.1.2.11 shows the power calculated and Figure 7.1.2,12 shows a second of the power calculated in the same second of data transmission interval.

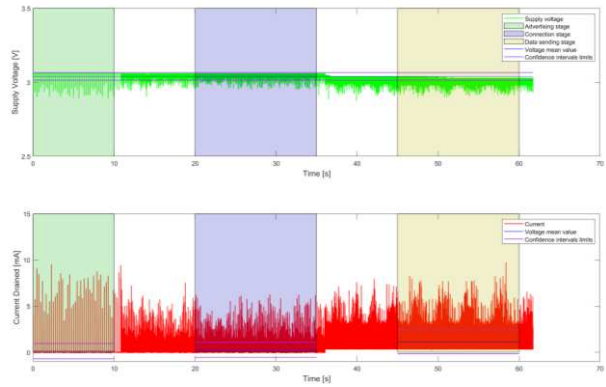

Figure 7.1.2.9 – Voltage and current plot.

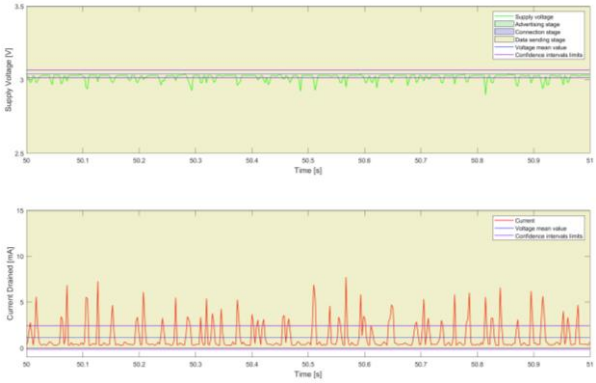

Figure 7.1.2.10 – Current and voltage 1s plot.

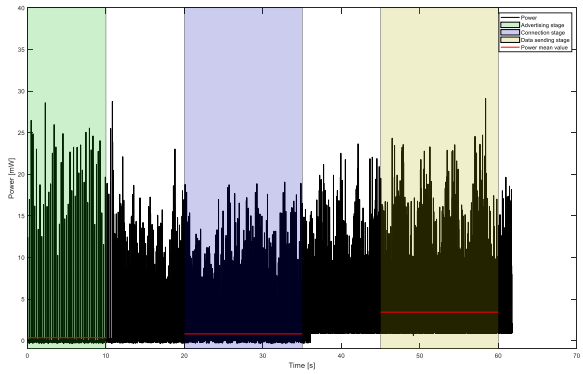

Figure 7.1.2.11 – Calculated power data plot.

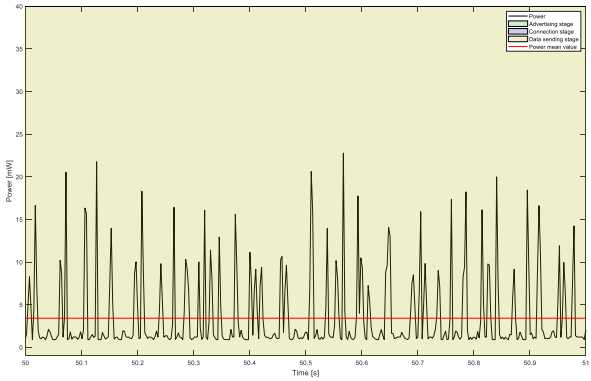

Figure 7.1.2.12 – Power data 1s plot.

For repetition number 4 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.1.2.13 and Figure 7.1.2.14 shows a second of the data transmission interval while Figure 7.1.2.15 shows the power calculated and Figure 7.1.2.16 shows a second of the power calculated in the same second of data transmission interval.

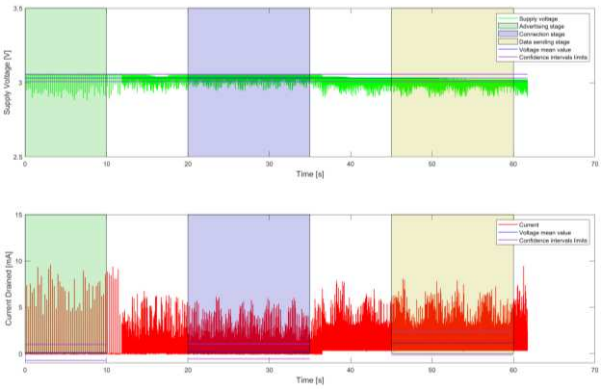

Figure 7.1.2.13 – Voltage and current plot.

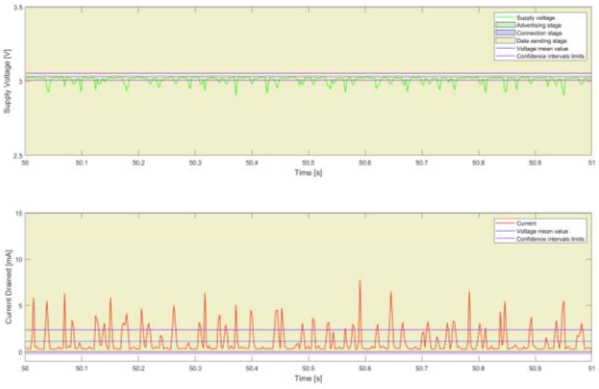

Figure 7.1.2.14 – Current and voltage 1s plot.

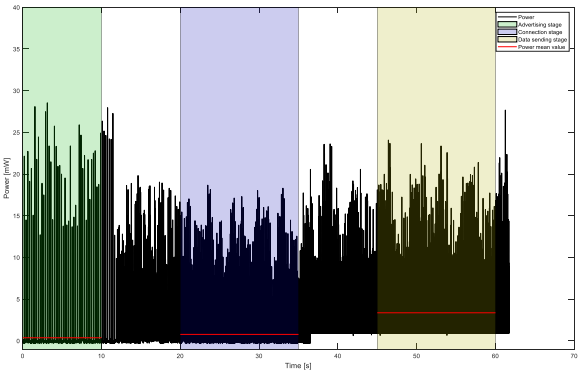

Figure 7.1.2.15 – Calculated power data plot.

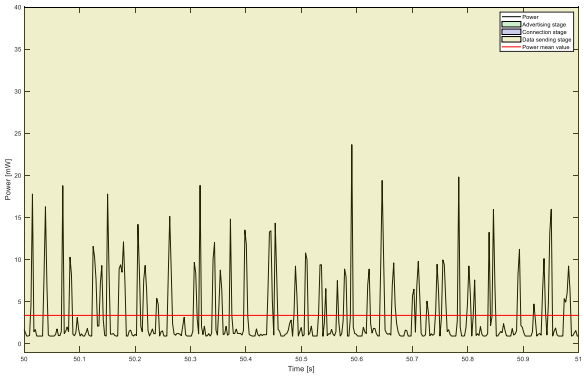

Figure 7.1.2.16 – Power data 1s plot.

For repetition number 5 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.1.2.17 and Figure 7.1.2.18 shows a second of the data transmission interval while Figure 7.1.2.19 shows the power calculated and Figure 7.1.2.20 shows a second of the power calculated in the same second of data transmission interval.

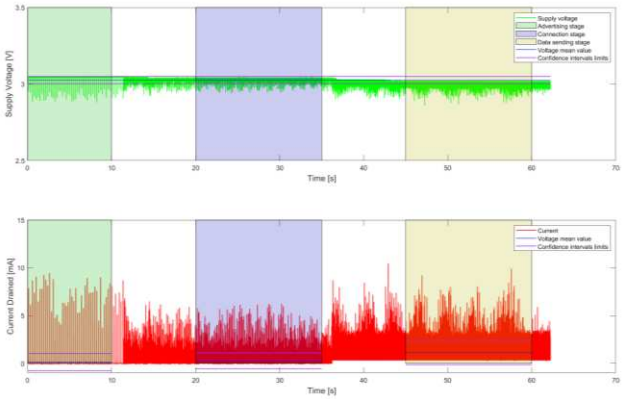

Figure 7.1.2.17 – Voltage and current plot.

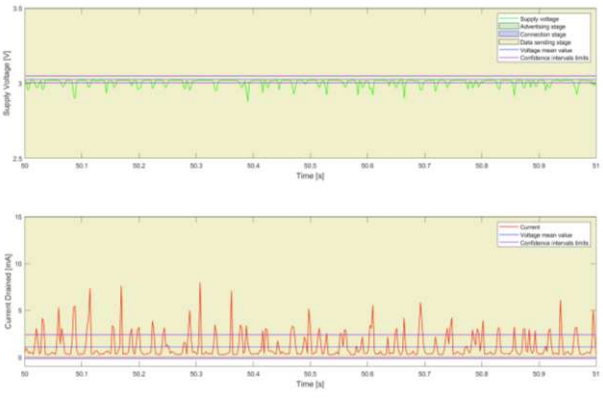

Figure 7.1.2.18 – Current and voltage 1s plot.

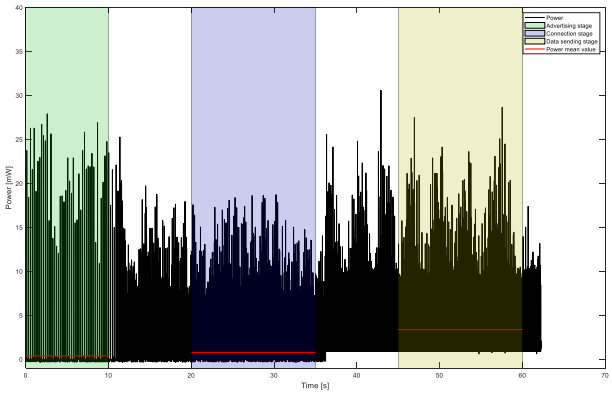

Figure 7.1.2.19 – Calculated power data plot.

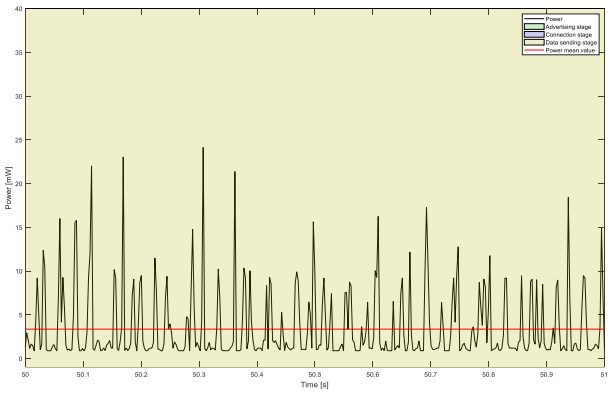

Figure 7.1.2.20 – Power data 1s plot.

Table 7.1.2.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.1.2.1 – Electrical values with accelerometer and pressure sensors active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.125	9.152	3.07	0.241	6.343	3.06	1.086	10.461	3.04
2	0.132	9.872	3.06	0.237	6.255	3.06	1.083	10.818	3.04
3	0.118	9.557	3.06	0.265	6.265	3.06	1.138	9.734	3.04
4	0.123	9.572	3.06	0.254	6.120	3.05	1.122	8.080	3.03
5	0.131	9.474	3.05	0.262	6.236	3.05	1.127	9.918	3.02

7.1.3 Accelerometer and humidity sensors active power test

For repetition number 1 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.1.3.1 and Figure 7.1.3.2 shows a second of the data transmission interval while Figure 7.1.3.3 shows the power calculated and Figure 7.1.3.4 shows a second of the power calculated in the same second of data transmission interval.

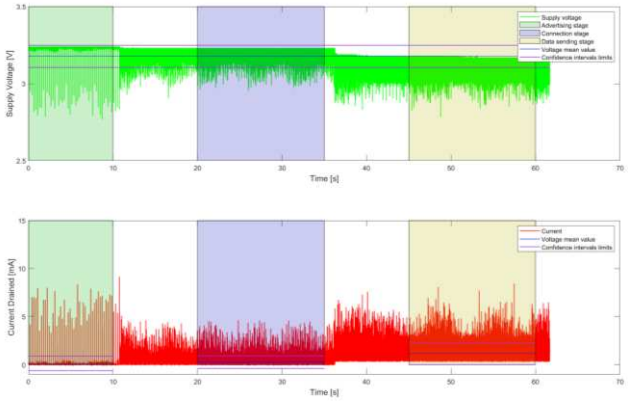

Figure 7.1.3.1 – Voltage and current plot.

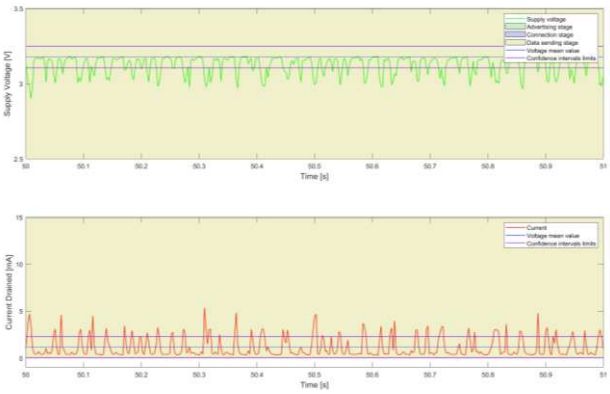

Figure 7.1.3.2 – Current and voltage 1s plot.

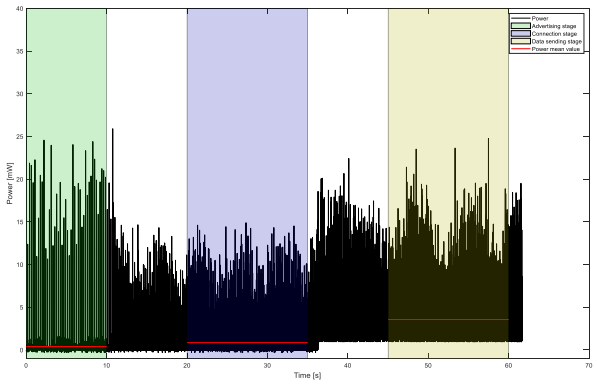

Figure 7.1.3.3 – Calculated power plot.

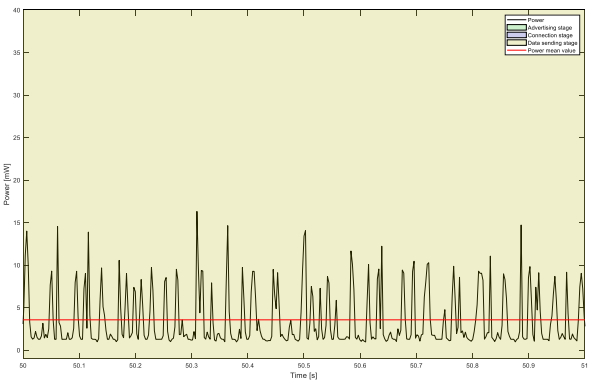

Figure 7.1.3.4 – Power data 1s plot.

For repetition number 2 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.1.3.5 and Figure 7.1.3.6 shows a second of the data transmission interval while Figure 7.1.3.7 shows the power calculated and Figure 7.1.3.8 shows a second of the power calculated in the same second of data transmission interval.

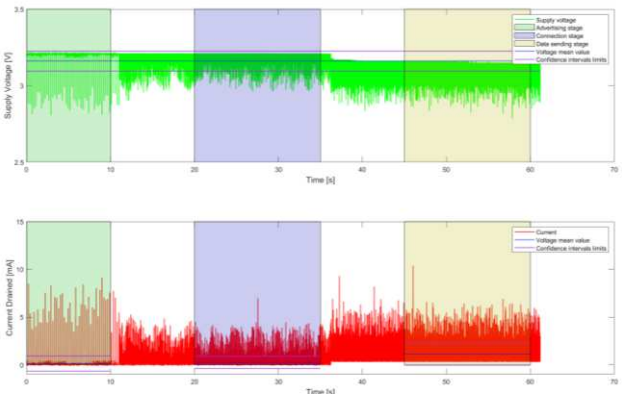

Figure 7.1.3.5 – Voltage and current plot.

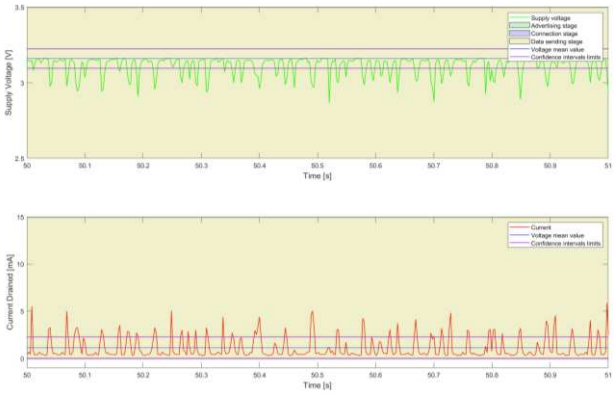

Figure 7.1.3.6 – Current and voltage 1s plot.

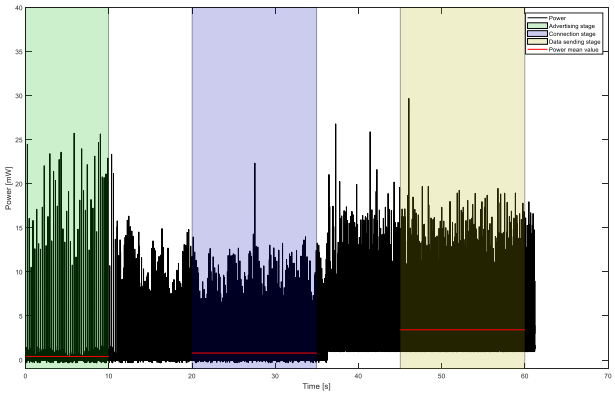

Figure 7.1.3.7 – Calculated power plot.

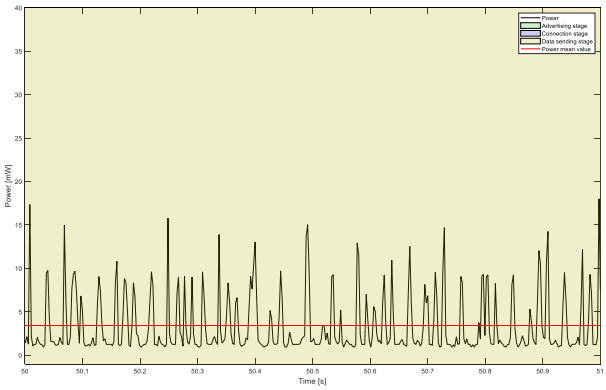

Figure 7.1.3.8 – Power data 1s plot.

For repetition number 3 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.1.3.9 and Figure 7.1.3.10 shows a second of the data transmission interval while Figure 7.1.3.11 shows the power calculated and Figure 7.1.3,12 shows a second of the power calculated in the same second of data transmission interval.

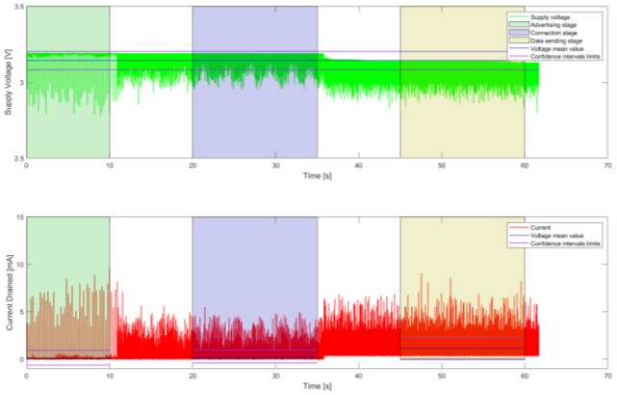

Figure 7.1.3.9 – Voltage and current plot.

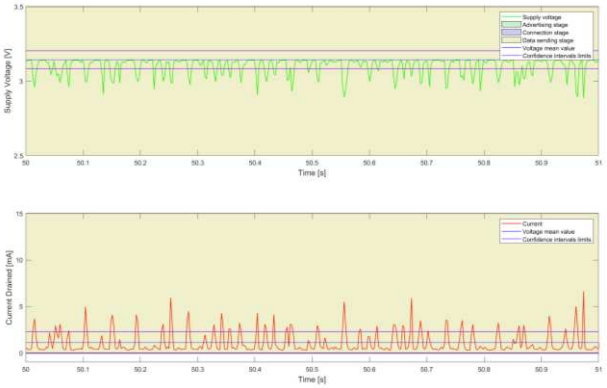

Figure 7.1.3.10 – Current and voltage 1s plot.

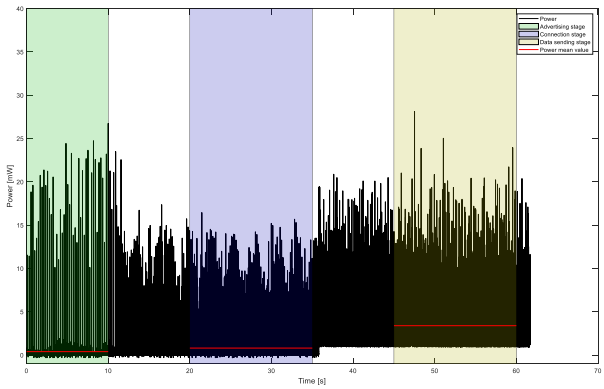

Figure 7.1.3.11 – Calculated power data plot.

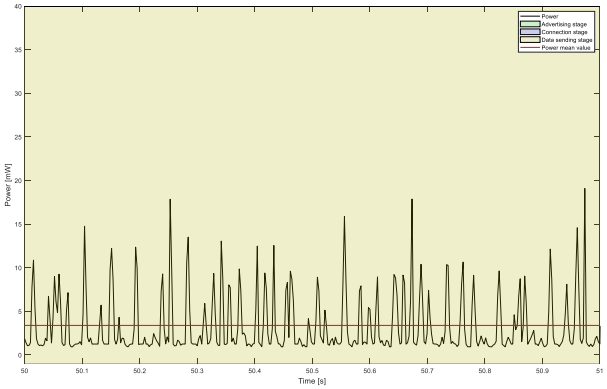

Figure 7.1.3.12 – Power data 1s plot.

For repetition number 4 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.1.3.13 and Figure 7.1.3.14 shows a second of the data transmission interval while Figure 7.1.3.15 shows the power calculated and Figure 7.1.3.16 shows a second of the power calculated in the same second of data transmission interval.

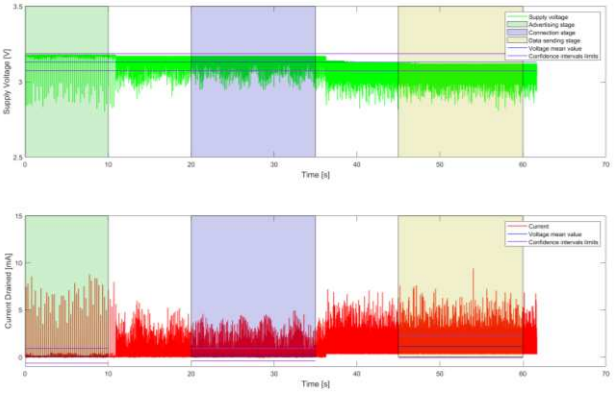

Figure 7.1.3.13 – Voltage and current plot.

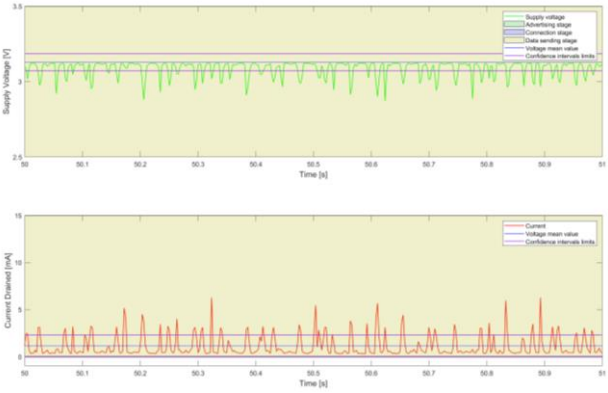

Figure 7.1.3.14 – Current and voltage 1s plot.

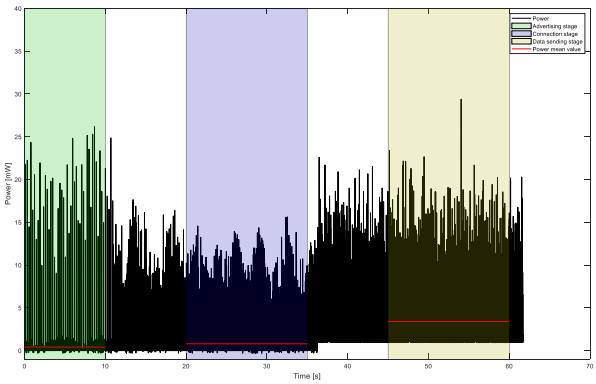

Figure 7.1.3.15 – Calculated power data plot.

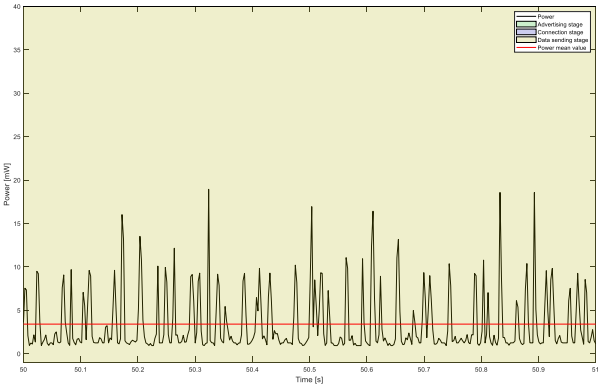

Figure 7.1.3.16 – Power data 1s plot.

For repetition number 5 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.1.3.17 and Figure 7.1.3.18 shows a second of the data transmission interval while Figure 7.1.3.19 shows the power calculated and Figure 7.1.3.20 shows a second of the power calculated in the same second of data transmission interval.

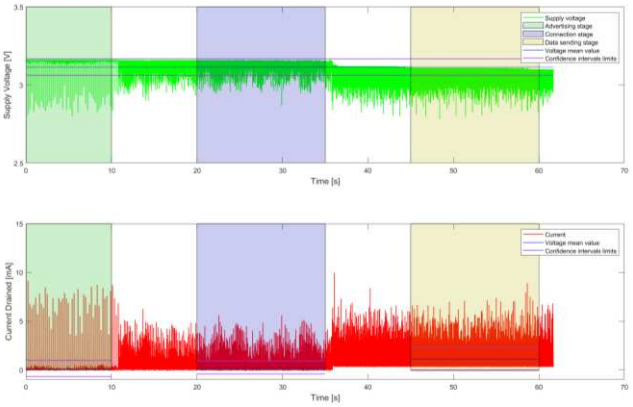

Figure 7.1.3.17 – Voltage and current plot.

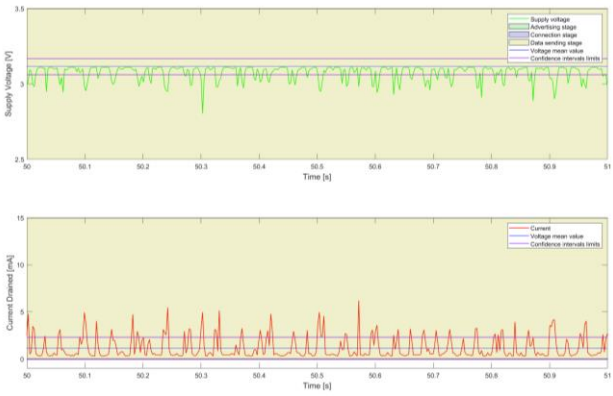

Figure 7.1.3.18 – Current and voltage 1s plot.

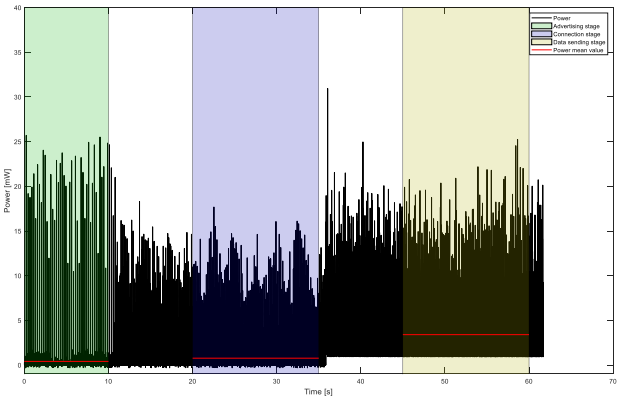

Figure 7.1.3.19 – Calculated power data plot.

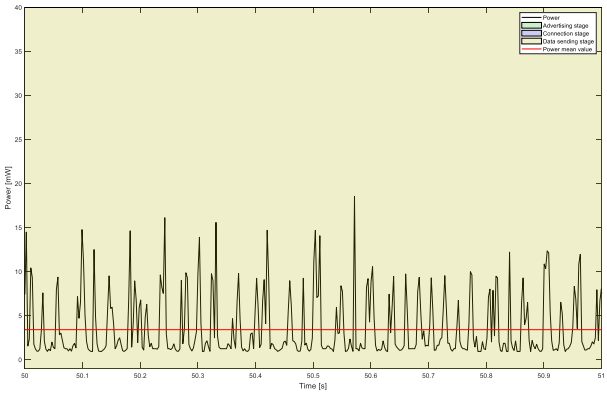

Figure 7.1.3.20 – Power data 1s plot.

Table 7.1.3.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.1.3.1 – Electrical values with accelerometer and humidity sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.132	8.341	3.24	0.271	4.617	3.23	1.157	8.449	3.18
2	0.134	9.130	3.22	0.251	6.971	3.21	1.120	10.379	3.16
3	0.132	9.580	3.20	0.258	5.467	3.19	1.110	9.041	3.14
4	0.137	8.805	3.18	0.255	4.932	3.17	1.119	9.419	3.13
5	0.137	9.147	3.16	0.248	5.601	3.16	1.120	8.910	3.12

7.1.4 Accelerometer and magnetometer sensors active power test

For repetition number 1 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.1.4.1 and Figure 7.1.4.2 shows a second of the data transmission interval while Figure 7.1.4.3 shows the power calculated and Figure 7.1.4.4 shows a second of the power calculated in the same second of data transmission interval.

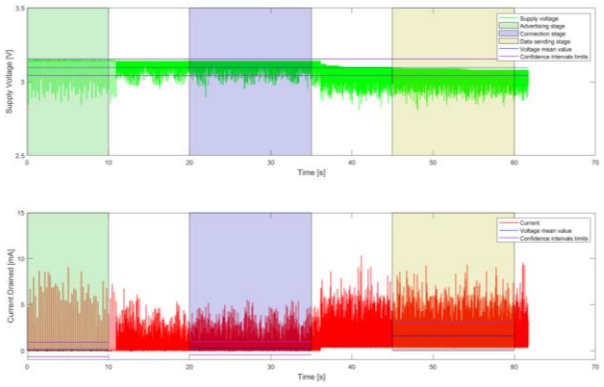

Figure 7.1.4.1 – Voltage and current plot.

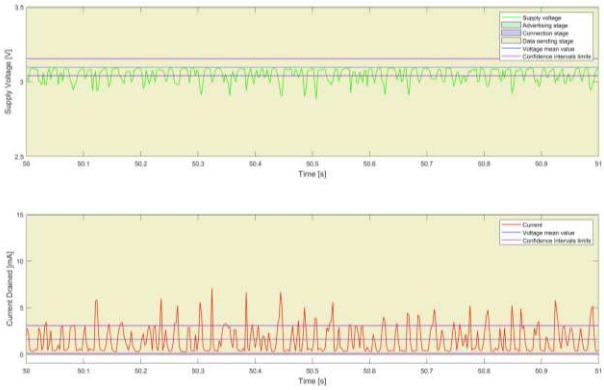

Figure 7.1.4.2 – Current and voltage 1s plot.

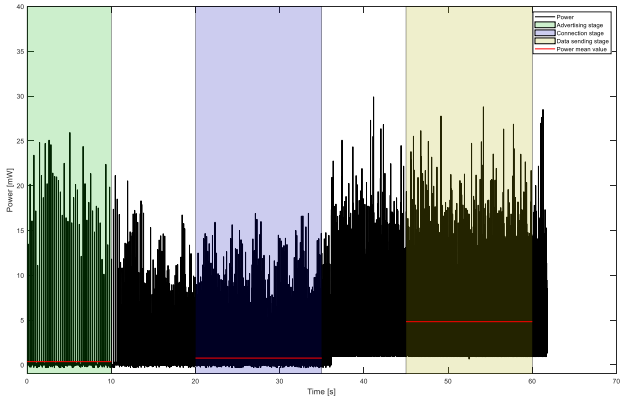

Figure 7.1.4.3 – Calculated power plot.

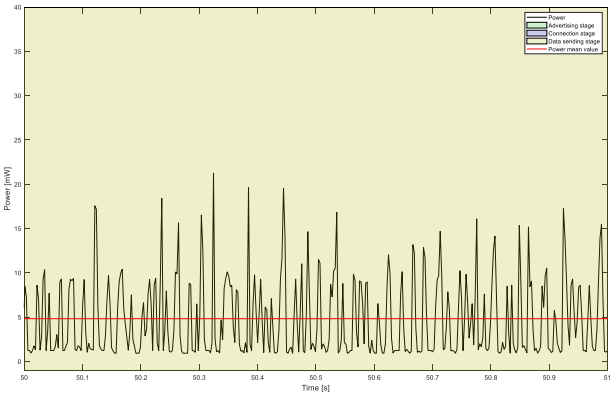

Figure 7.1.4.4 – Power data 1s plot.

For repetition number 2 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.1.4.5 and Figure 7.1.4.6 shows a second of the data transmission interval while Figure 7.1.4.7 shows the power calculated and Figure 7.1.4.8 shows a second of the power calculated in the same second of data transmission interval.

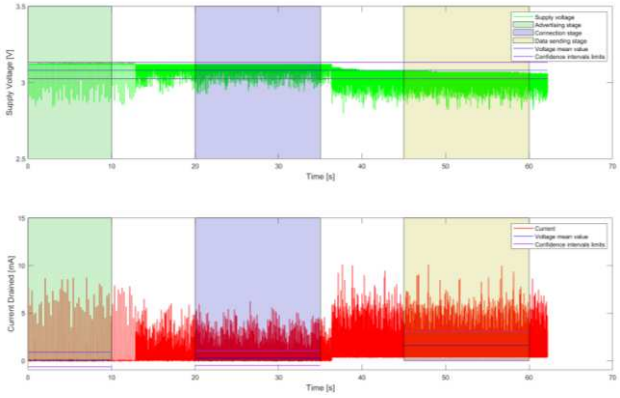

Figure 7.1.4.5 – Voltage and current plot.

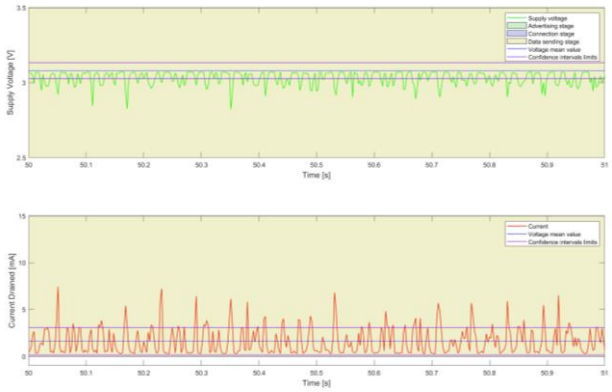

Figure 7.1.4.6 – Current and voltage 1s plot.

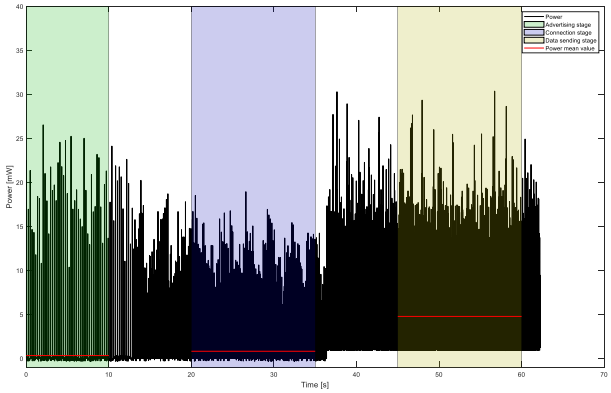

Figure 7.1.4.7 – Calculated power plot.

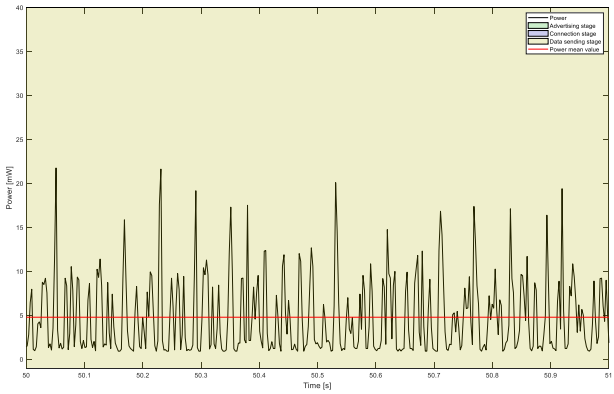

Figure 7.1.4.8 – Power data 1s plot.

For repetition number 3 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.1.4.9 and Figure 7.1.4.10 shows a second of the data transmission interval while Figure 7.1.4.11 shows the power calculated and Figure 7.1.4,12 shows a second of the power calculated in the same second of data transmission interval.

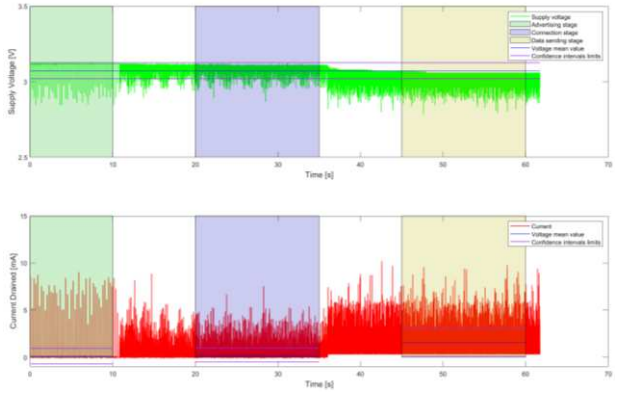

Figure 7.1.4.9 – Voltage and current plot.

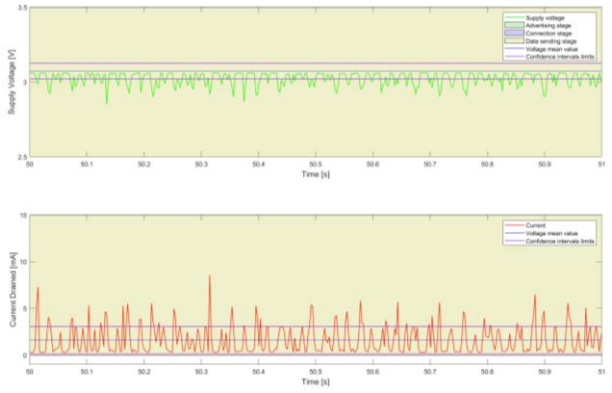

Figure 7.1.4.10 – Current and voltage 1s plot.

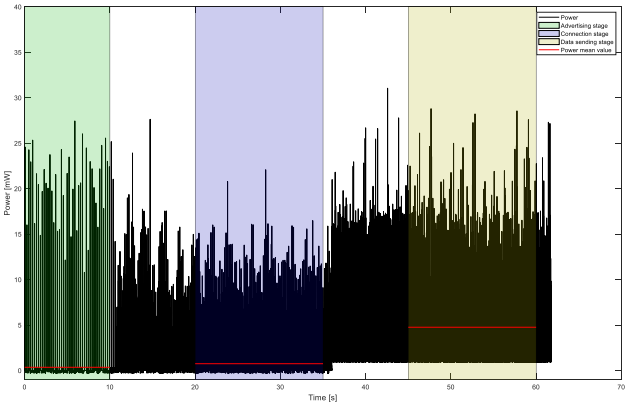

Figure 7.1.4.11 – Calculated power data plot.

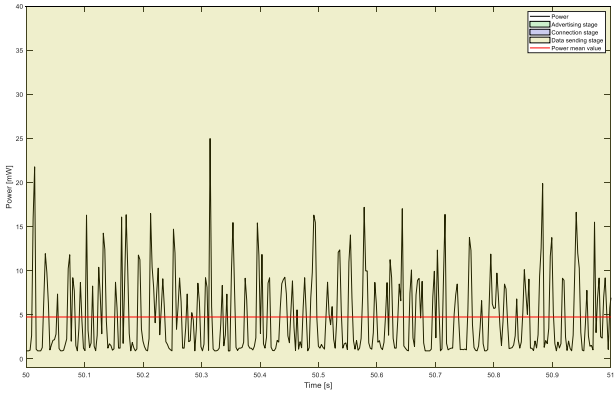

Figure 7.1.4.12 – Power data 1s plot.

For repetition number 4 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.1.4.13 and Figure 7.1.4.14 shows a second of the data transmission interval while Figure 7.1.4.15 shows the power calculated and Figure 7.1.4.16 shows a second of the power calculated in the same second of data transmission interval.

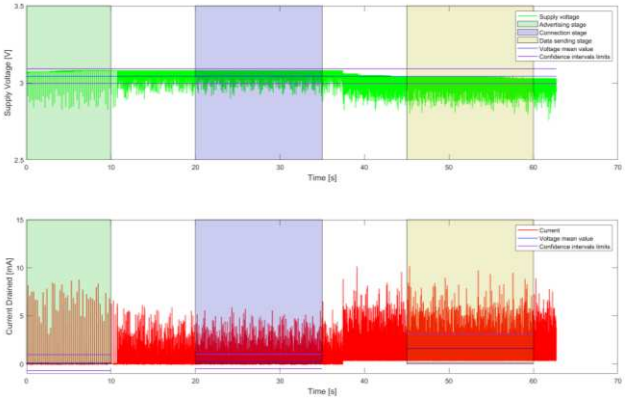

Figure 7.1.3.13 – Voltage and current plot.

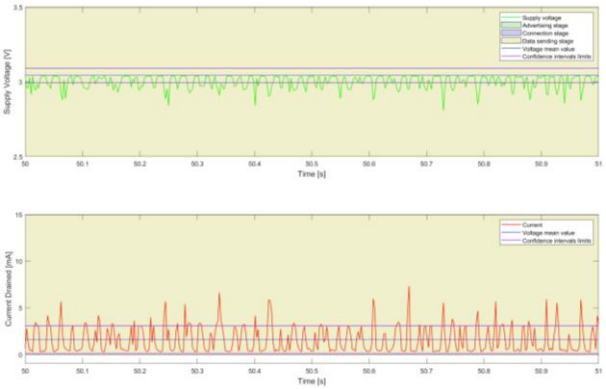

Figure 7.1.3.14 – Current and voltage 1s plot.

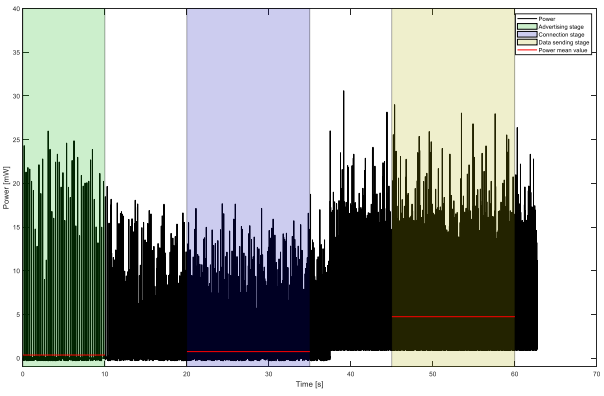

Figure 7.1.4.15 – Calculated power data plot.

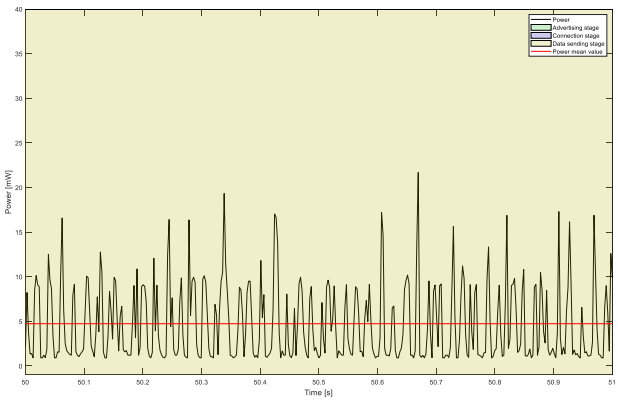

Figure 7.1.4.16 – Power data 1s plot.

For repetition number 5 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.1.4.17 and Figure 7.1.4.18 shows a second of the data transmission interval while Figure 7.1.4.19 shows the power calculated and Figure 7.1.4.20 shows a second of the power calculated in the same second of data transmission interval.

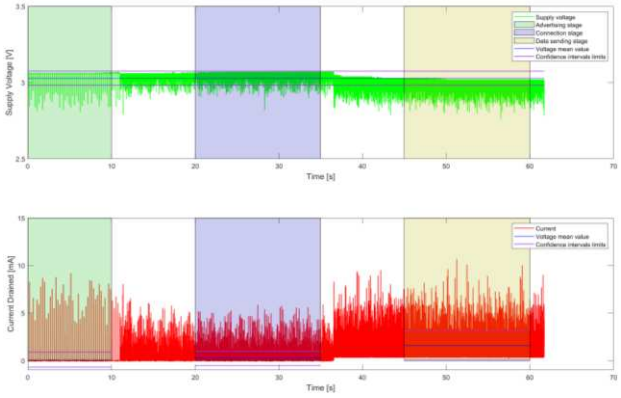

Figure 7.1.4.17 – Voltage and current plot.

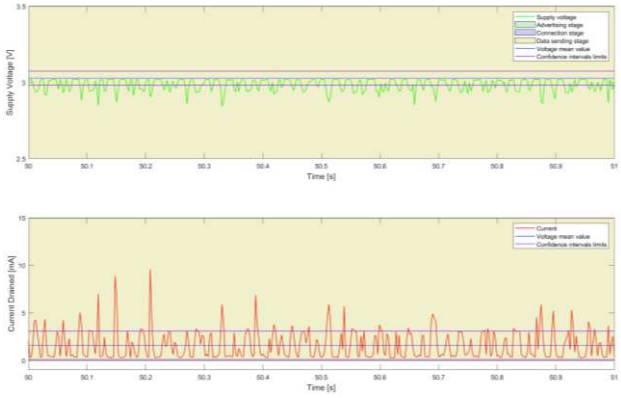

Figure 7.1.4.18 – Current and voltage 1s plot.

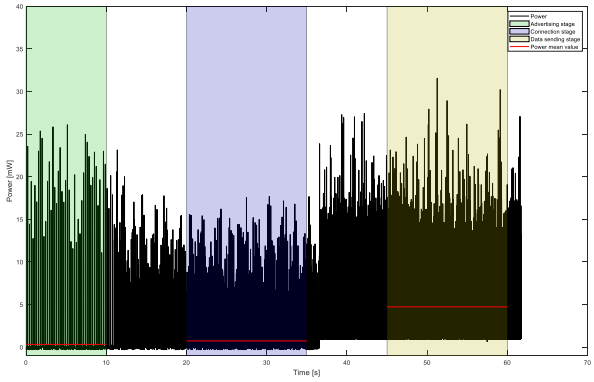

Figure 7.1.4.19 – Calculated power data plot.

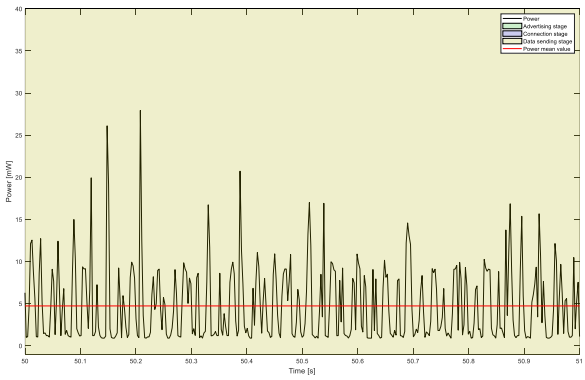

Figure 7.1.4.20 – Power data 1s plot.

Table 7.1.4.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.1.4.1 – Electrical values with accelerometer and magnetometer sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.120	9.046	3.15	0.245	5.539	3.14	1.600	9.349	3.09
2	0.113	8.730	3.13	0.268	6.244	3.12	1.594	10.085	3.08
3	0.118	9.020	3.12	0.243	7.545	3.12	1.589	9.795	3.07
4	0.119	8.784	3.08	0.244	5.888	3.08	1.595	10.159	3.04
5	0.110	9.205	3.07	0.240	5.874	3.07	1.598	10.694	3.03

7.1.5 Accelerometer and proximity sensors active power test

For repetition number 1 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.1.5.1 and Figure 7.1.5.2 shows a second of the data transmission interval while Figure 7.1.5.3 shows the power calculated and Figure 7.1.5.4 shows a second of the power calculated in the same second of data transmission interval.

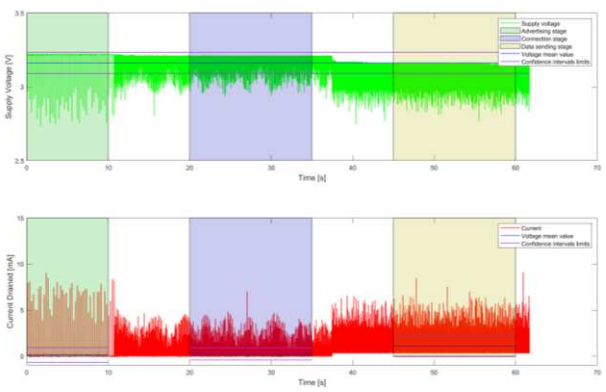

Figure 7.1.5.1 – Voltage and current plot.

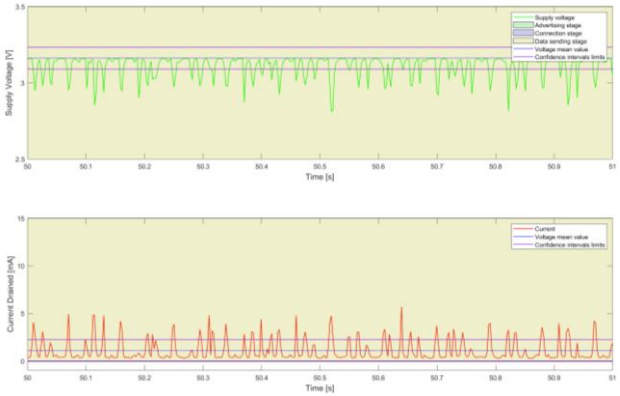

Figure 7.1.5.2 – Current and voltage 1s plot.

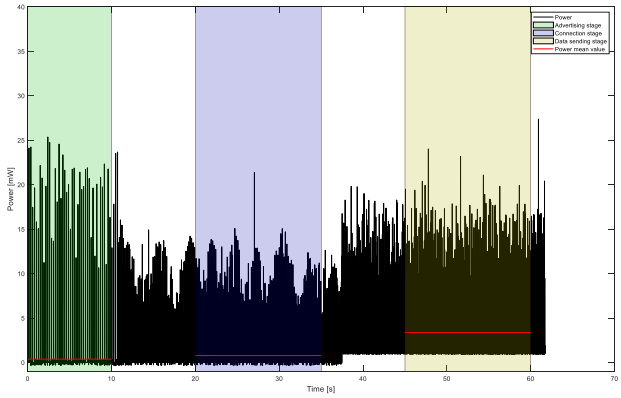

Figure 7.1.5.3 – Calculated power plot.

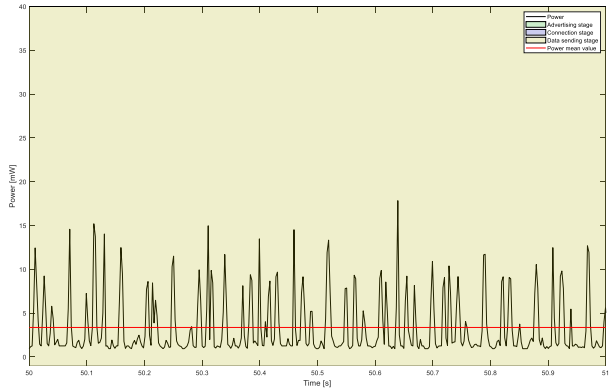

Figure 7.1.5.4 – Power data 1s plot.

For repetition number 2 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.1.5.5 and Figure 7.1.5.6 shows a second of the data transmission interval while Figure 7.1.5.7 shows the power calculated and Figure 7.1.5.8 shows a second of the power calculated in the same second of data transmission interval.

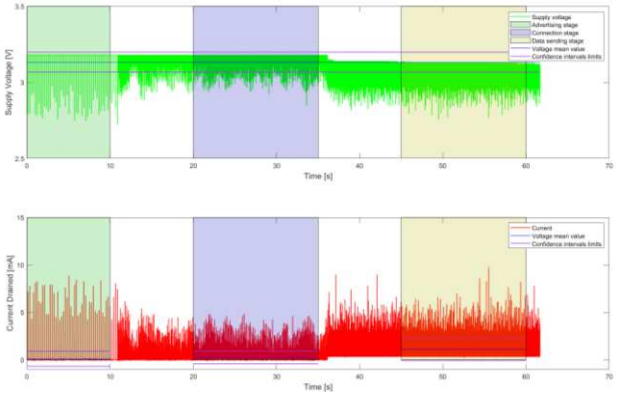

Figure 7.1.5.5 – Voltage and current plot.

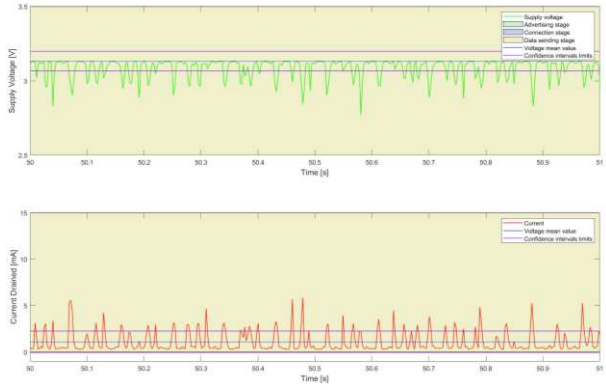

Figure 7.1.5.6 – Current and voltage 1s plot.

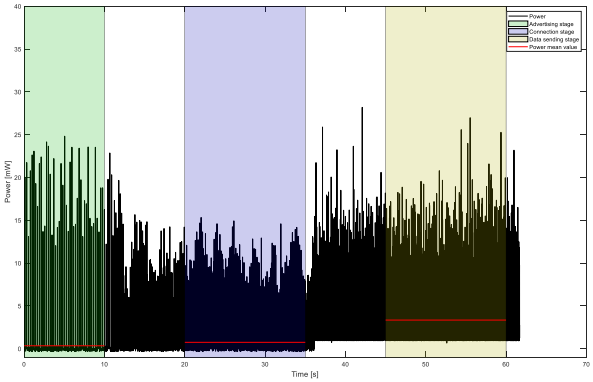

Figure 7.1.5.7 – Calculated power plot.

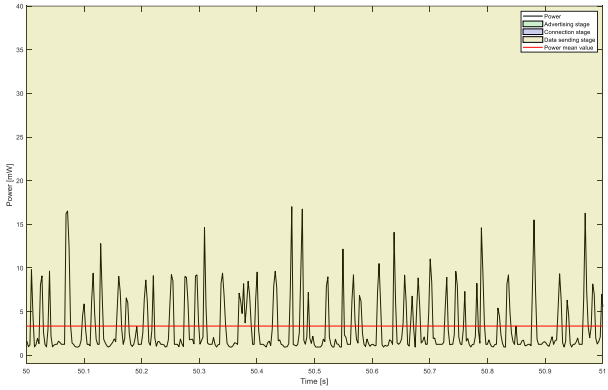

Figure 7.1.5.8 – Power data 1s plot.

For repetition number 3 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.1.5.9 and Figure 7.1.5.10 shows a second of the data transmission interval while Figure 7.1.5.11 shows the power calculated and Figure 7.1.5,12 shows a second of the power calculated in the same second of data transmission interval.

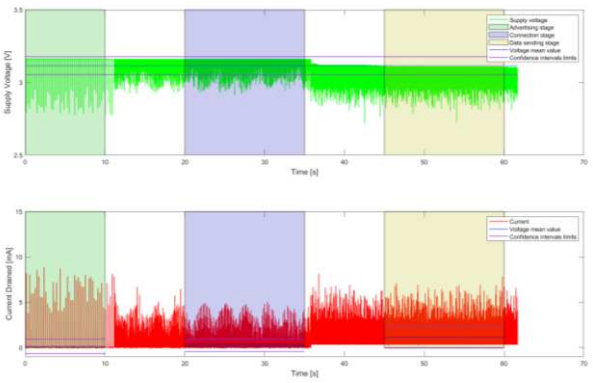

Figure 7.1.5.9 – Voltage and current plot.

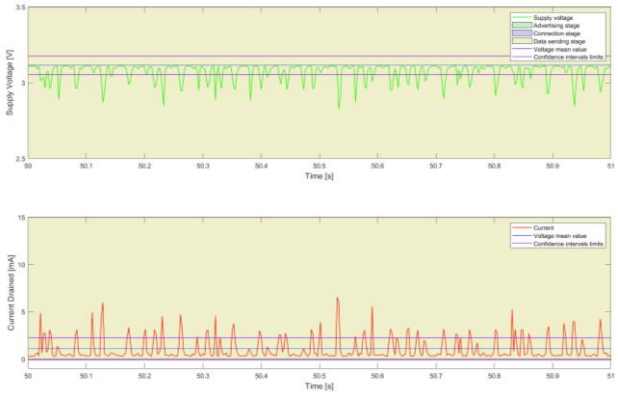

Figure 7.1.5.10 – Current and voltage 1s plot.

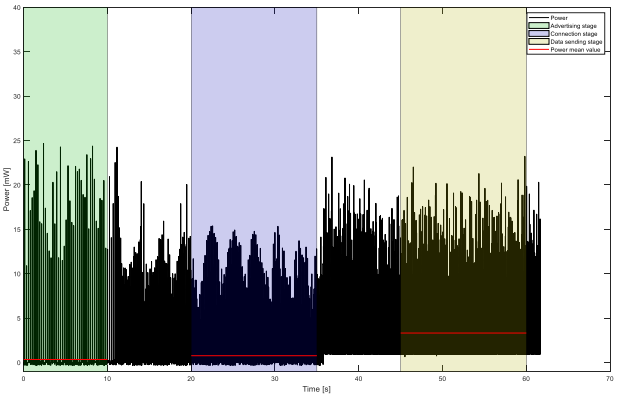

Figure 7.1.5.11 – Calculated power data plot.

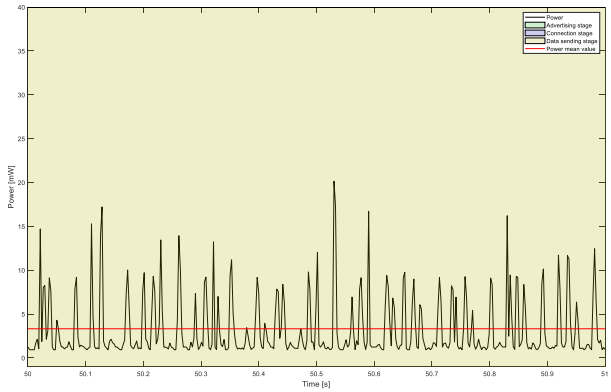

Figure 7.1.5.12 – Power data 1s plot.

For repetition number 4 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.1.5.13 and Figure 7.1.5.14 shows a second of the data transmission interval while Figure 7.1.5.15 shows the power calculated and Figure 7.1.5.16 shows a second of the power calculated in the same second of data transmission interval.

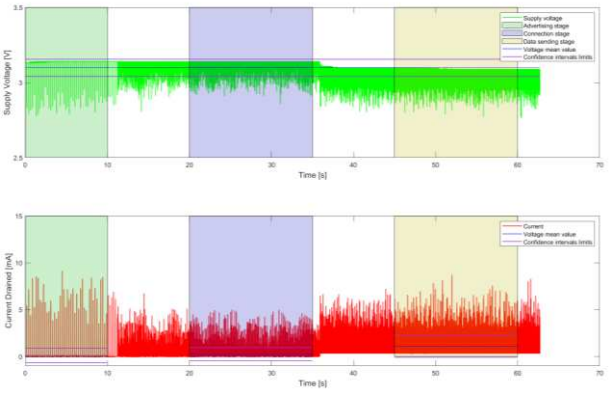

Figure 7.1.5.13 – Voltage and current plot.

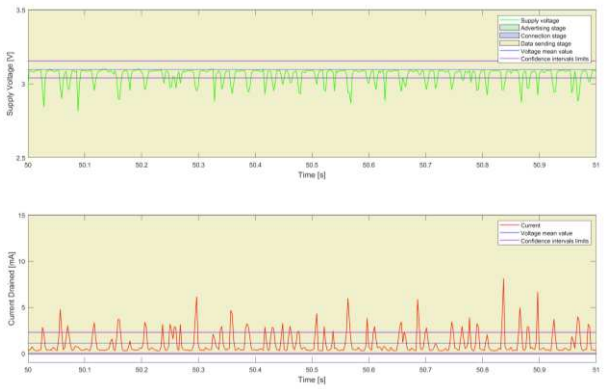

Figure 7.1.5.14 – Current and voltage 1s plot.

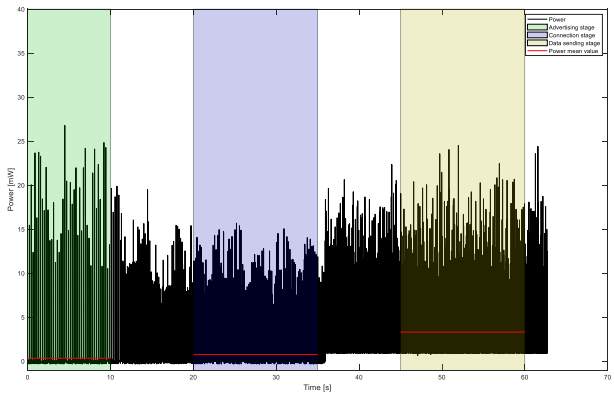

Figure 7.1.5.15 – Calculated power data plot.

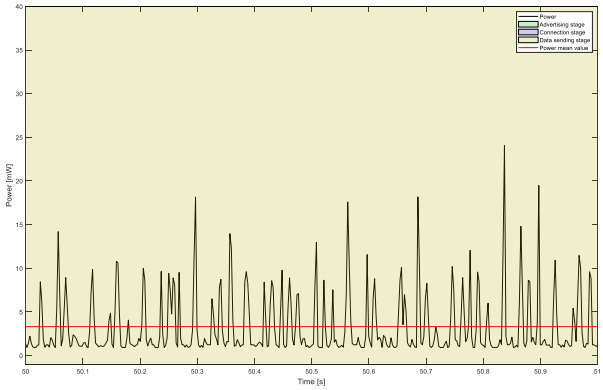

Figure 7.1.5.16 – Power data 1s plot.

For repetition number 5 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.1.5.17 and Figure 7.1.5.18 shows a second of the data transmission interval while Figure 7.1.5.19 shows the power calculated and Figure 7.1.5.20 shows a second of the power calculated in the same second of data transmission interval.

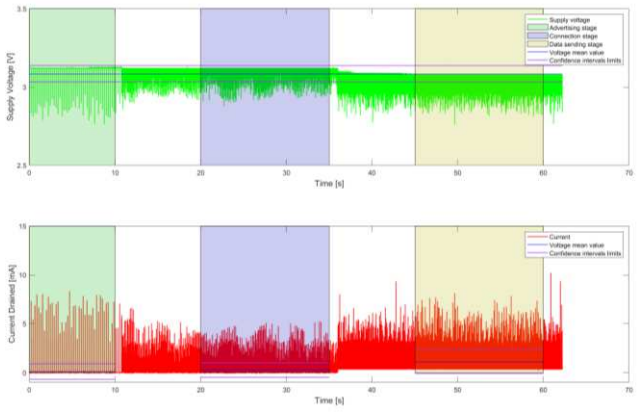

Figure 7.1.5.17 – Voltage and current plot.

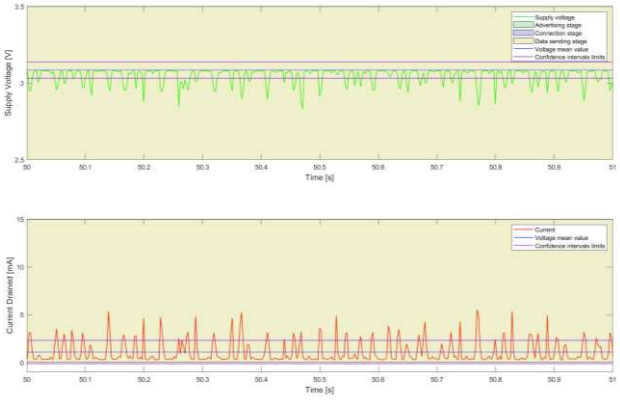

Figure 7.1.5.18 – Current and voltage 1s plot.

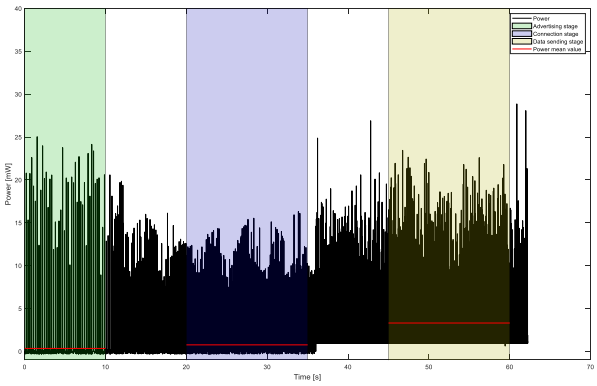

Figure 7.1.5.19 – Calculated power data plot.

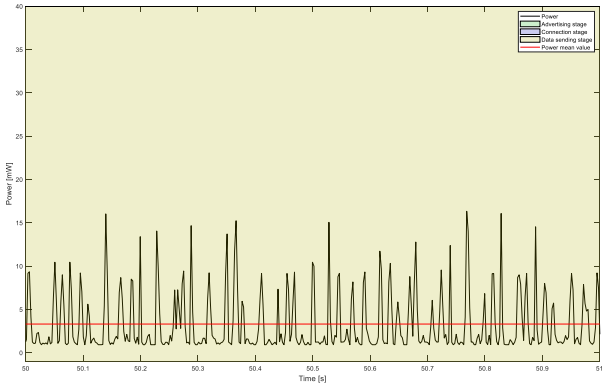

Figure 7.1.5.20 – Power data 1s plot.

Table 7.1.5.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.1.5.1 – Electrical values with accelerometer and proximity sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.127	9.053	3.22	0.249	6.981	3.21	1.102	8.483	3.16
2	0.116	8.899	3.18	0.239	4.863	3.18	1.101	9.759	3.14
3	0.117	8.828	3.16	0.248	5.029	3.16	1.098	7.798	3.12
4	0.114	9.142	3.14	0.245	4.995	3.14	1.097	8.724	3.10
5	0.116	8.332	3.13	0.247	5.227	3.12	1.100	8.134	3.08

7.1.6 Accelerometer and pedometer sensors active power test

For repetition number 1 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.6.1 and Figure 7.1.6.2 shows a second of the data transmission interval while Figure 7.1.6.3 shows the power calculated and Figure 7.1.6.4 shows a second of the power calculated in the same second of data transmission interval.

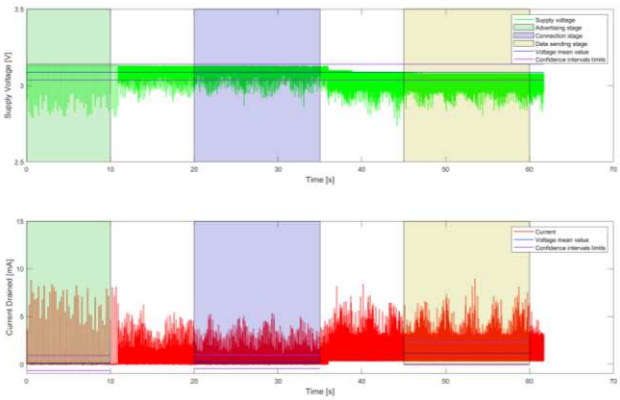

Figure 7.1.6.1 – Voltage and current plot.

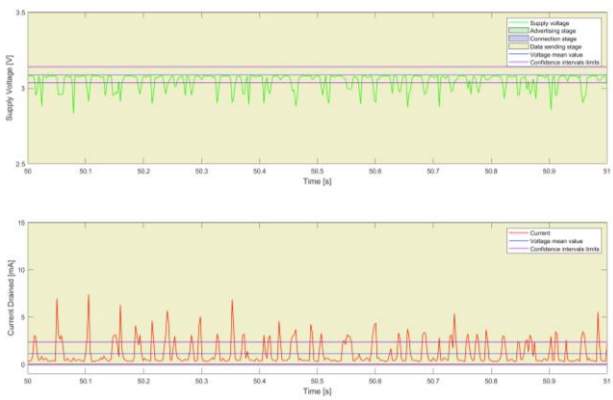

Figure 7.1.6.2 – Current and voltage 1s plot.

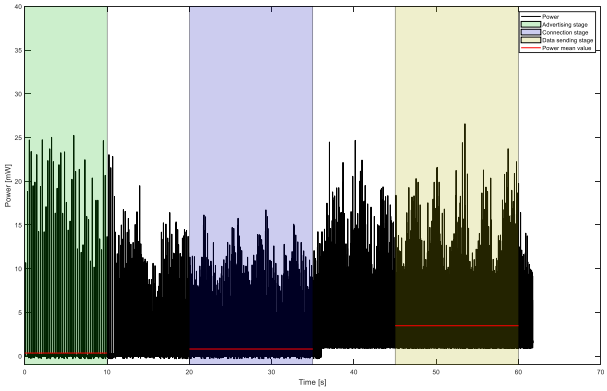

Figure 7.1.6.3 – Calculated power plot.

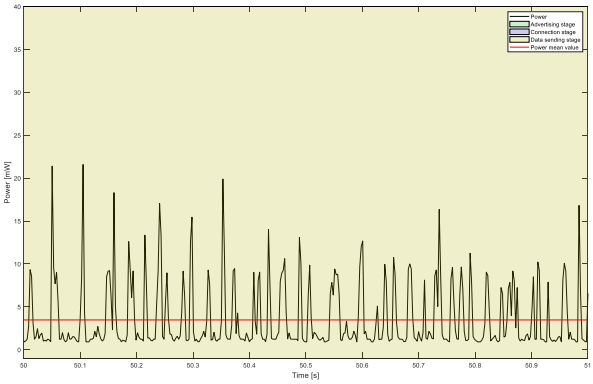

Figure 7.1.6.4 – Power data 1s plot.

For repetition number 2 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.6.5 and Figure 7.1.6.6 shows a second of the data transmission interval while Figure 7.1.6.7 shows the power calculated and Figure 7.1.6.8 shows a second of the power calculated in the same second of data transmission interval.

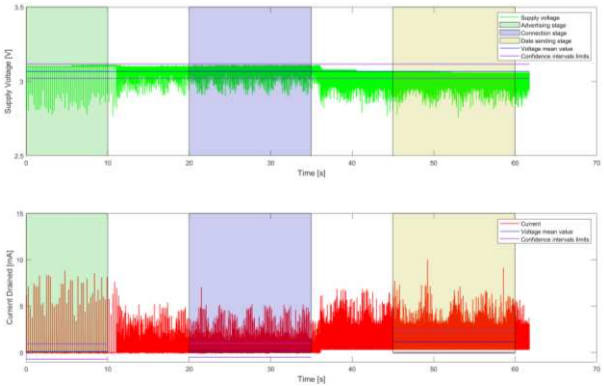

Figure 7.1.6.5 – Voltage and current plot.

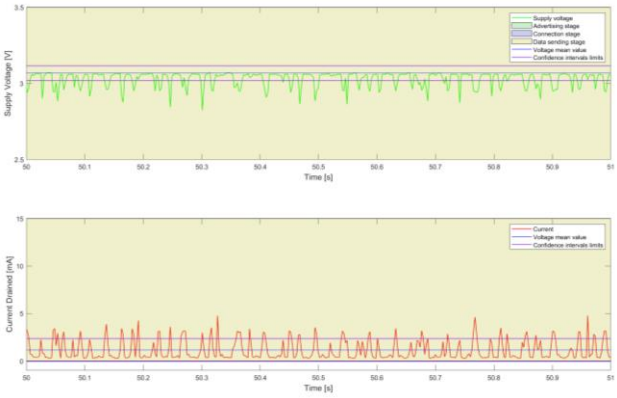

Figure 7.1.6.6 – Current and voltage 1s plot.

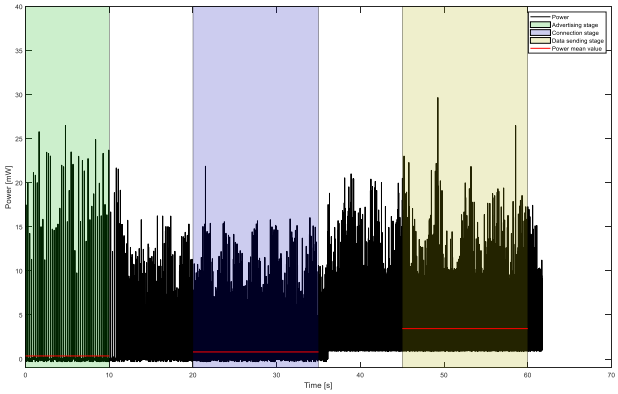

Figure 7.1.6.7 – Calculated power plot.

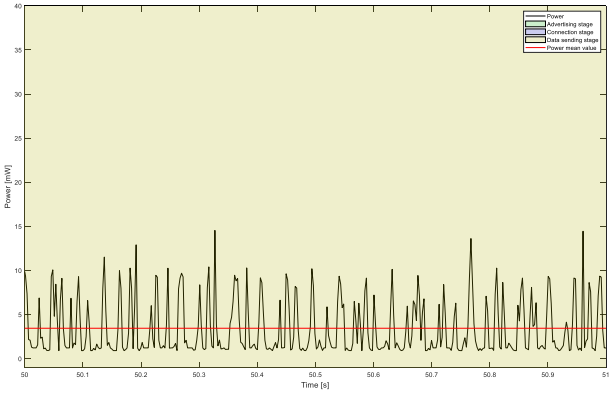

Figure 7.1.6.8 – Power data 1s plot.

For repetition number 3 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.6.9 and Figure 7.1.6.10 shows a second of the data transmission interval while Figure 7.1.6.11 shows the power calculated and Figure 7.1.6,12 shows a second of the power calculated in the same second of data transmission interval.

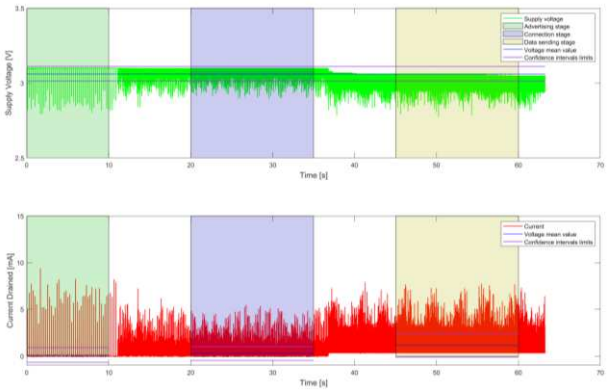

Figure 7.1.6.9 – Voltage and current plot.

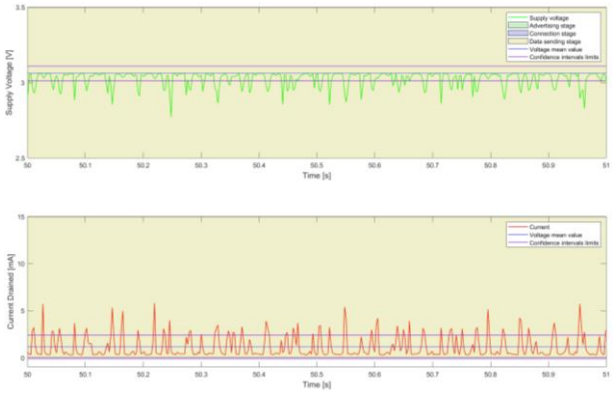

Figure 7.1.6.10 – Current and voltage 1s plot.

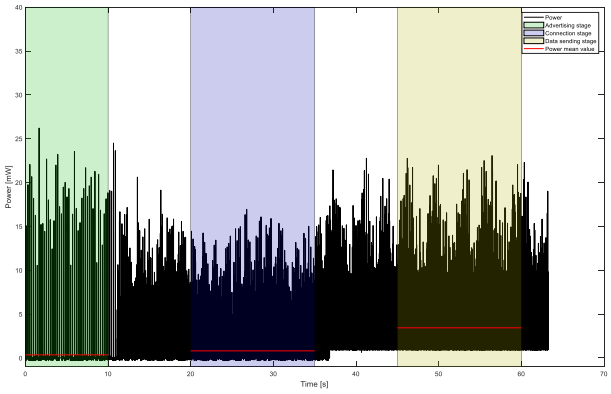

Figure 7.1.6.11 – Calculated power data plot.

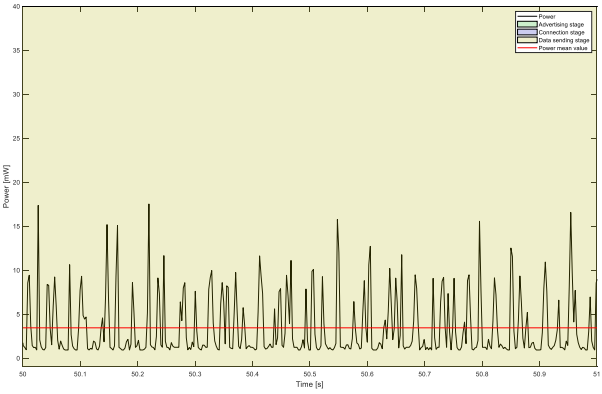

Figure 7.1.6.12 – Power data 1s plot.

For repetition number 4 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.6.13 and Figure 7.1.6.14 shows a second of the data transmission interval while Figure 7.1.6.15 shows the power calculated and Figure 7.1.6.16 shows a second of the power calculated in the same second of data transmission interval.

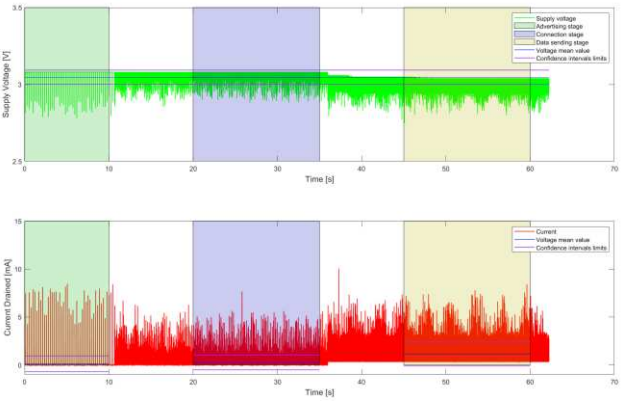

Figure 7.1.6.13 – Voltage and current plot.

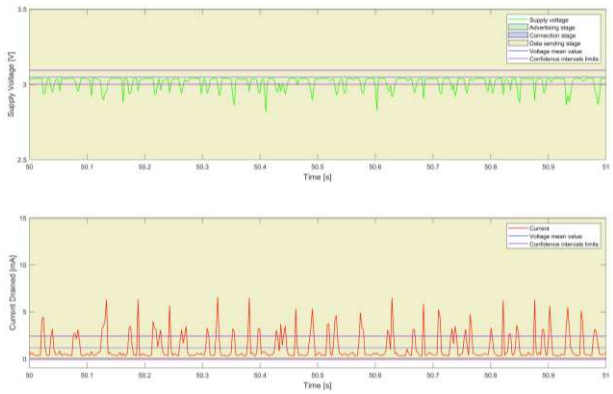

Figure 7.1.6.14 – Current and voltage 1s plot.

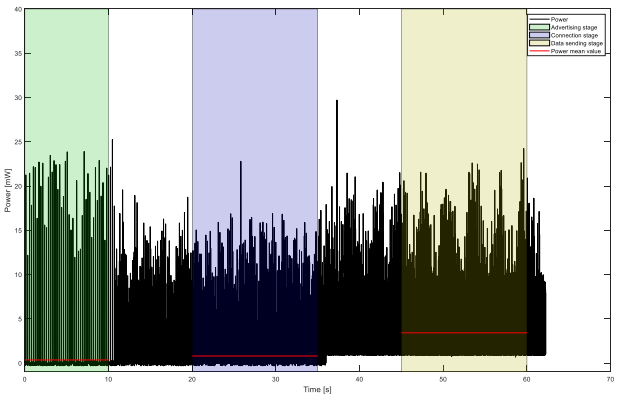

Figure 7.1.6.15 – Calculated power data plot.

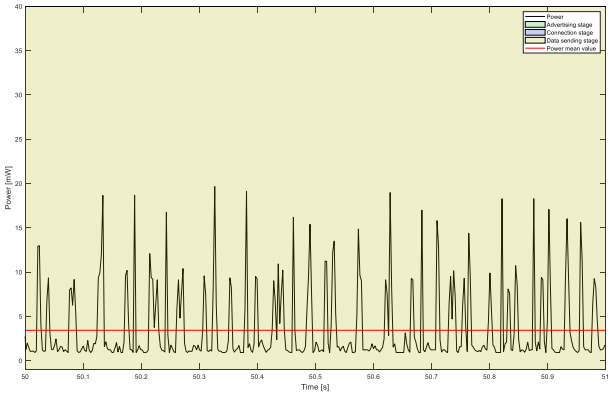

Figure 7.1.6.16 – Power data 1s plot.

For repetition number 5 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.6.17 and Figure 7.1.6.18 shows a second of the data transmission interval while Figure 7.1.6.19 shows the power calculated and Figure 7.1.6.20 shows a second of the power calculated in the same second of data transmission interval.

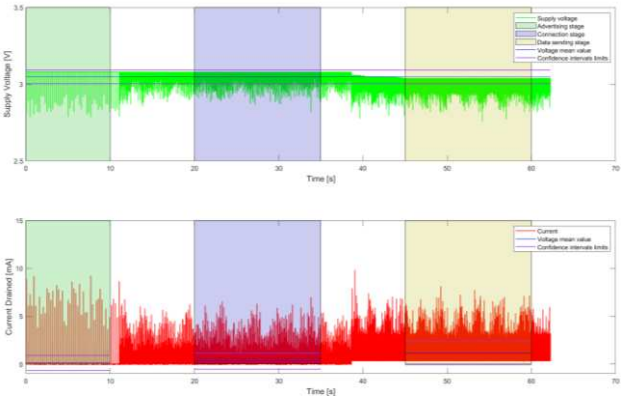

Figure 7.1.6.17 – Voltage and current plot.

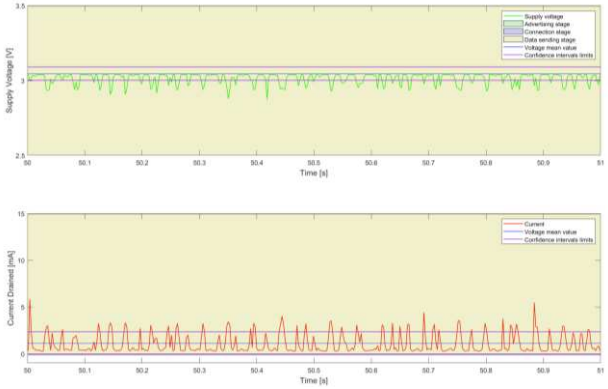

Figure 7.1.6.18 – Current and voltage 1s plot.

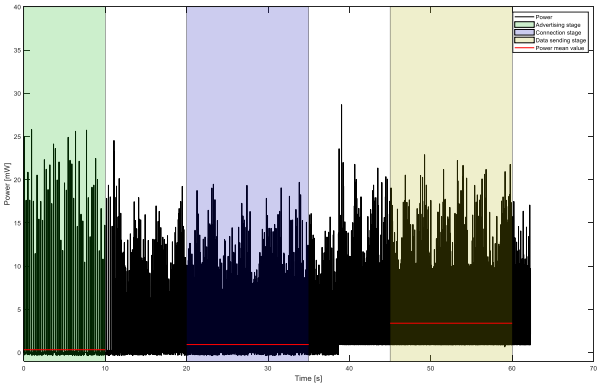

Figure 7.1.6.19 – Calculated power data plot.

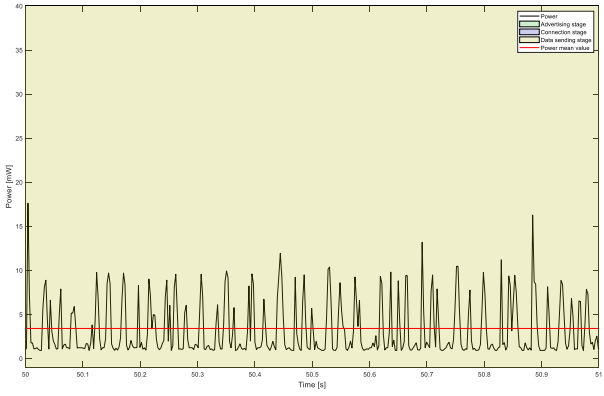

Figure 7.1.6.20 – Power data 1s plot.

Table 7.1.6.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.1.6.1 – Electrical values with accelerometer and pedometer sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.119	8.850	3.13	0.264	5.360	3.13	1.154	8.987	3.09
2	0.119	8.858	3.11	0.263	7.057	3.11	1.151	10.012	3.07
3	0.121	9.393	3.10	0.265	5.484	3.10	1.149	7.740	3.06
4	0.122	8.453	3.08	0.265	7.651	3.08	1.147	8.393	3.05
5	0.114	9.243	3.08	0.308	6.986	3.08	1.140	8.133	3.04

7.1.7 Just accelerometer active power test

For repetition number 1 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.7.1 and Figure 7.1.7.2 shows a second of the data transmission interval while Figure 7.1.7.3 shows the power calculated and Figure 7.1.7.4 shows a second of the power calculated in the same second of data transmission interval.

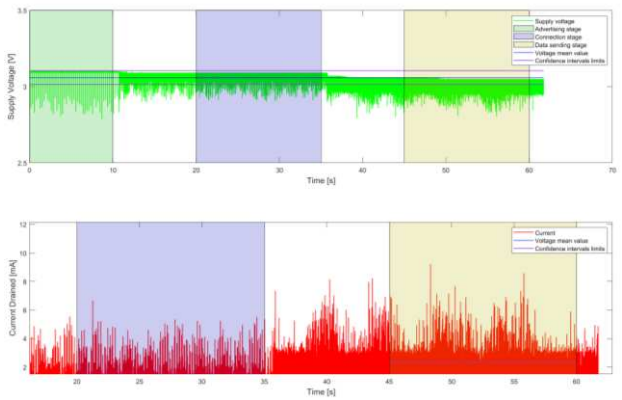

Figure 7.1.7.1 – Voltage and current plot.

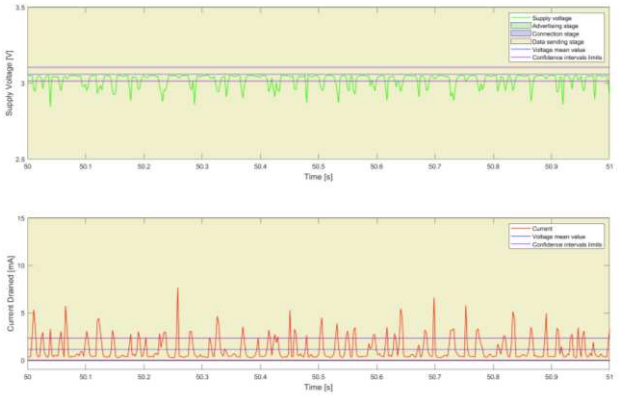

Figure 7.1.7.2 – Current and voltage 1s plot.

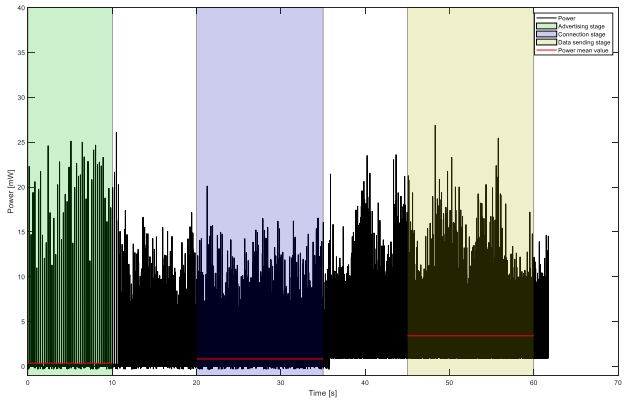

Figure 7.1.7.3 – Calculated power plot.

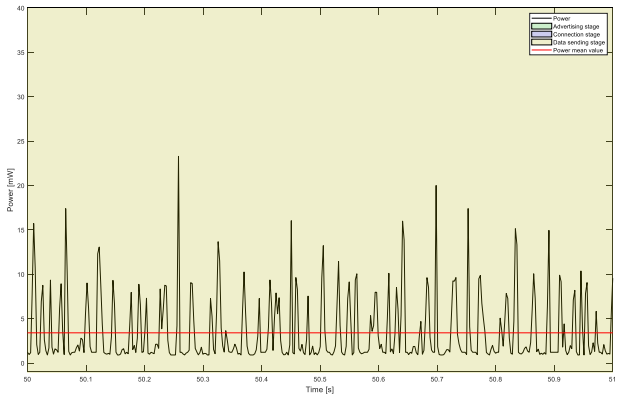

Figure 7.1.7.4 – Power data 1s plot.

For repetition number 2 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.7.5 and Figure 7.1.7.6 shows a second of the data transmission interval while Figure 7.1.7.7 shows the power calculated and Figure 7.1.7.8 shows a second of the power calculated in the same second of data transmission interval.

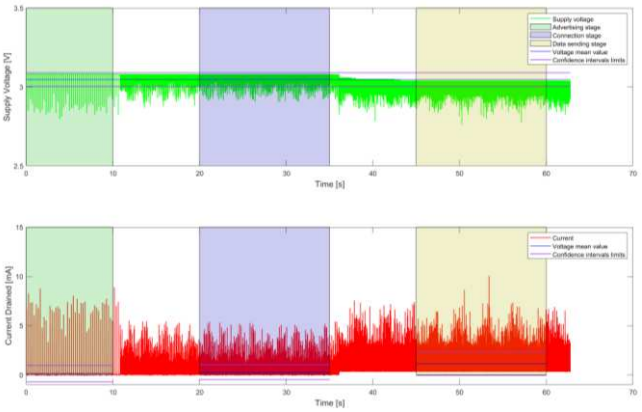

Figure 7.1.7.5 – Voltage and current plot.

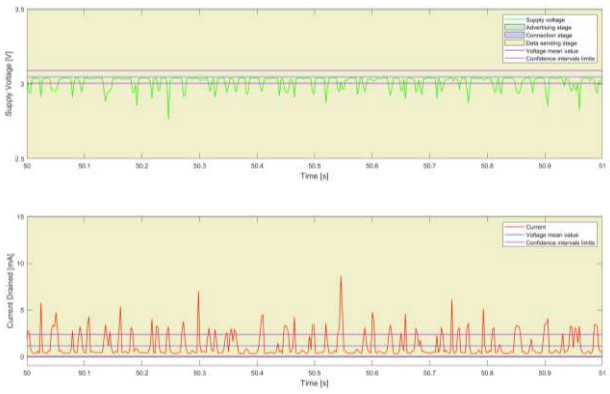

Figure 7.1.7.6 – Current and voltage 1s plot.

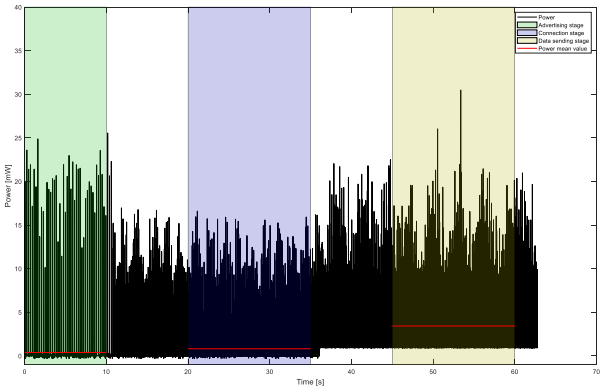

Figure 7.1.7.7 – Calculated power plot.

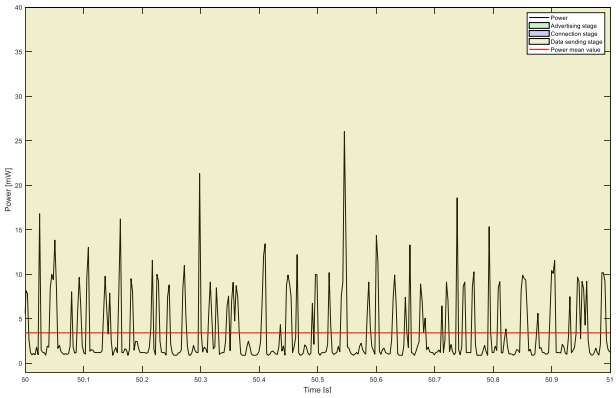

Figure 7.1.7.8 – Power data 1s plot.

For repetition number 3 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.7.9 and Figure 7.1.7.10 shows a second of the data transmission interval while Figure 7.1.7.11 shows the power calculated and Figure 7.1.7,12 shows a second of the power calculated in the same second of data transmission interval.

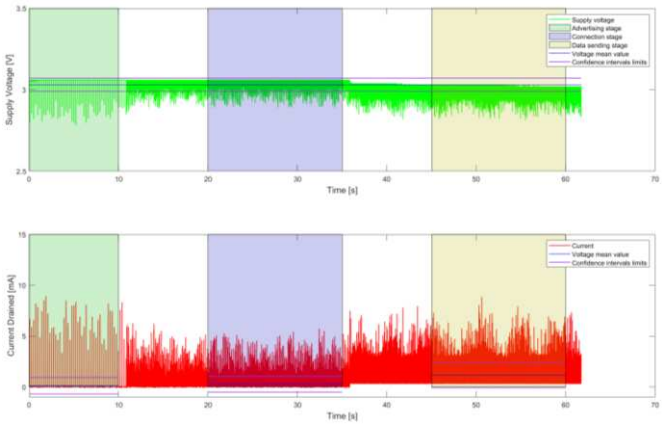

Figure 7.1.7.9 – Voltage and current plot.

Figure 7.1.7.10 – Current and voltage 1s plot.

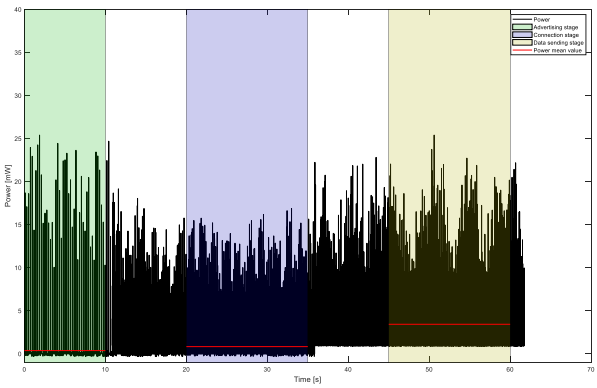

Figure 7.1.7.11 – Calculated power data plot.

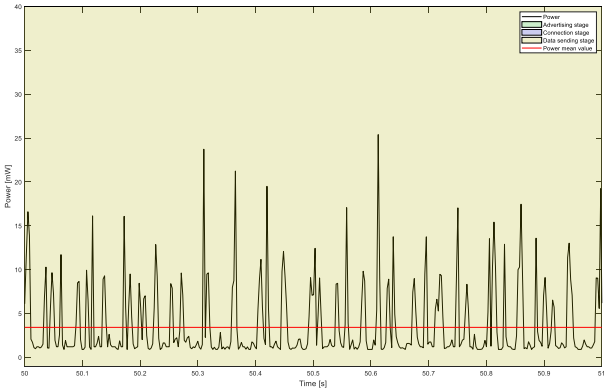

Figure 7.1.7.12 – Power data 1s plot.

For repetition number 4 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.7.13 and Figure 7.1.7.14 shows a second of the data transmission interval while Figure 7.1.7.15 shows the power calculated and Figure 7.1.7.16 shows a second of the power calculated in the same second of data transmission interval.

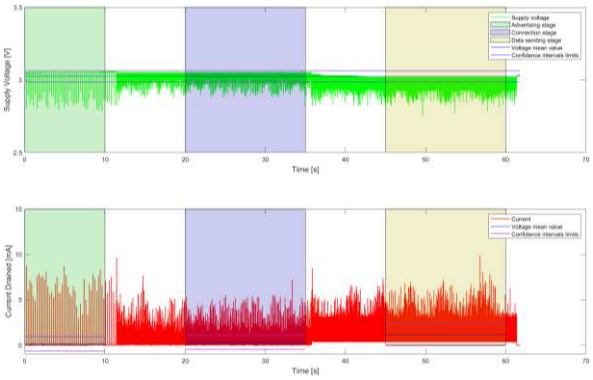

Figure 7.1.7.13 – Voltage and current plot.

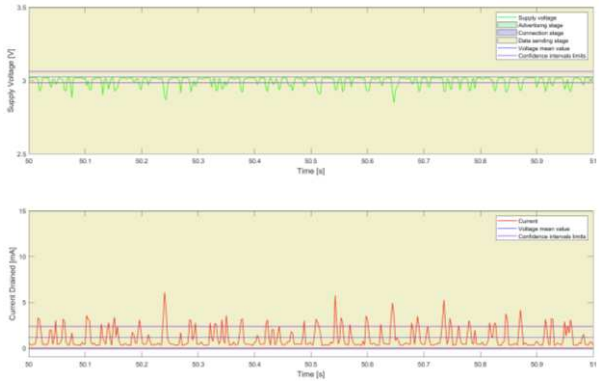

Figure 7.1.7.14 – Current and voltage 1s plot.

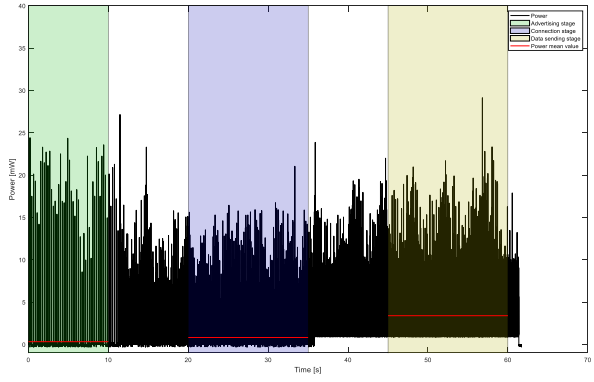

Figure 7.1.7.15 – Calculated power data plot.

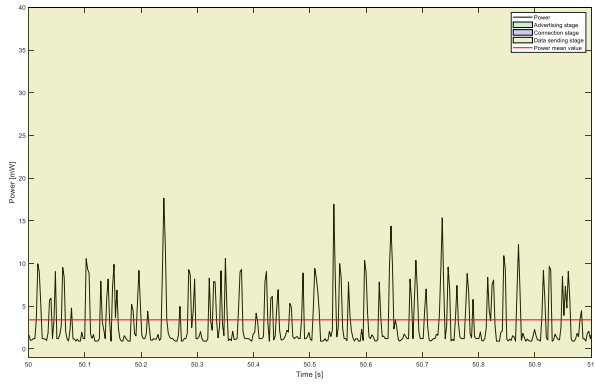

Figure 7.1.7.16 – Power data 1s plot.

For repetition number 5 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.1.7.17 and Figure 7.1.7.18 shows a second of the data transmission interval while Figure 7.1.7.19 shows the power calculated and Figure 7.1.7.20 shows a second of the power calculated in the same second of data transmission interval.

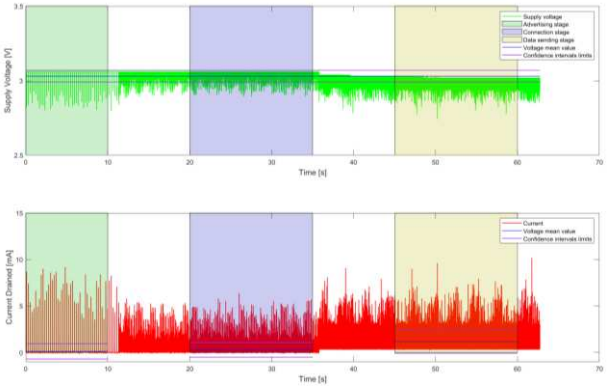

Figure 7.1.7.17 – Voltage and current plot.

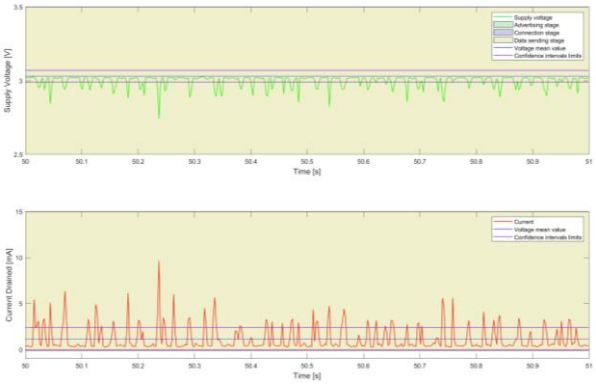

Figure 7.1.7.18 – Current and voltage 1s plot.

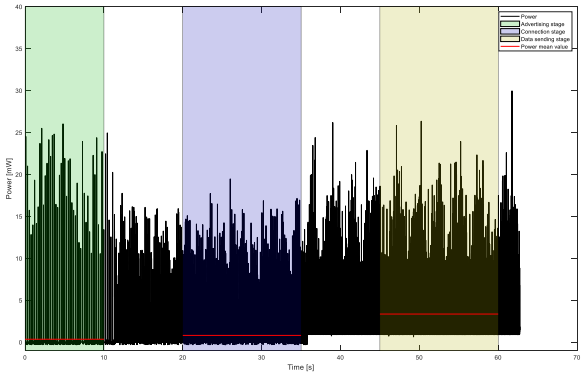

Figure 7.1.7.19 – Calculated power data plot.

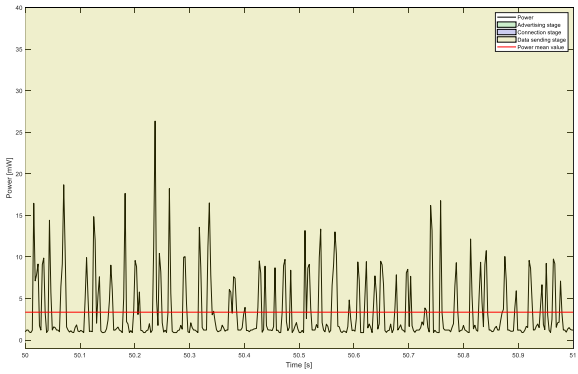

Figure 7.1.7.20 – Power data 1s plot.

Table 7.1.7.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.1.7.1 – Electrical values with just the accelerometer sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.121	8.867	3.10	0.271	6.680	3.09	1.139	9.220	3.06
2	0.131	8.778	3.08	0.269	5.391	3.08	1.148	10.068	3.04
3	0.126	8.929	3.06	0.274	5.736	3.06	1.151	8.872	3.03
4	0.115	8.724	3.06	0.275	7.197	3.06	1.148	9.137	3.02
5	0.121	9.202	3.06	0.269	6.362	3.06	1.129	9.605	3.03

7.2. Tests with data acquisition at 120Hz

The experiment is performed again with the same sensor configurations and respecting the times the program previously defined in section 6.5 to analyse in each stage and that are described in the same section. The accelerometer sensor is originally configured to work at 52 Hz and with an acceleration measurement range of ±16 g. The time that triggers the data acquisition of the accelerometer is set to work at 120Hz or each 6.66ms. Each configuration is considered a test that will be repeated 5 times.

7.2.1 All sensors active power test

For repetition number 1 when all sensors are active voltage and current measured data is shown in Figure 7.2.1.1 and Figure 7.2.1.2 shows a second of the data transmission interval while Figure 7.2.1.3 shows the power calculated and Figure 7.2.1.4 shows a second of the power calculated in the same second of data transmission interval.

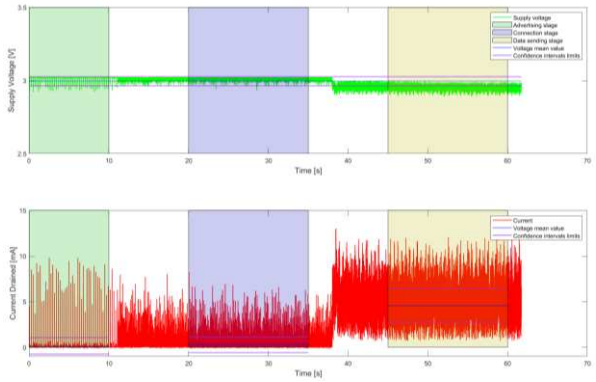

Figure 7.2.1.1 – Voltage and current plot.

Figure 7.2.1.2 – Current and voltage 1s plot.

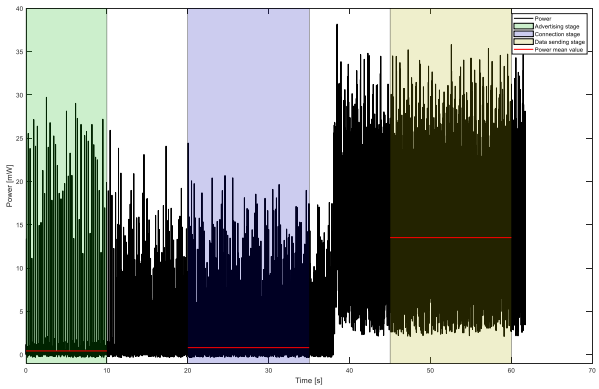

Figure 7.2.1.3 – Calculated power plot.

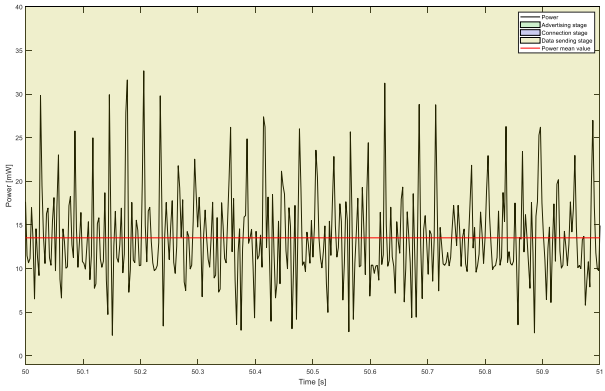

Figure 7.2.1.4 – Power data 1s plot.

For repetition number 2 when all sensors are active voltage and current measured data is shown in Figure 7.2.1.5 and Figure 7.2.1.6 shows a second of the data transmission interval while Figure 7.2.1.7 shows the power calculated and Figure 7.2.1.8 shows a second of the power calculated in the same second of data transmission interval.

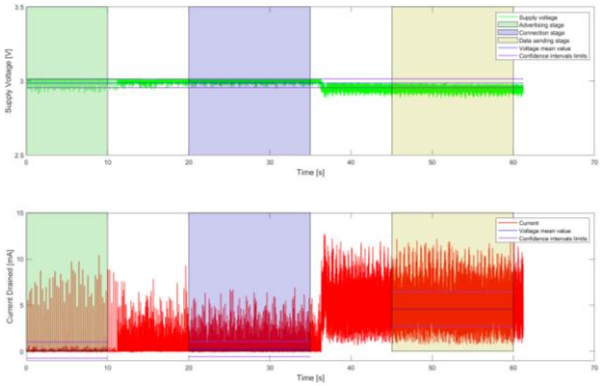

Figure 7.2.1.5 – Voltage and current plot.

Figure 7.2.1.6 – Current and voltage 1s plot.

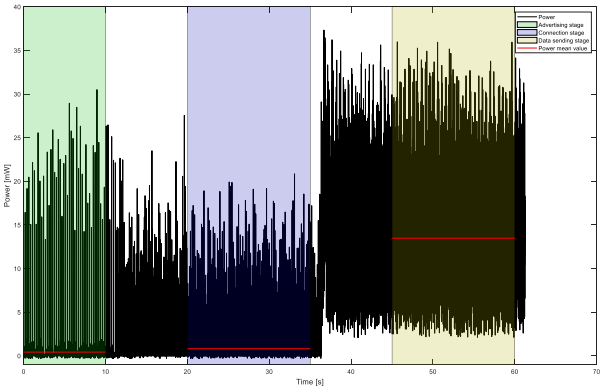

Figure 7.2.1.7 – Calculated power plot.

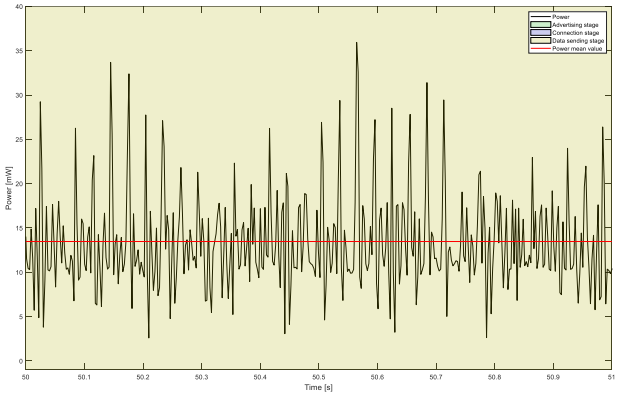

Figure 7.2.1.8 – Power data 1s plot.

For repetition number 3 when all sensors are active voltage and current measured data is shown in Figure 7.2.1.9 and Figure 7.2.1.10 shows a second of the data transmission interval while Figure 7.2.1.11 shows the power calculated and Figure 7.2.1,12 shows a second of the power calculated in the same second of data transmission interval.

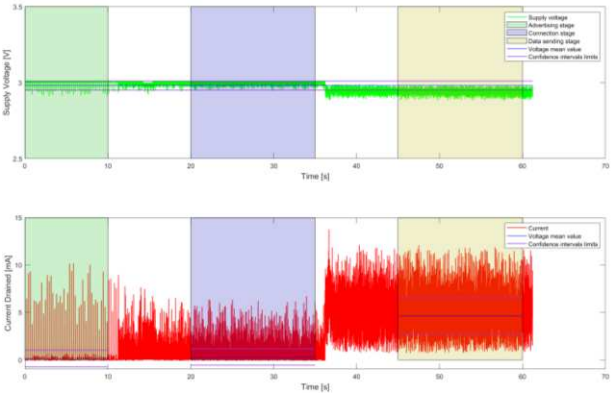

Figure 7.2.1.9 – Voltage and current plot.

Figure 7.2.1.10 – Current and voltage 1s plot.

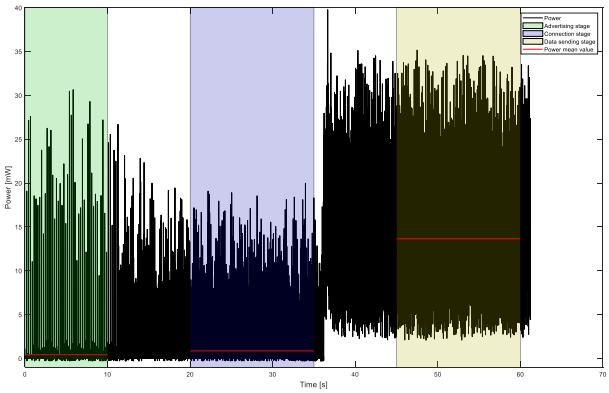

Figure 7.2.1.11 – Calculated power data plot.

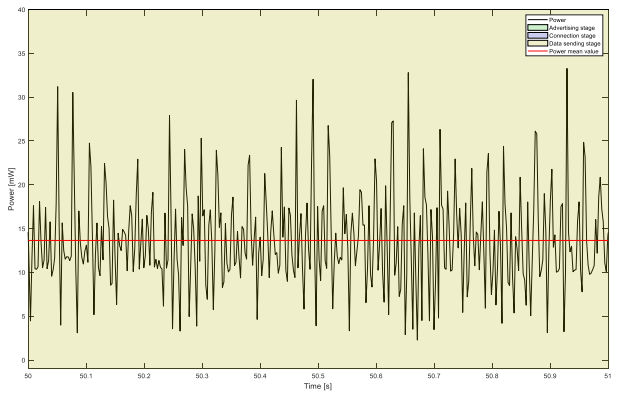

Figure 7.2.1.12 – Power data 1s plot.

For repetition number 4 when all sensors are active voltage and current measured data is shown in Figure 7.2.1.13 and Figure 7.2.1.14 shows a second of the data transmission interval while Figure 7.2.1.15 shows the power calculated and Figure 7.2.1.16 shows a second of the power calculated in the same second of data transmission interval.

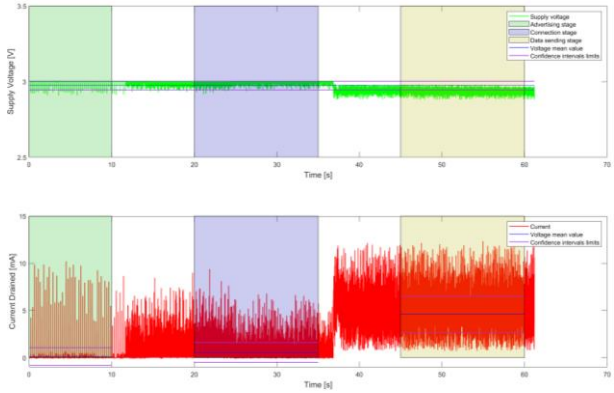

Figure 7.2.1.13 – Voltage and current plot.

Figure 7.2.1.14 – Current and voltage 1s plot.

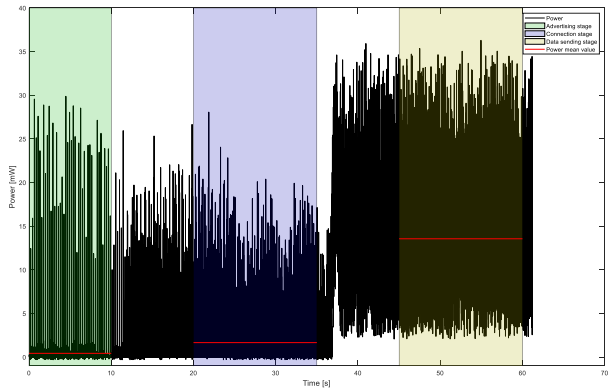

Figure 7.2.1.15 – Calculated power data plot.

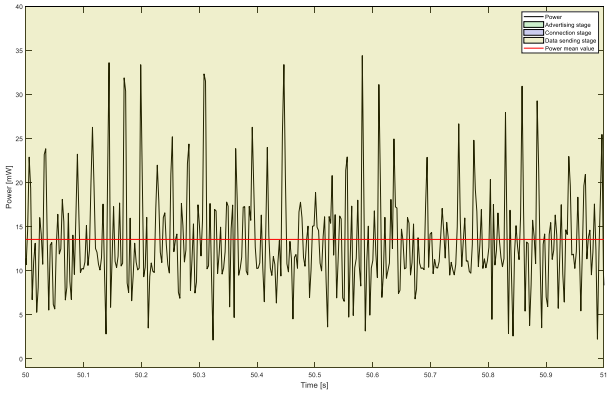

Figure 7.2.1.16 – Power data 1s plot.

For repetition number 5 when all sensors are active voltage and current measured data is shown in Figure 7.2.1.17 and Figure 7.2.1.18 shows a second of the data transmission interval while Figure 7.2.1.19 shows the power calculated and Figure 7.2.1.20 shows a second of the power calculated in the same second of data transmission interval.

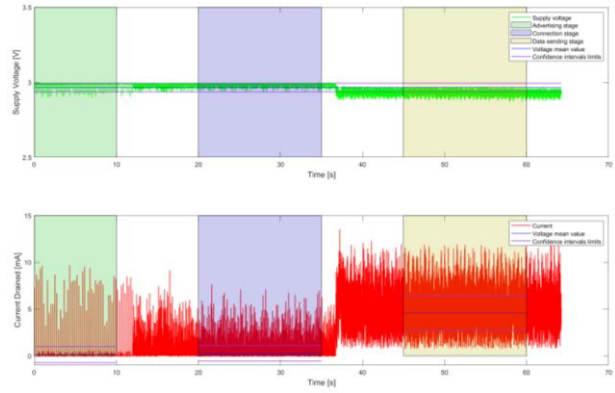

Figure 7.2.1.17 – Voltage and current plot.

Figure 7.2.1.18 – Current and voltage 1s plot.

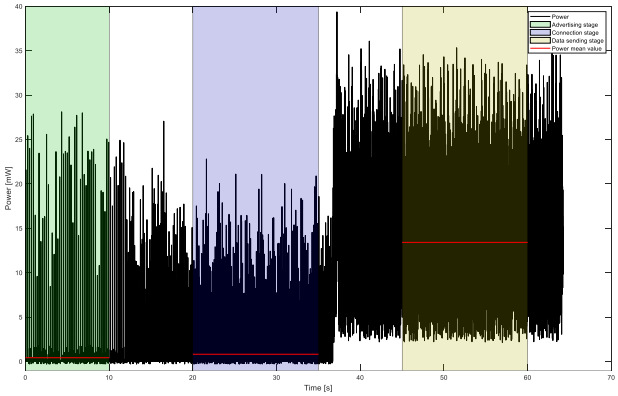

Figure 7.2.1.19 – Calculated power data plot.

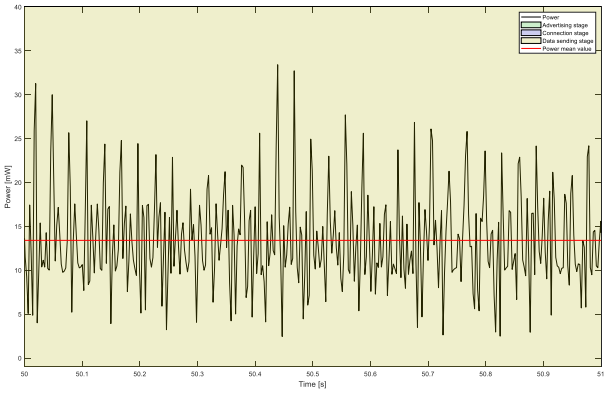

Figure 7.2.1.20 – Power data 1s plot.

Table 7.2.1.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.2.1.1 – Electrical values with all sensors active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.146	9.845	3.02	0.271	8.230	3.02	4.581	12.060	3.00
2	0.142	10.444	3.01	0.271	6.925	3.01	4.571	12.189	2.98
3	0.142	10.191	3.01	0.287	6.704	3.01	4.636	12.088	2.97
4	0.148	10.213	3.00	0.558	9.388	3.00	4.615	12.347	2.98
5	0.140	9.673	2.99	0.270	7.648	2.99	4.575	11.900	2.96

7.2.2 Accelerometer and pressure sensors active power test

For repetition number 1 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.2.2.1 and Figure 7.2.2.2 shows a second of the data transmission interval while Figure 7.2.2.3 shows the power calculated and Figure 7.2.2.4 shows a second of the power calculated in the same second of data transmission interval.

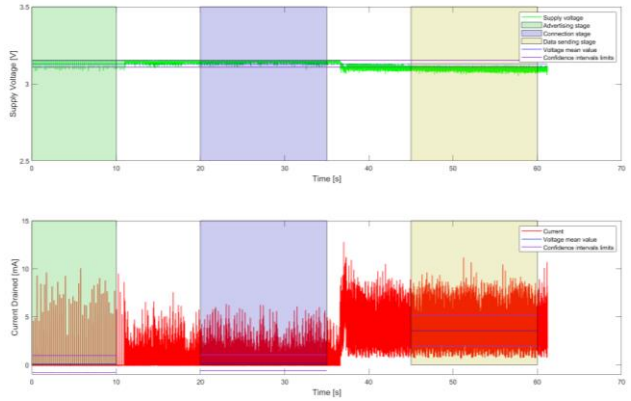

Figure 7.2.2.1 – Voltage and current plot.

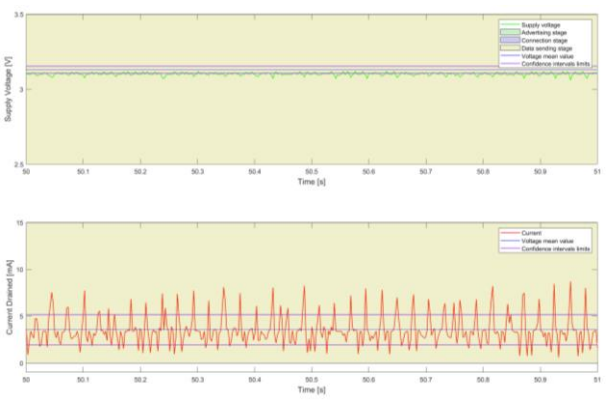

Figure 7.2.2.2 – Current and voltage 1s plot.

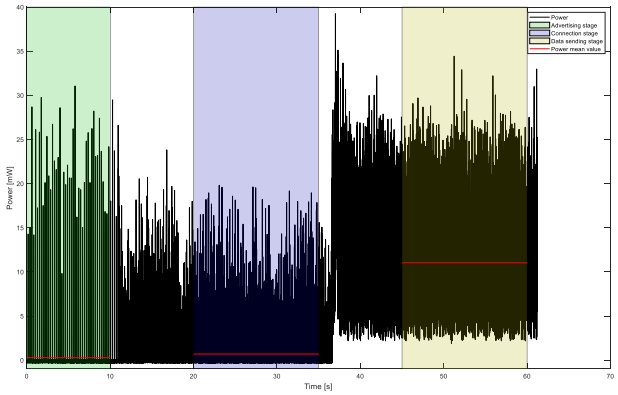

Figure 7.2.2.3 – Calculated power plot.

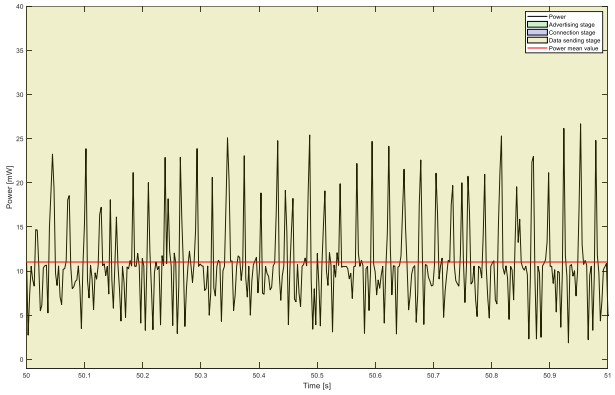

Figure 7.2.2.4 – Power data 1s plot.

For repetition number 2 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.2.2.5 and Figure 7.2.2.6 shows a second of the data transmission interval while Figure 7.2.2.7 shows the power calculated and Figure 7.2.2.8 shows a second of the power calculated in the same second of data transmission interval.

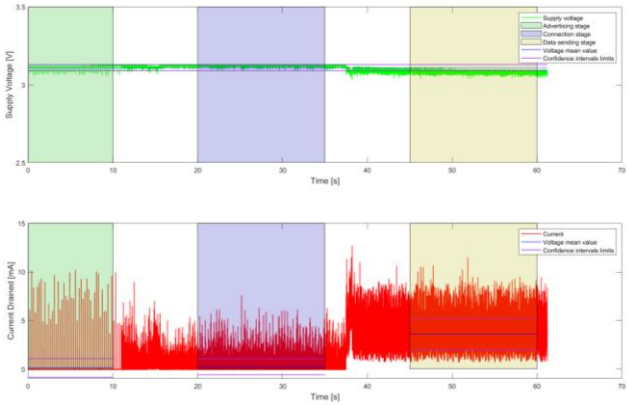

Figure 7.2.2.5 – Voltage and current plot.

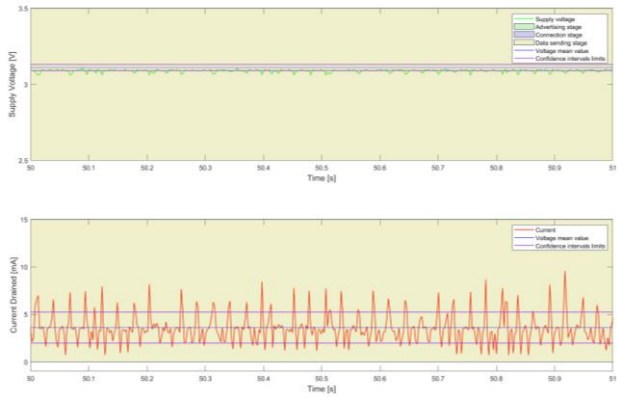

Figure 7.2.2.6 – Current and voltage 1s plot.

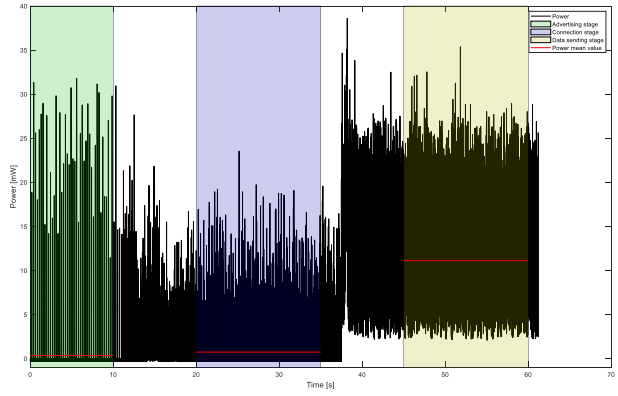

Figure 7.2.2.7 – Calculated power plot.

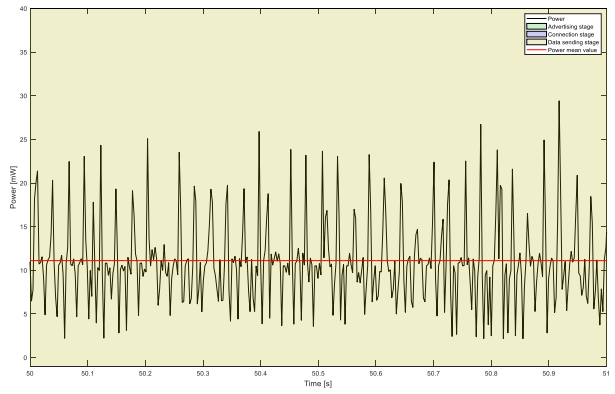

Figure 7.2.2.8 – Power data 1s plot.

For repetition number 3 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.2.2.9 and Figure 7.2.2.10 shows a second of the data transmission interval while Figure 7.2.2.11 shows the power calculated and Figure 7.2.2,12 shows a second of the power calculated in the same second of data transmission interval.

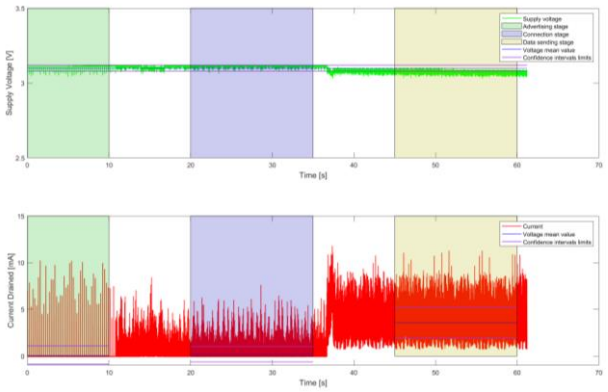

Figure 7.2.2.9 – Voltage and current plot.

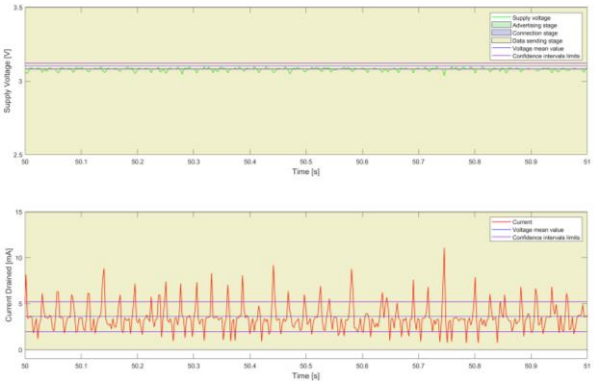

Figure 7.2.2.10 – Current and voltage 1s plot.

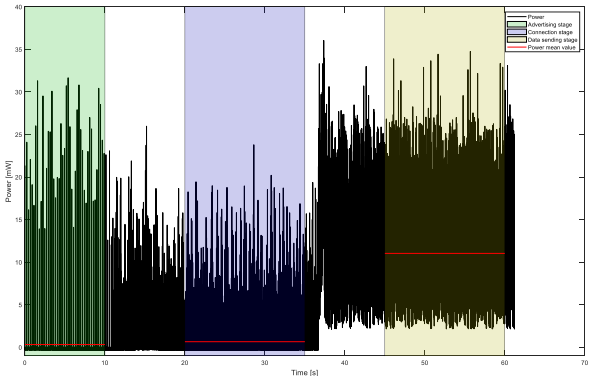

Figure 7.2.2.11 – Calculated power data plot.

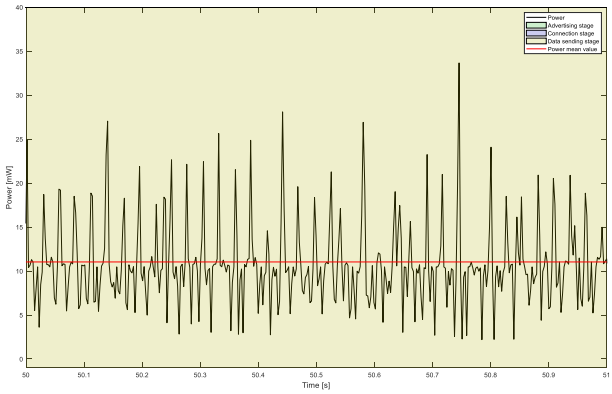

Figure 7.2.2.12 – Power data 1s plot.

For repetition number 4 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.2.2.13 and Figure 7.2.2.14 shows a second of the data transmission interval while Figure 7.2.2.15 shows the power calculated and Figure 7.2.2.16 shows a second of the power calculated in the same second of data transmission interval.

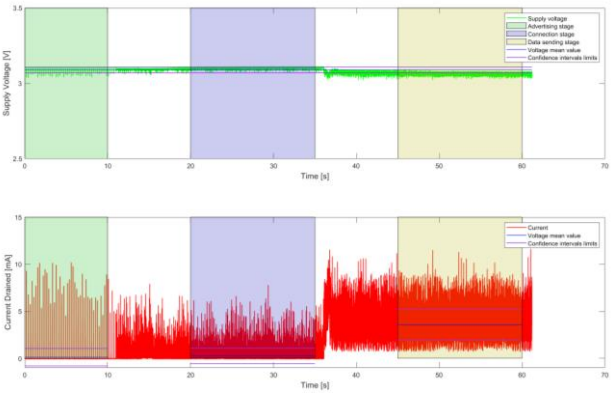

Figure 7.2.2.13 – Voltage and current plot.

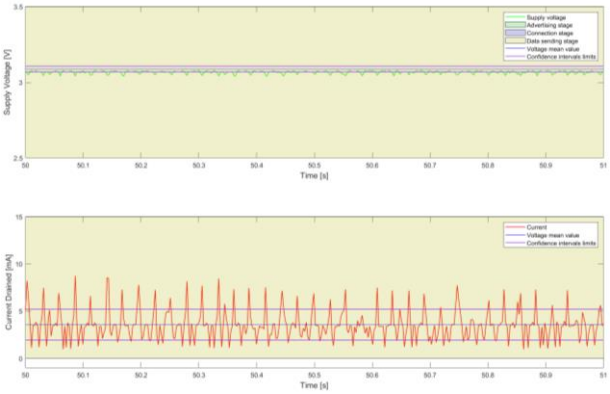

Figure 7.2.2.14 – Current and voltage 1s plot.

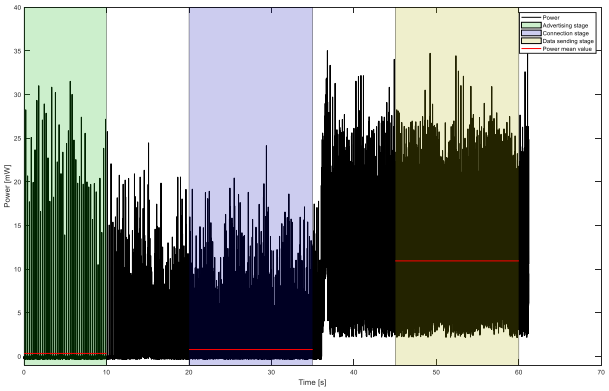

Figure 7.2.2.15 – Calculated power data plot.

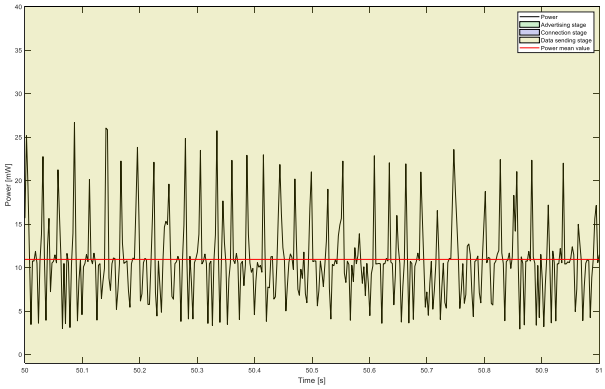

Figure 7.2.2.16 – Power data 1s plot.

For repetition number 5 when accelerometer and pressure sensors are active voltage and current measured data is shown in Figure 7.2.2.17 and Figure 7.2.2.18 shows a second of the data transmission interval while Figure 7.2.2.19 shows the power calculated and Figure 7.2.2.20 shows a second of the power calculated in the same second of data transmission interval.

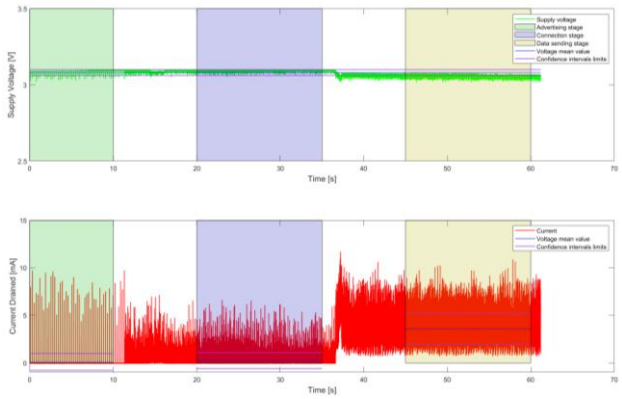

Figure 7.2.2.17 – Voltage and current plot.

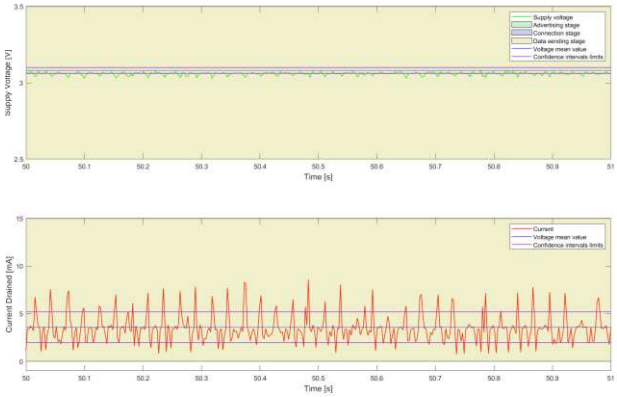

Figure 7.2.2.18 – Current and voltage 1s plot.

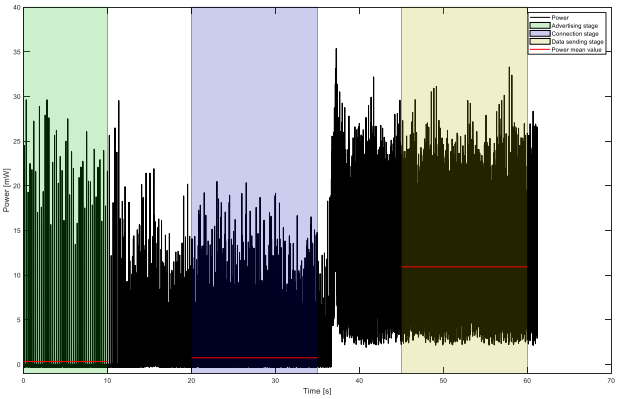

Figure 7.2.2.19 – Calculated power data plot.

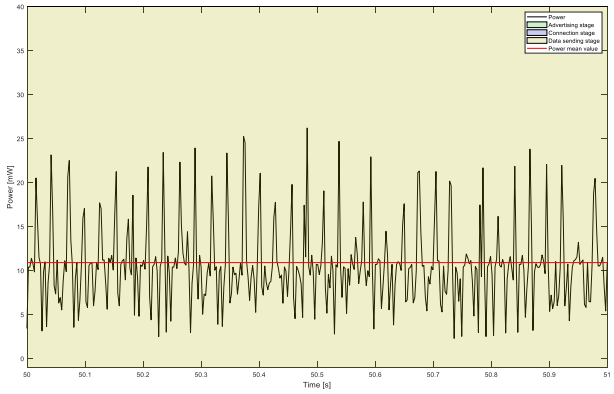

Figure 7.2.2.20 – Power data 1s plot.

Table 7.2.2.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.2.2.1 – Electrical values with accelerometer and pressure sensors active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.093	10.042	3.15	0.220	6.329	3.15	3.558	11.176	3.12
2	0.115	10.190	3.13	0.236	7.601	3.13	3.601	11.460	3.11
3	0.108	10.249	3.12	0.212	7.626	3.12	3.589	11.288	3.10
4	0.108	10.200	3.10	0.251	7.785	3.11	3.5697	11.494	3.09
5	0.105	9.734	3.10	0.237	6.605	3.10	3.571	10.884	3.07

7.2.3 Accelerometer and humidity sensors active power test

For repetition number 1 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.2.3.1 and Figure 7.2.3.2 shows a second of the data transmission interval while Figure 7.2.3.3 shows the power calculated and Figure 7.2.3.4 shows a second of the power calculated in the same second of data transmission interval.

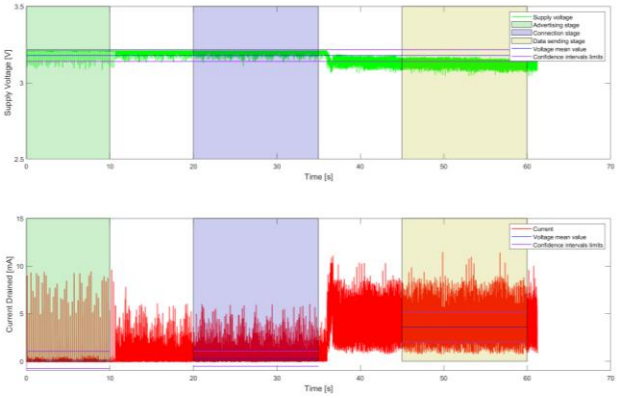

Figure 7.2.3.1 – Voltage and current plot.

Figure 7.2.3.2 – Current and voltage 1s plot.

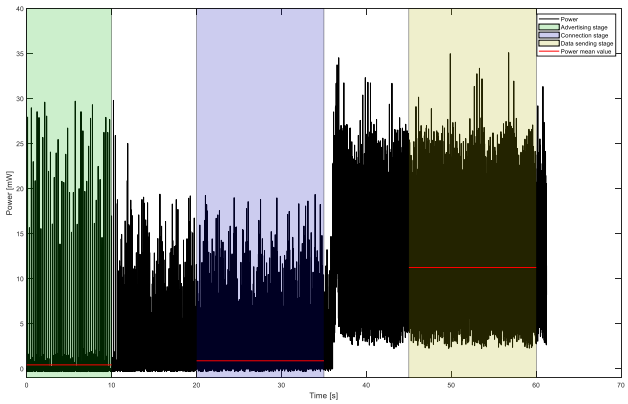

Figure 7.2.3.3 – Calculated power plot.

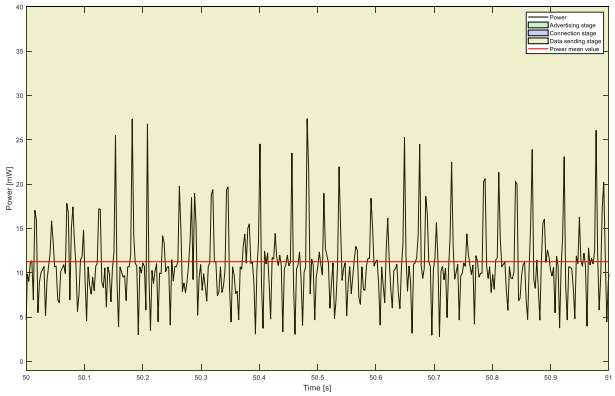

Figure 7.2.3.4 – Power data 1s plot.

For repetition number 2 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.2.3.5 and Figure 7.2.3.6 shows a second of the data transmission interval while Figure 7.2.3.7 shows the power calculated and Figure 7.2.3.8 shows a second of the power calculated in the same second of data transmission interval.

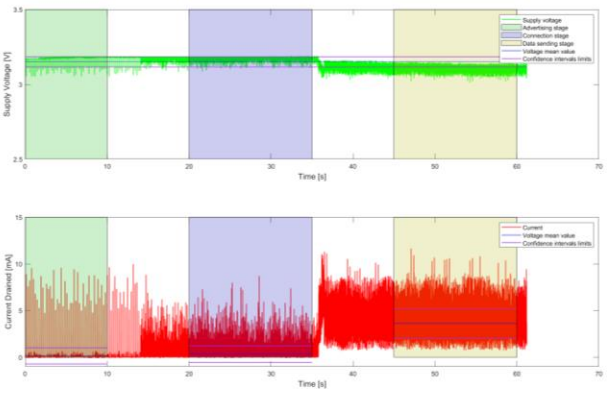

Figure 7.2.3.5 – Voltage and current plot.

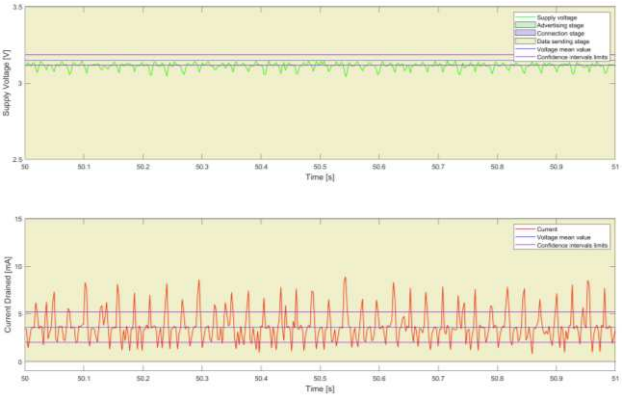

Figure 7.2.3.6 – Current and voltage 1s plot.

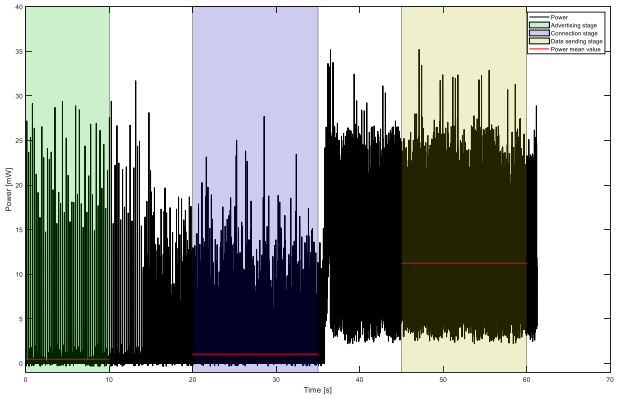

Figure 7.2.3.7 – Calculated power plot.

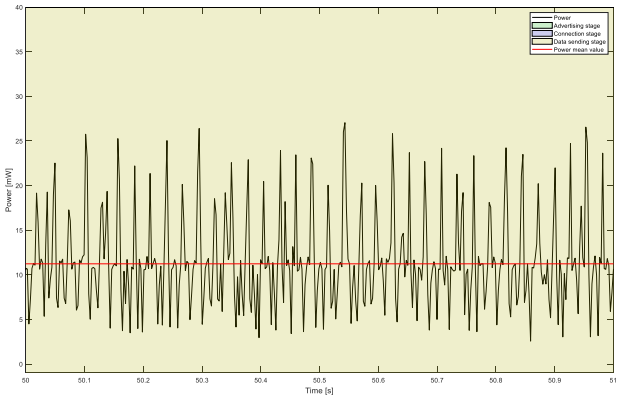

Figure 7.2.3.8 – Power data 1s plot.

For repetition number 3 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.2.3.9 and Figure 7.2.3.10 shows a second of the data transmission interval while Figure 7.2.3.11 shows the power calculated and Figure 7.2.3,12 shows a second of the power calculated in the same second of data transmission interval.

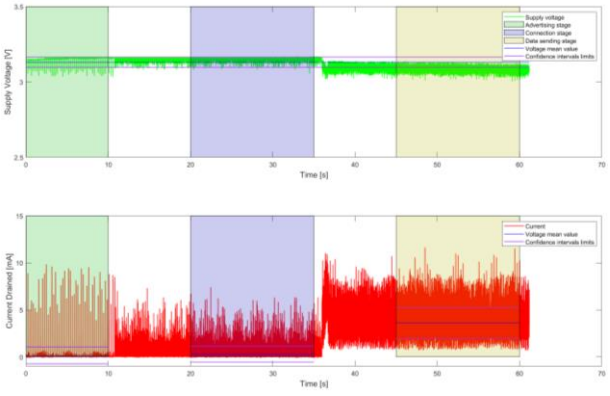

Figure 7.2.3.9 – Voltage and current plot.

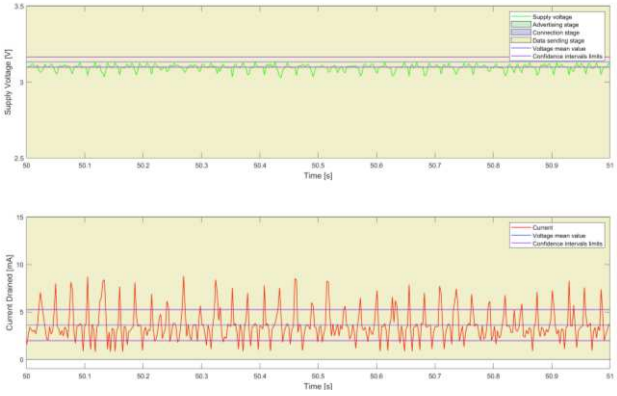

Figure 7.2.3.10 – Current and voltage 1s plot.

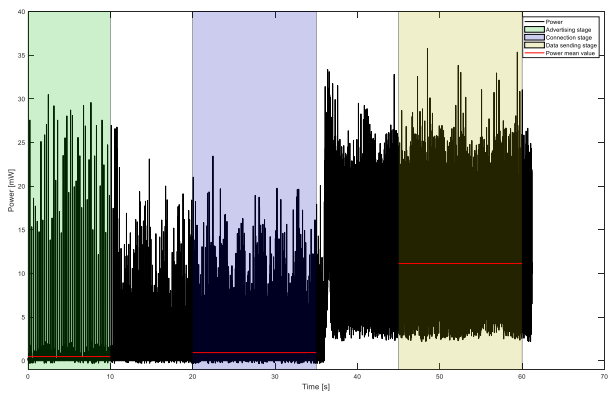

Figure 7.2.3.11 – Calculated power data plot.

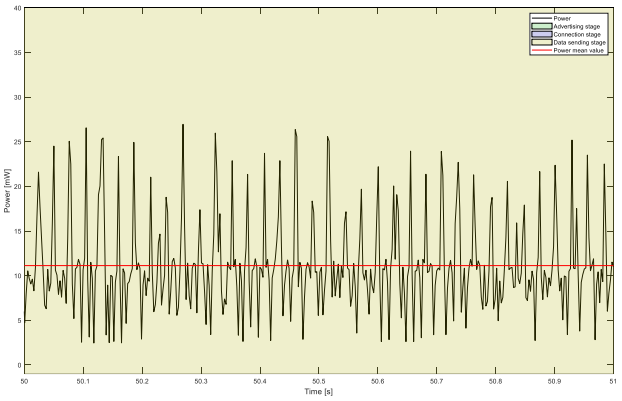

Figure 7.2.3.12 – Power data 1s plot.

For repetition number 4 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.2.3.13 and Figure 7.2.3.14 shows a second of the data transmission interval while Figure 7.2.3.15 shows the power calculated and Figure 7.2.3.16 shows a second of the power calculated in the same second of data transmission interval.

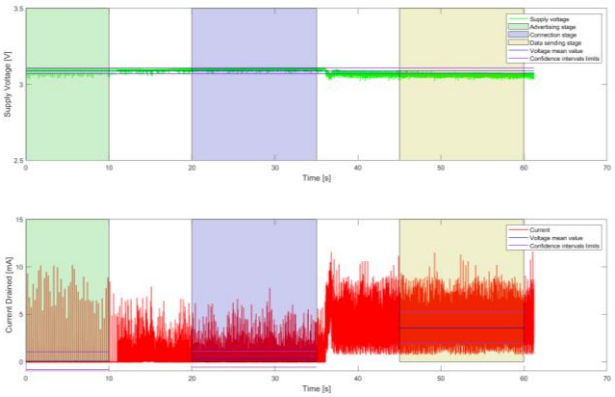

Figure 7.2.3.13 – Voltage and current plot.

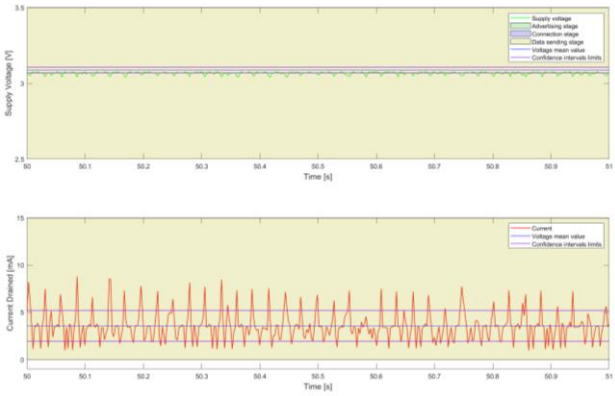

Figure 7.2.3.14 – Current and voltage 1s plot.

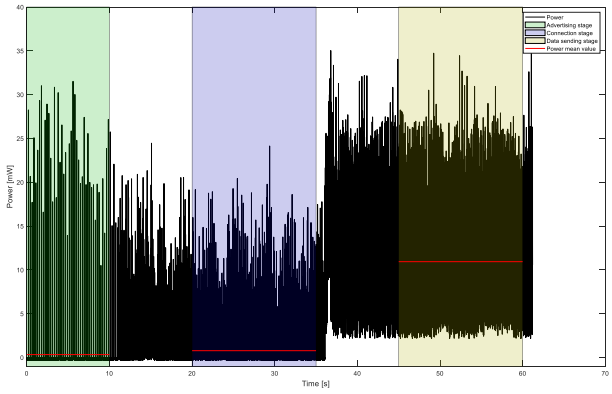

Figure 7.2.3.15 – Calculated power data plot.

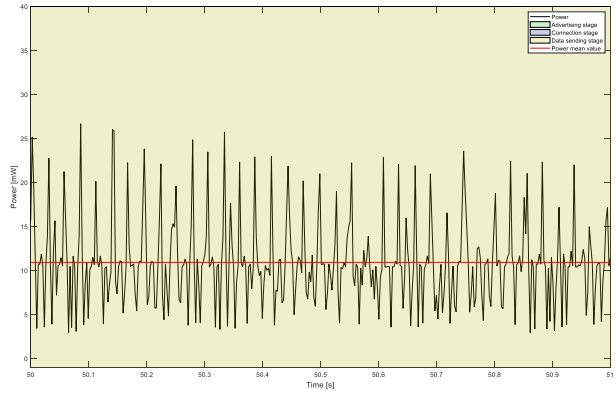

Figure 7.2.3.16 – Power data 1s plot.

For repetition number 5 when accelerometer and humidity sensors are active voltage and current measured data is shown in Figure 7.2.3.17 and Figure 7.2.3.18 shows a second of the data transmission interval while Figure 7.2.3.19 shows the power calculated and Figure 7.2.3.20 shows a second of the power calculated in the same second of data transmission interval.

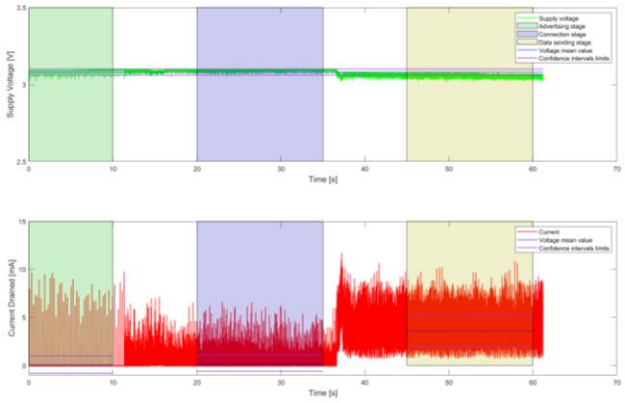

Figure 7.2.3.17 – Voltage and current plot.

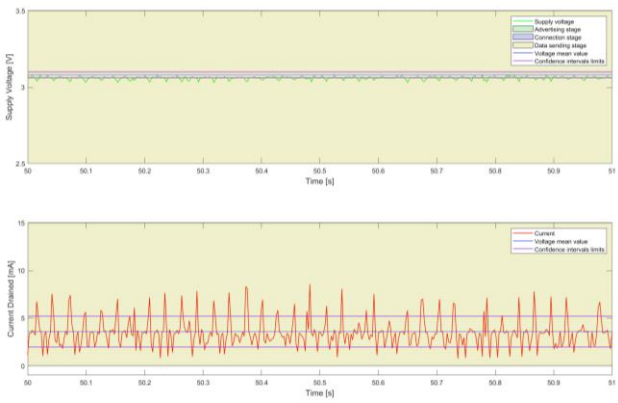

Figure 7.2.3.18 – Current and voltage 1s plot.

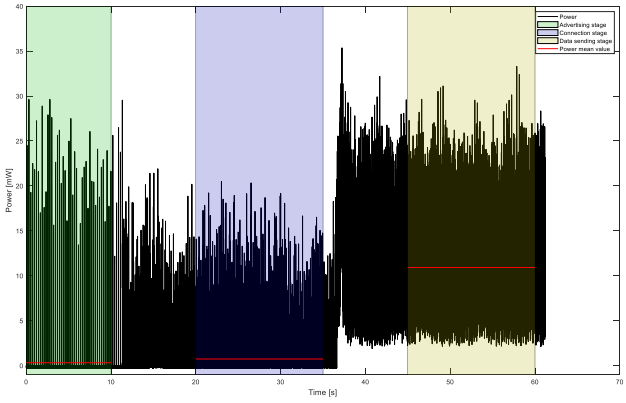

Figure 7.2.3.19 – Calculated power data plot.

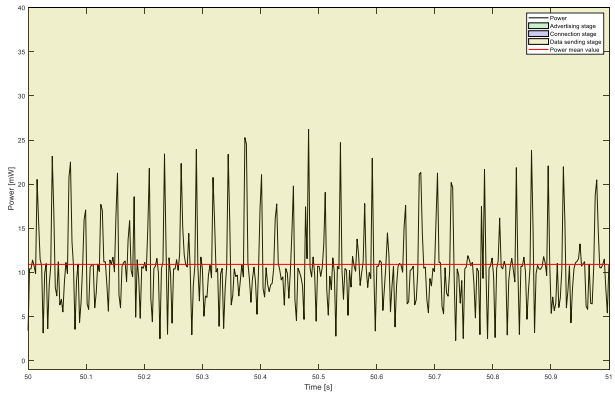

Figure 7.2.3.20 – Power data 1s plot.

Table 7.2.3.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.2.3.1 – Electrical values with accelerometer and humidity sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.136	9.429	3.21	0.276	6.030	3.21	3.596	11.469	3.17
2	0.148	9.579	3.18	0.330	8.708	3.19	3.616	11.657	3.14
3	0.151	9.839	3.16	0.293	7.418	3.17	3.603	11.628	3.13
4	0.165	9.900	3.14	0.291	6.272	3.15	3.565	11.265	3.12
5	0.148	9.980	3.15	0.284	6.923	3.15	3.600	11.058	3.12

7.2.4 Accelerometer and magnetometer sensors active power test

For repetition number 1 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.2.4.1 and Figure 7.2.4.2 shows a second of the data transmission interval while Figure 7.2.4.3 shows the power calculated and Figure 7.2.4.4 shows a second of the power calculated in the same second of data transmission interval.

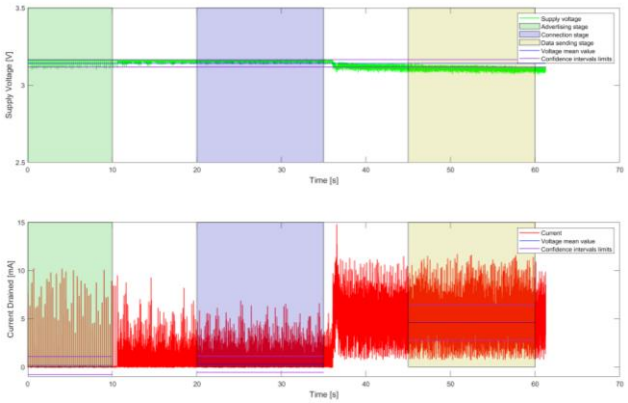

Figure 7.2.4.1 – Voltage and current plot.

Figure 7.2.4.2 – Current and voltage 1s plot.

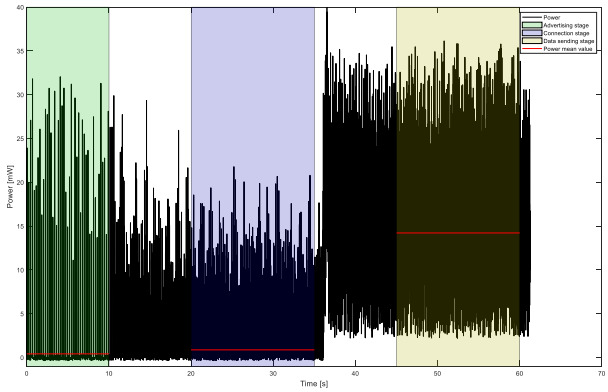

Figure 7.2.4.3 – Calculated power plot.

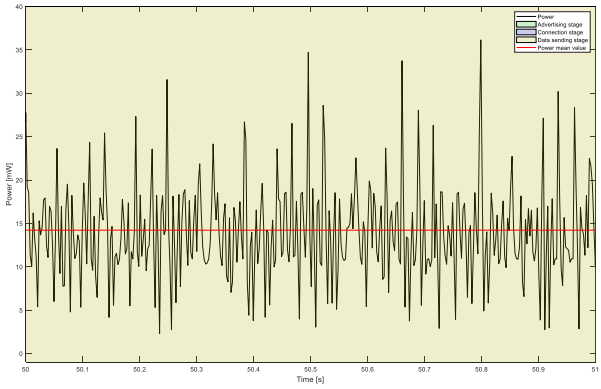

Figure 7.2.4.4 – Power data 1s plot.

For repetition number 2 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.2.4.5 and Figure 7.2.4.6 shows a second of the data transmission interval while Figure 7.2.4.7 shows the power calculated and Figure 7.2.4.8 shows a second of the power calculated in the same second of data transmission interval.

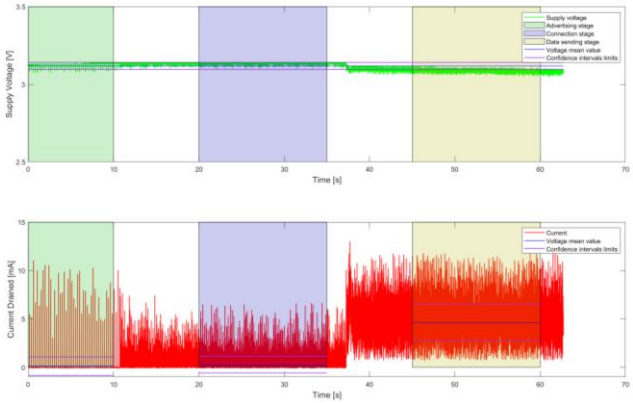

Figure 7.2.4.5 – Voltage and current plot.

Figure 7.2.4.6 – Current and voltage 1s plot.

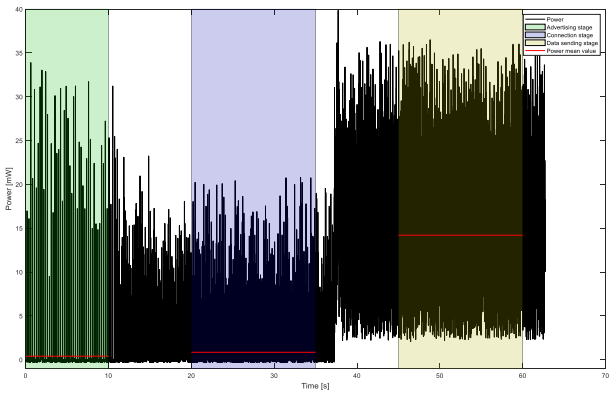

Figure 7.2.4.7 – Calculated power plot.

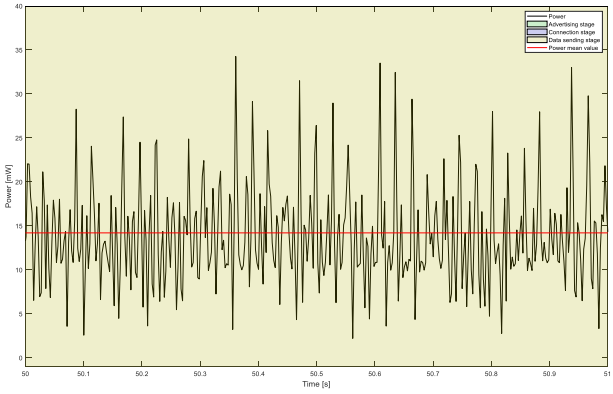

Figure 7.2.4.8 – Power data 1s plot.

For repetition number 3 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.2.4.9 and Figure 7.2.4.10 shows a second of the data transmission interval while Figure 7.2.4.11 shows the power calculated and Figure 7.2.4,12 shows a second of the power calculated in the same second of data transmission interval.

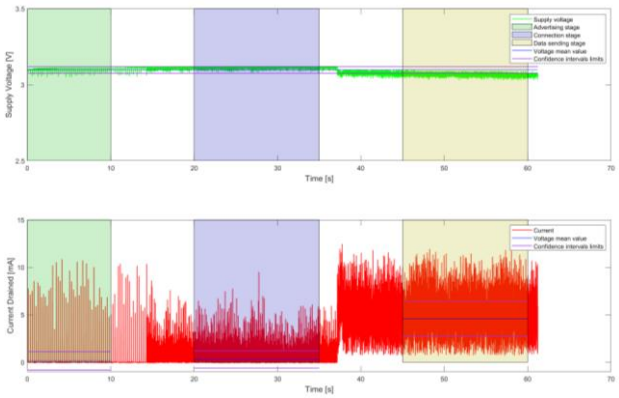

Figure 7.2.4.9 – Voltage and current plot.

Figure 7.2.4.10 – Current and voltage 1s plot.

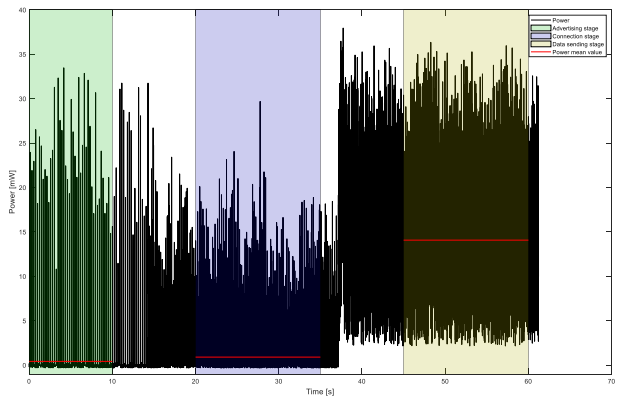

Figure 7.2.4.11 – Calculated power data plot.

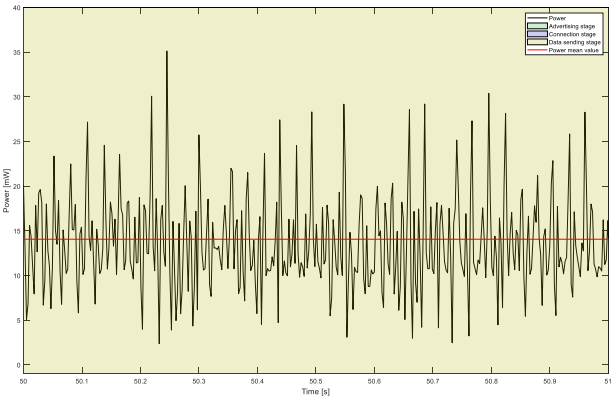

Figure 7.2.4.12 – Power data 1s plot.

For repetition number 4 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.2.4.13 and Figure 7.2.4.14 shows a second of the data transmission interval while Figure 7.2.4.15 shows the power calculated and Figure 7.2.4.16 shows a second of the power calculated in the same second of data transmission interval.

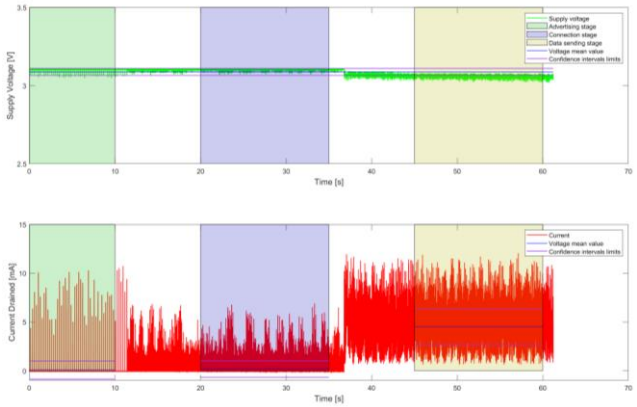

Figure 7.2.3.13 – Voltage and current plot.

Figure 7.2.3.14 – Current and voltage 1s plot.

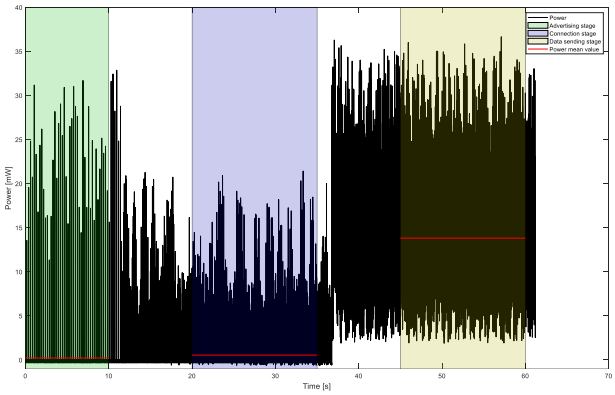

Figure 7.2.4.15 – Calculated power data plot.

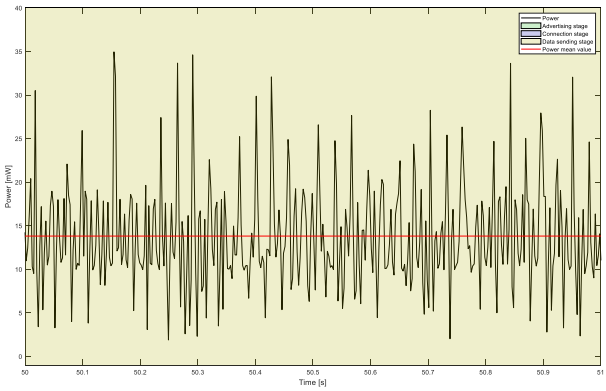

Figure 7.2.4.16 – Power data 1s plot.

For repetition number 5 when accelerometer and magnetometer sensors are active voltage and current measured data is shown in Figure 7.2.4.17 and Figure 7.2.4.18 shows a second of the data transmission interval while Figure 7.2.4.19 shows the power calculated and Figure 7.2.4.20 shows a second of the power calculated in the same second of data transmission interval.

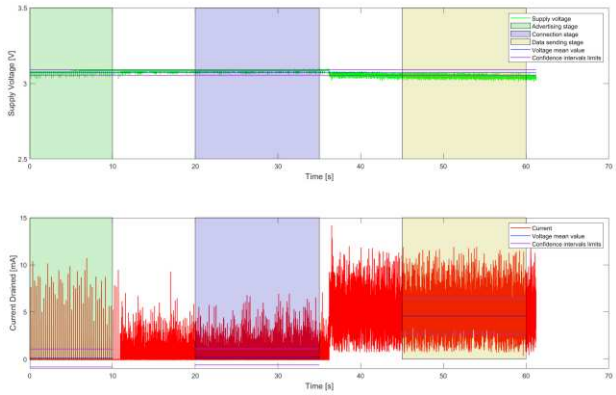

Figure 7.2.4.17 – Voltage and current plot.

Figure 7.2.4.18 – Current and voltage 1s plot.

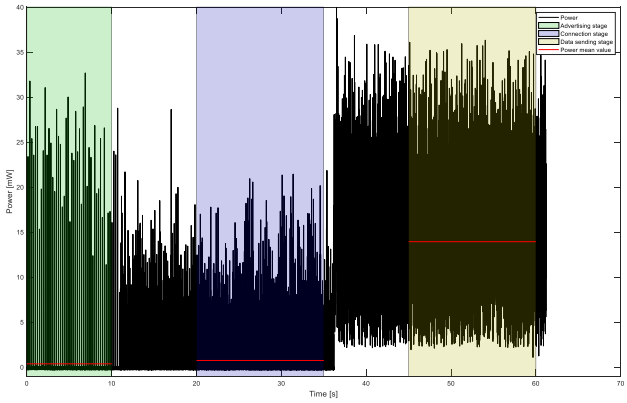

Figure 7.2.4.19 – Calculated power data plot.

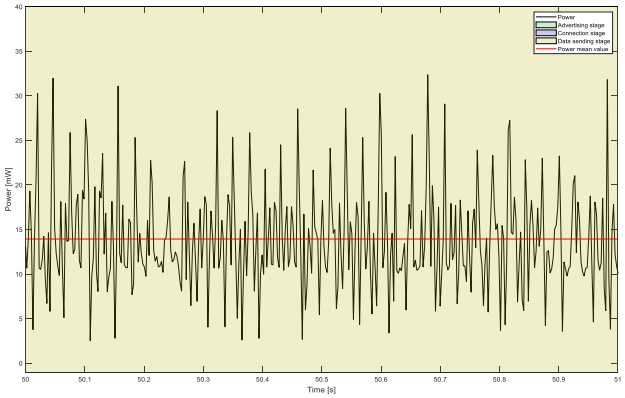

Figure 7.2.4.20 – Power data 1s plot.

Table 7.2.4.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.2.4.1 – Electrical values with accelerometer and magnetometer sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.134	10.244	3.16	0.278	6.894	3.16	4.577	11.714	3.14
2	0.130	11.038	3.14	0.271	6.651	3.14	4.600	11.794	3.12
3	0.137	10.850	3.11	0.291	9.515	3.12	4.587	11.926	3.09
4	0.075	10.290	3.11	0.177	6.913	3.11	4.516	12.058	3.08
5	0.117	10.729	3.09	0.236	6.937	3.09	4.569	11.910	3.07

7.2.5 Accelerometer and proximity sensors active power test

For repetition number 1 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.2.5.1 and Figure 7.2.5.2 shows a second of the data transmission interval while Figure 7.2.5.3 shows the power calculated and Figure 7.2.5.4 shows a second of the power calculated in the same second of data transmission interval.

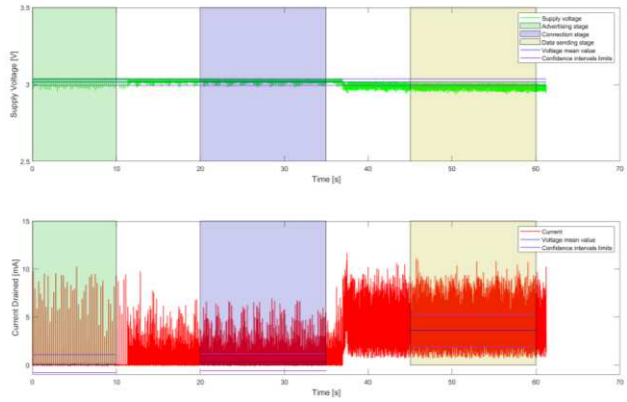

Figure 7.2.5.1 – Voltage and current plot.

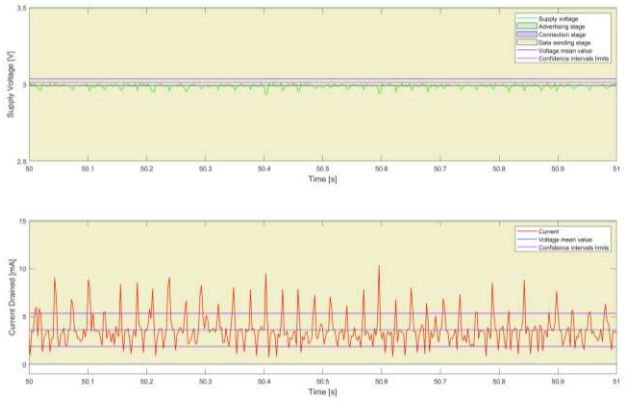

Figure 7.2.5.2 – Current and voltage 1s plot.

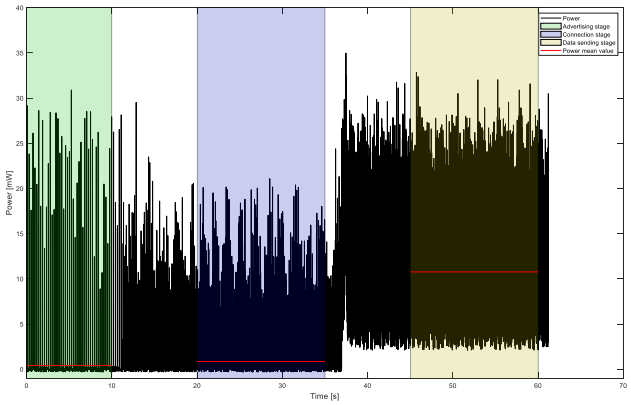

Figure 7.2.5.3 – Calculated power plot.

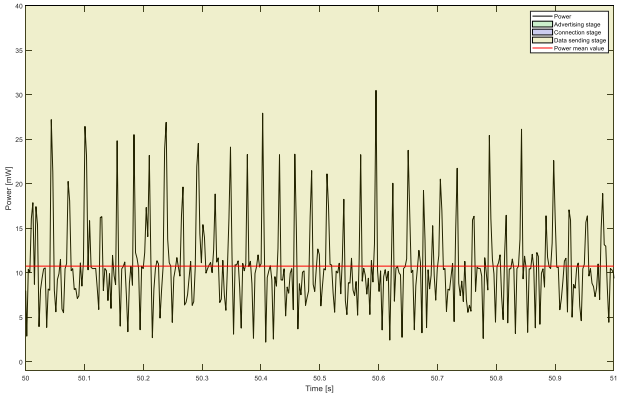

Figure 7.2.5.4 – Power data 1s plot.

For repetition number 2 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.2.5.5 and Figure 7.2.5.6 shows a second of the data transmission interval while Figure 7.2.5.7 shows the power calculated and Figure 7.2.5.8 shows a second of the power calculated in the same second of data transmission interval.

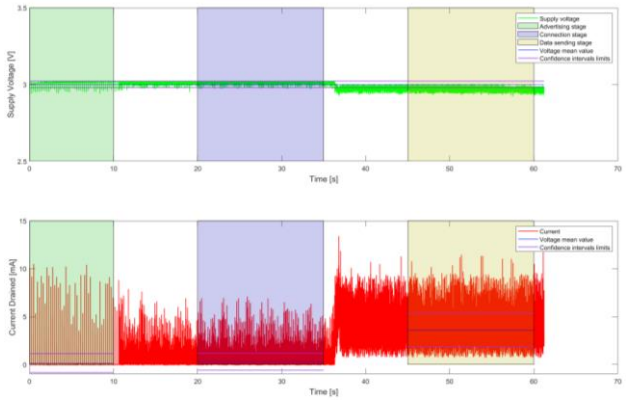

Figure 7.2.5.5 – Voltage and current plot.

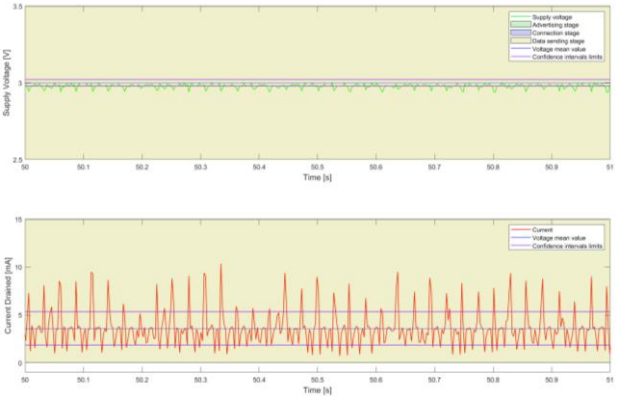

Figure 7.2.5.6 – Current and voltage 1s plot.

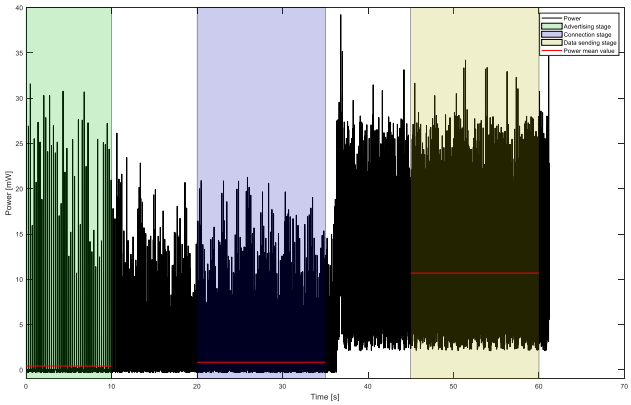

Figure 7.2.5.7 – Calculated power plot.

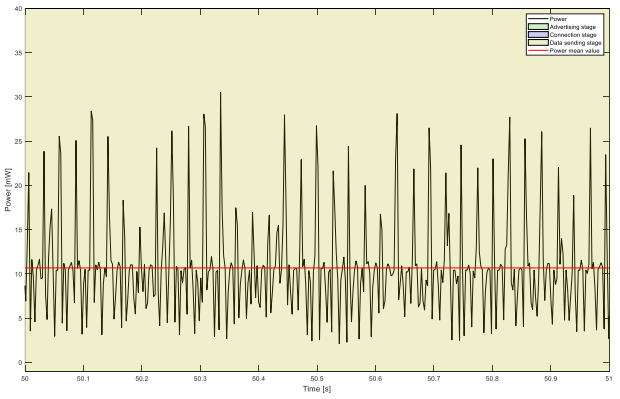

Figure 7.2.5.8 – Power data 1s plot.

For repetition number 3 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.2.5.9 and Figure 7.2.5.10 shows a second of the data transmission interval while Figure 7.2.5.11 shows the power calculated and Figure 7.2.5,12 shows a second of the power calculated in the same second of data transmission interval.

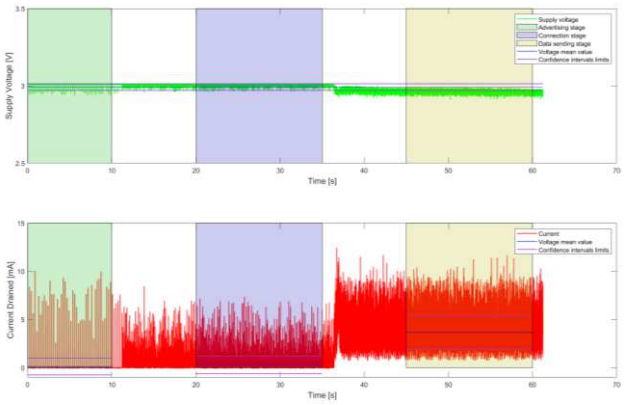

Figure 7.2.5.9 – Voltage and current plot.

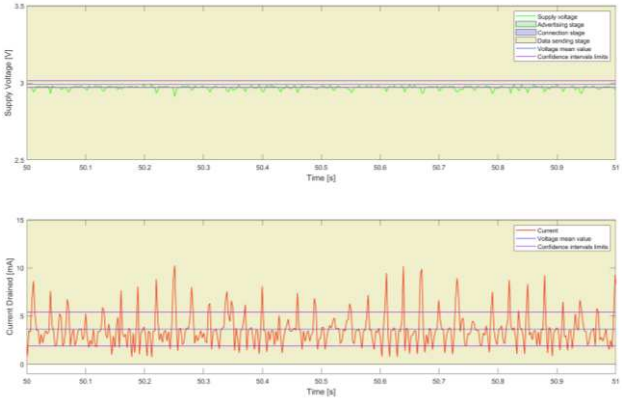

Figure 7.2.5.10 – Current and voltage 1s plot.

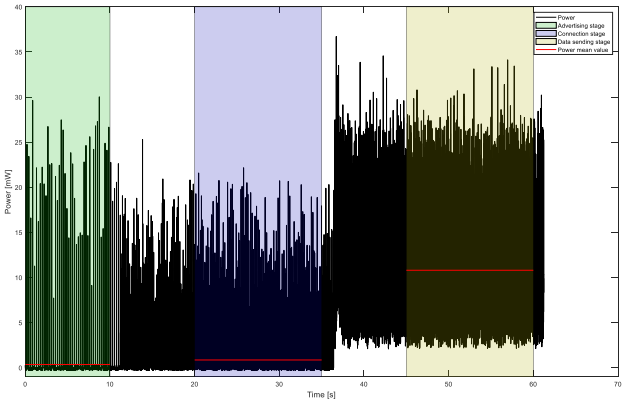

Figure 7.2.5.11 – Calculated power data plot.

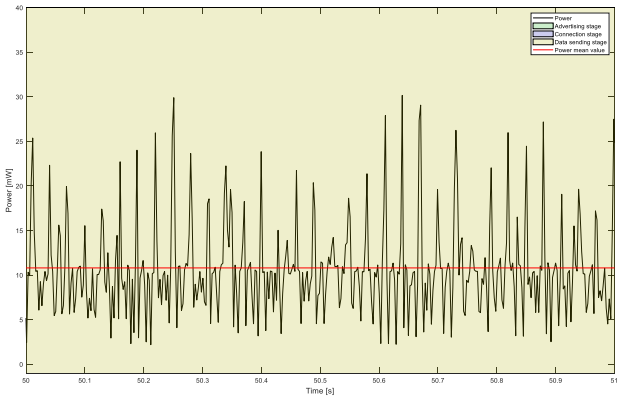

Figure 7.2.5.12 – Power data 1s plot.

For repetition number 4 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.2.5.13 and Figure 7.2.5.14 shows a second of the data transmission interval while Figure 7.2.5.15 shows the power calculated and Figure 7.2.5.16 shows a second of the power calculated in the same second of data transmission interval.

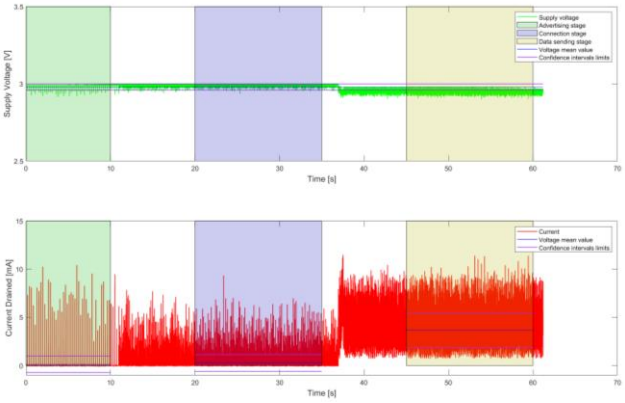

Figure 7.2.5.7 – Voltage and current plot.

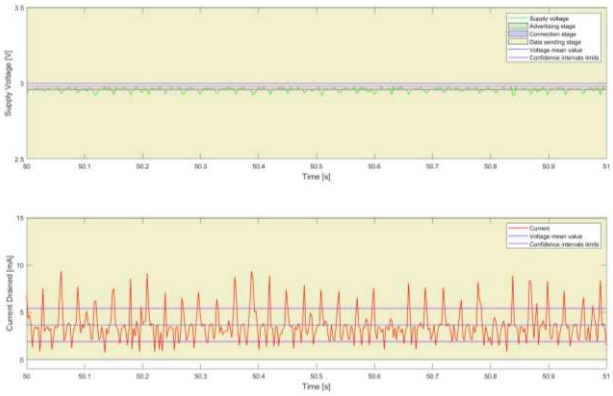

Figure 7.2.5.14 – Current and voltage 1s plot.

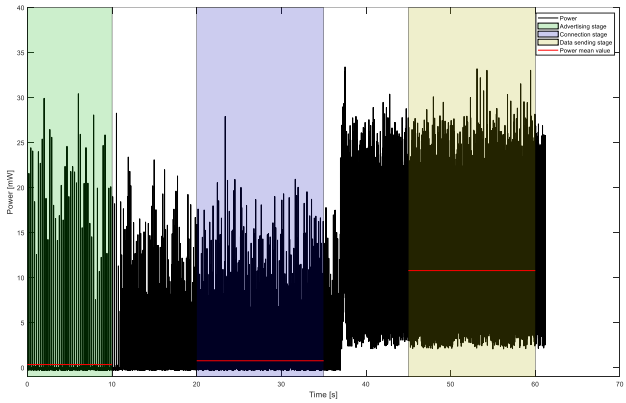

Figure 7.2.5.15 – Calculated power data plot.

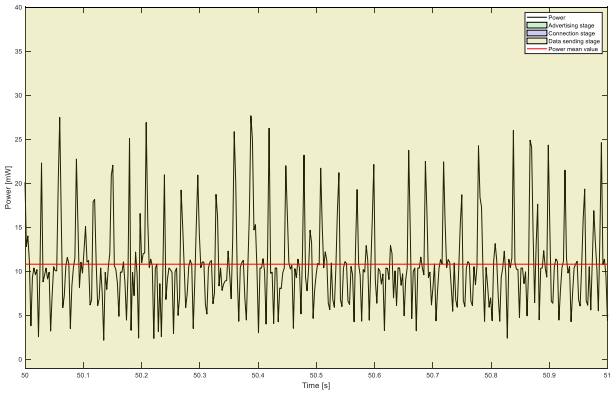

Figure 7.2.5.16 – Power data 1s plot.

For repetition number 5 when accelerometer and proximity sensors are active voltage and current measured data is shown in Figure 7.2.5.17 and Figure 7.2.5.18 shows a second of the data transmission interval while Figure 7.2.5.19 shows the power calculated and Figure 7.2.5.20 shows a second of the power calculated in the same second of data transmission interval.

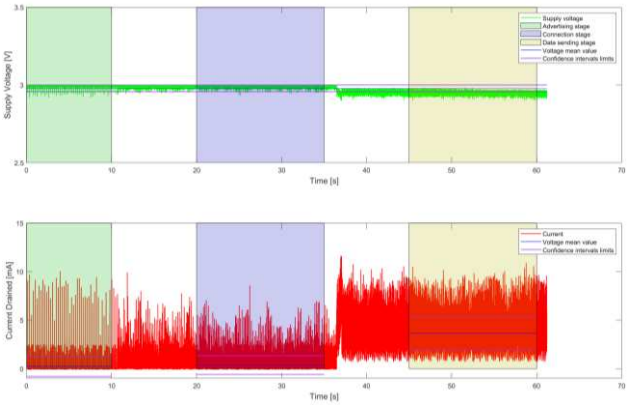

Figure 7.2.5.17 – Voltage and current plot.

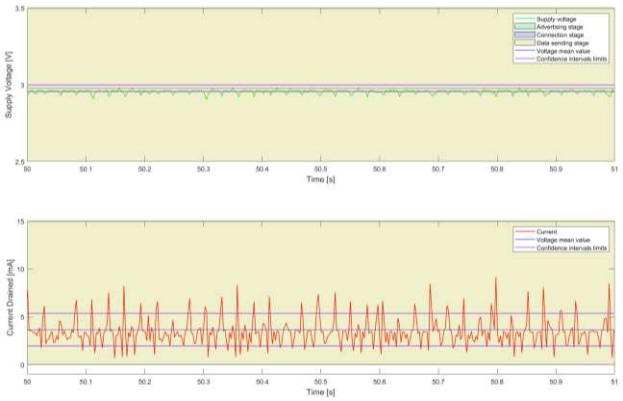

Figure 7.2.5.18 – Current and voltage 1s plot.

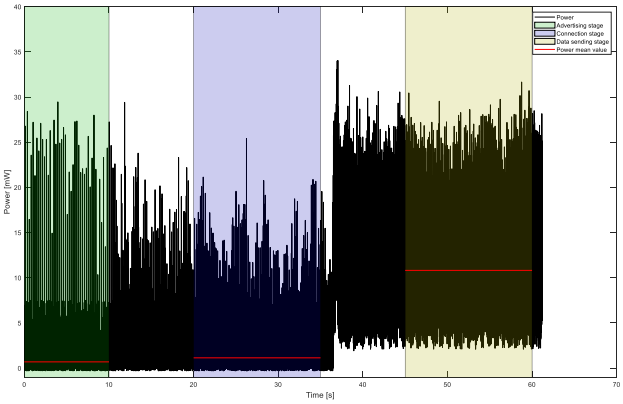

Figure 7.2.5.19 – Calculated power data plot.

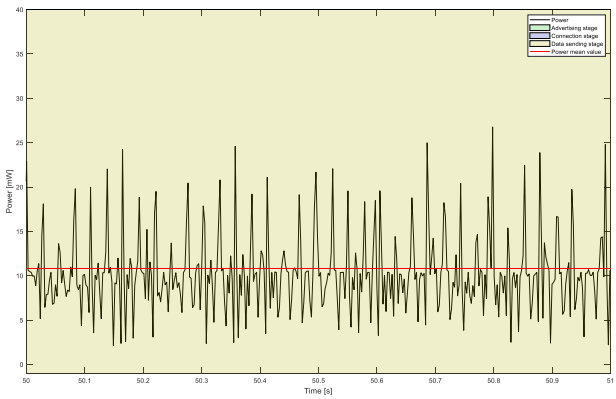

Figure 7.2.5.20 – Power data 1s plot.

Table 7.2.5.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.2.5.1 – Electrical values with accelerometer and proximity sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.139	10.241	3.04	0.281	6.957	3.04	3.605	11.127	3.01
2	0.140	10.500	3.02	0.280	7.088	3.02	3.592	11.477	3.00
3	0.122	10.039	3.01	0.288	7.364	3.01	3.647	11.647	2.99
4	0.121	10.419	3.00	0.260	9.335	3.00	3.654	11.408	2.98
5	0.233	10.053	3.00	0.381	8.581	3.00	3.666	10.908	2.97

7.2.6 Accelerometer and pedometer sensors active power test

For repetition number 1 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.6.1 and Figure 7.2.6.2 shows a second of the data transmission interval while Figure 7.2.6.3 shows the power calculated and Figure 7.2.6.4 shows a second of the power calculated in the same second of data transmission interval.

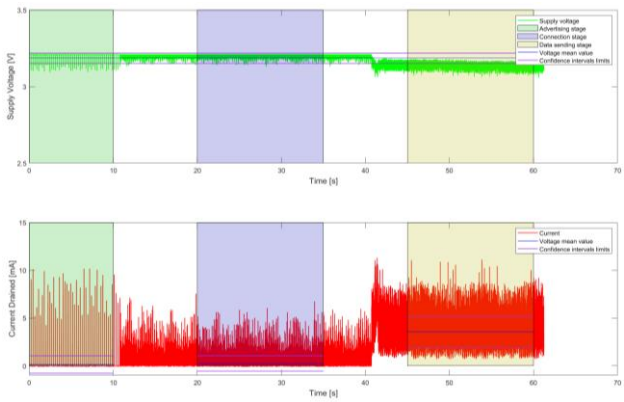

Figure 7.2.6.1 – Voltage and current plot.

Figure 7.2.6.2 – Current and voltage 1s plot.

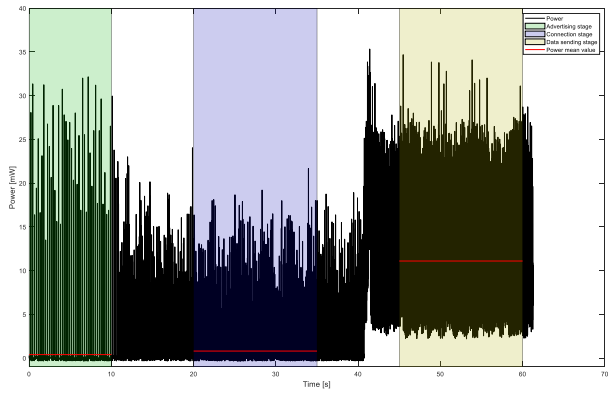

Figure 7.2.6.3 – Calculated power plot.

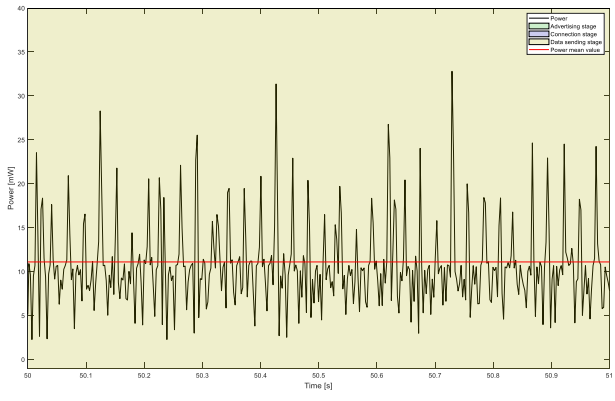

Figure 7.2.6.4 – Power data 1s plot.

For repetition number 2 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.6.5 and Figure 7.2.6.6 shows a second of the data transmission interval while Figure 7.2.6.7 shows the power calculated and Figure 7.2.6.8 shows a second of the power calculated in the same second of data transmission interval.

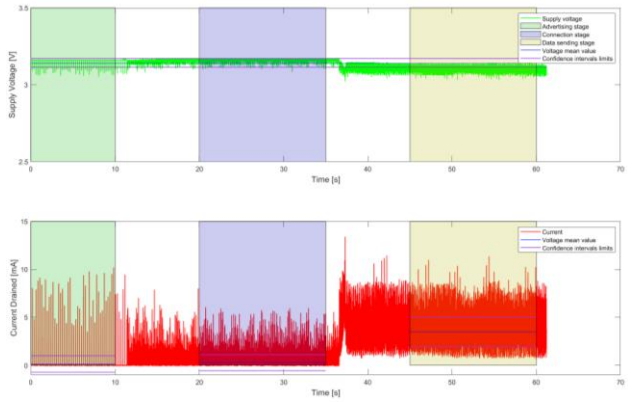

Figure 7.2.6.5 – Voltage and current plot.

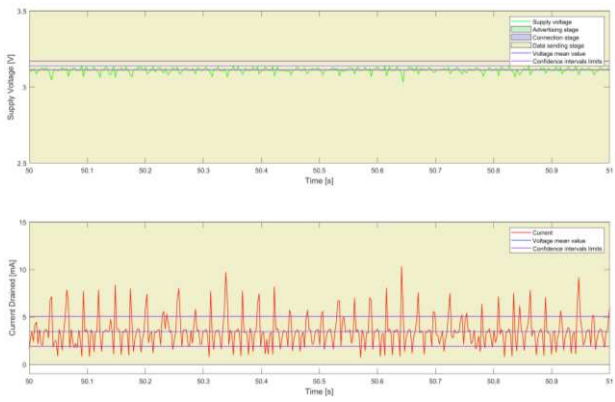

Figure 7.2.6.6 – Current and voltage 1s plot.

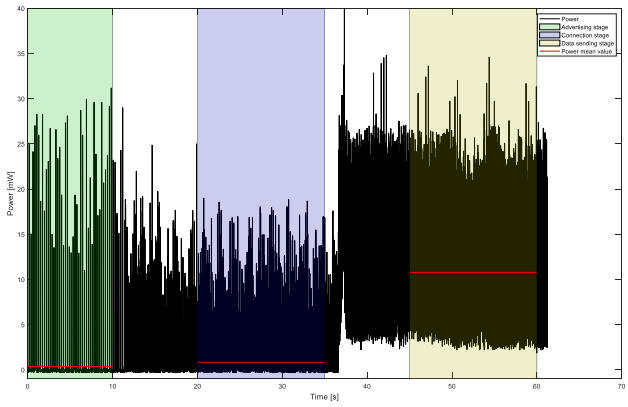

Figure 7.2.6.7 – Calculated power plot.

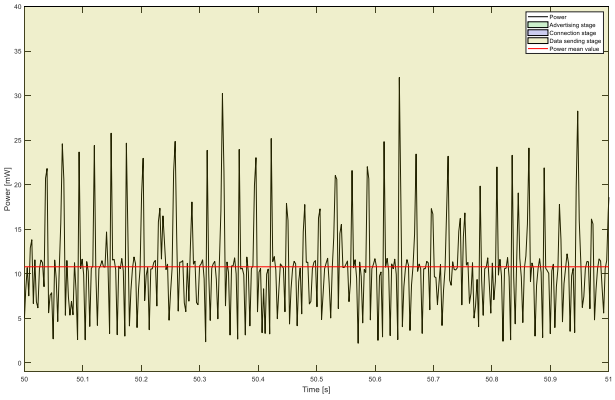

Figure 7.2.6.8 – Power data 1s plot.

For repetition number 3 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.6.9 and Figure 7.2.6.10 shows a second of the data transmission interval while Figure 7.2.6.11 shows the power calculated and Figure 7.2.6,12 shows a second of the power calculated in the same second of data transmission interval.

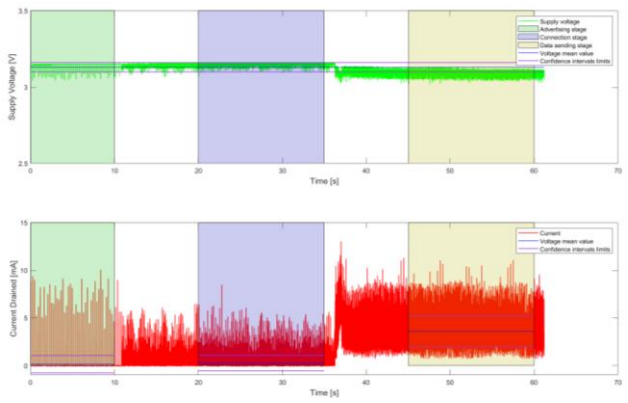

Figure 7.2.6.9 – Voltage and current plot.

Figure 7.2.6.10 – Current and voltage 1s plot.

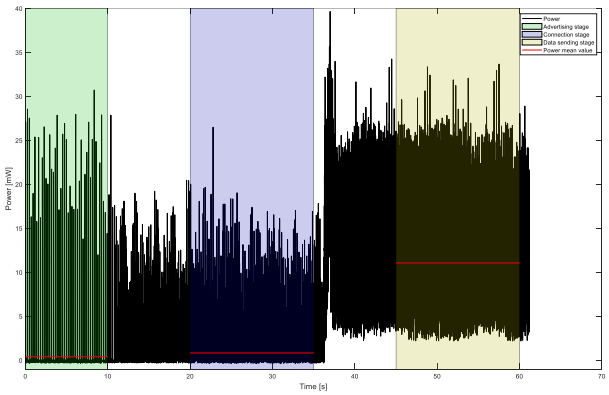

Figure 7.2.6.11 – Calculated power data plot.

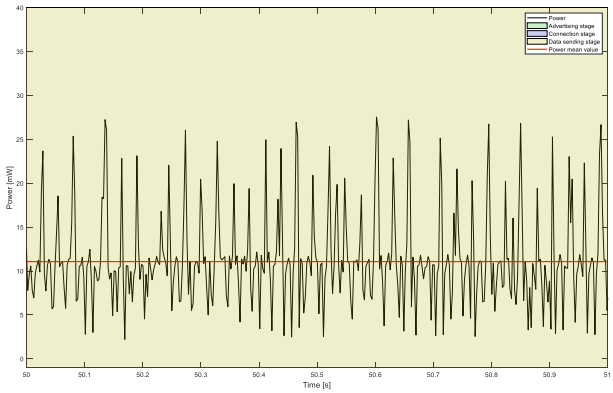

Figure 7.2.6.12 – Power data 1s plot.

For repetition number 4 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.6.13 and Figure 7.2.6.14 shows a second of the data transmission interval while Figure 7.2.6.15 shows the power calculated and Figure 7.2.6.16 shows a second of the power calculated in the same second of data transmission interval.

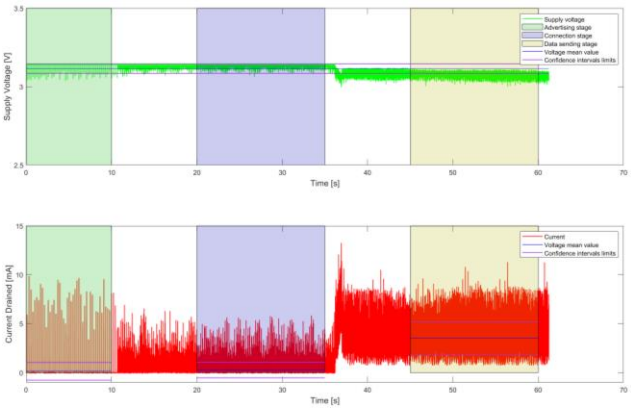

Figure 7.2.6.13 – Voltage and current plot.

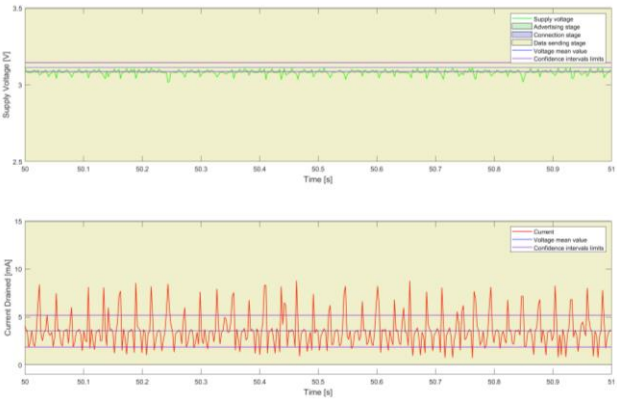

Figure 7.2.6.14 – Current and voltage 1s plot.

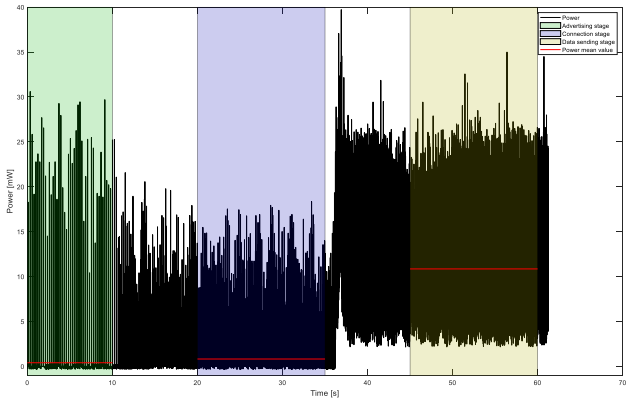

Figure 7.2.6.15 – Calculated power data plot.

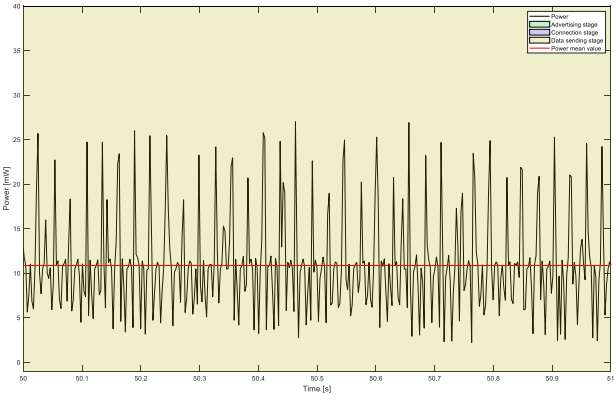

Figure 7.2.6.16 – Power data 1s plot.

For repetition number 5 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.6.17 and Figure 7.2.6.18 shows a second of the data transmission interval while Figure 7.2.6.19 shows the power calculated and Figure 7.2.6.20 shows a second of the power calculated in the same second of data transmission interval.

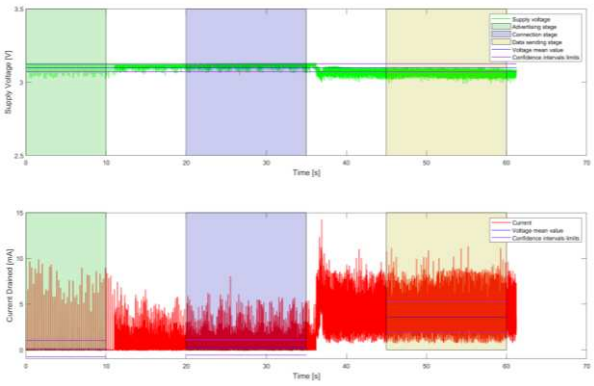

Figure 7.2.6.17 – Voltage and current plot.

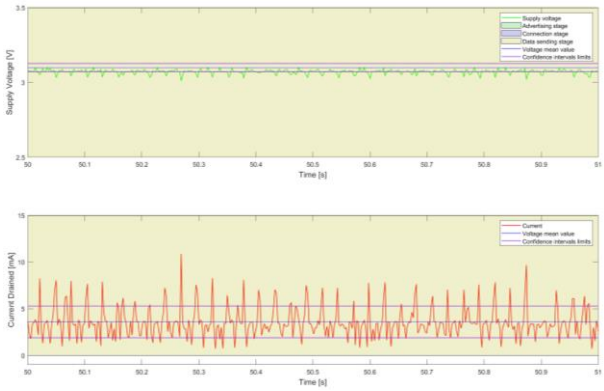

Figure 7.2.6.18 – Current and voltage 1s plot.

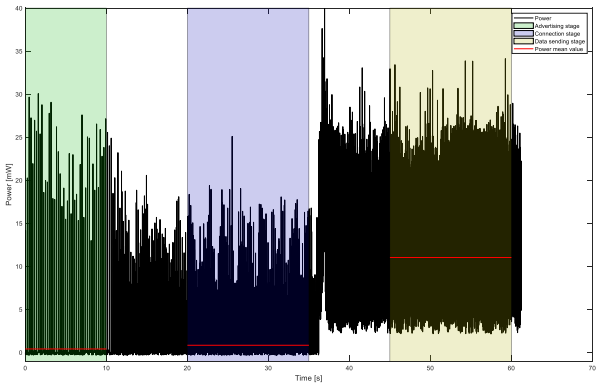

Figure 7.2.6.19 – Calculated power data plot.

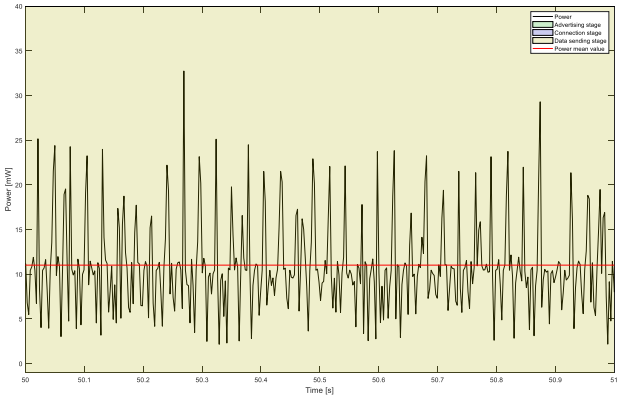

Figure 7.2.6.20 – Power data 1s plot.

Table 7.2.6.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.2.6.1 – Electrical values with accelerometer and pedometer sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.129	10.174	3.21	0.254	6.750	3.21	3.539	11.132	3.18
2	0.121	10.192	3.16	0.267	6.052	3.17	3.475	11.366	3.14
3	0.130	10.065	3.15	0.263	8.487	3.16	3.580	11.074	3.13
4	0.132	9.880	3.14	0.263	5.843	3.14	3.528	11.312	3.12
5	0.130	9.905	3.12	0.267	8.042	3.13	3.598	11.280	3.10

7.2.7 Just accelerometer active power test

For repetition number 1 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.7.1 and Figure 7.2.7.2 shows a second of the data transmission interval while Figure 7.2.7.3 shows the power calculated and Figure 7.2.7.4 shows a second of the power calculated in the same second of data transmission interval.

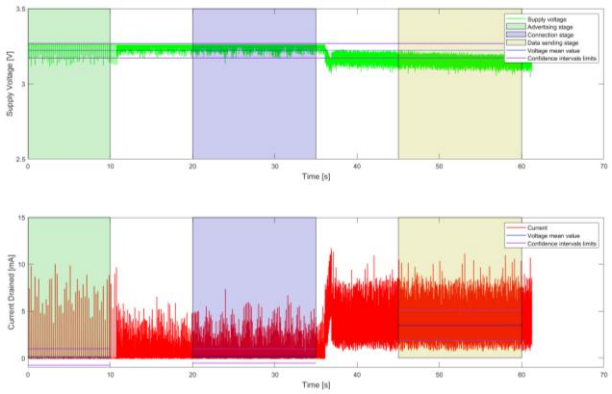

Figure 7.2.7.1 – Voltage and current plot.

Figure 7.2.7.2 – Current and voltage 1s plot.

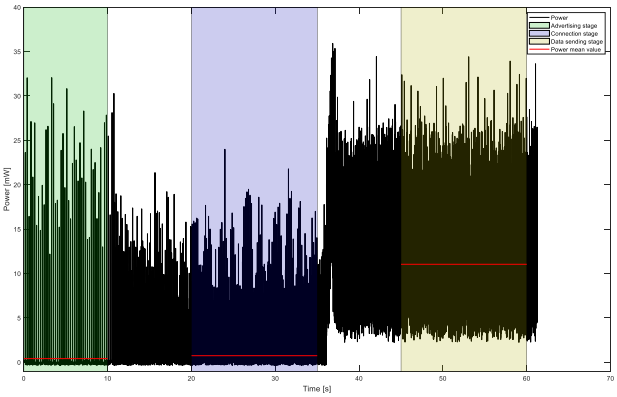

Figure 7.2.7.3 – Calculated power plot.

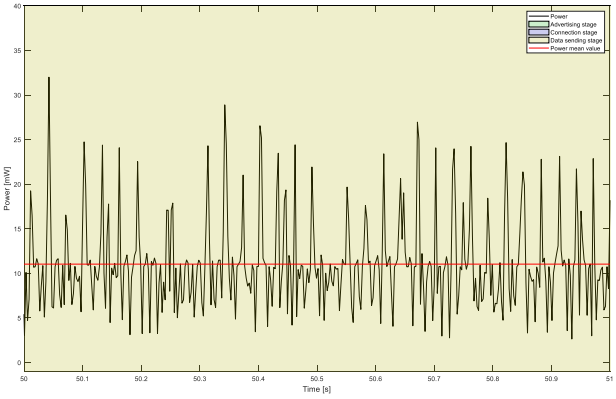

Figure 7.2.7.4 – Power data 1s plot.

For repetition number 2 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.7.5 and Figure 7.2.7.6 shows a second of the data transmission interval while Figure 7.2.7.7 shows the power calculated and Figure 7.2.7.8 shows a second of the power calculated in the same second of data transmission interval.

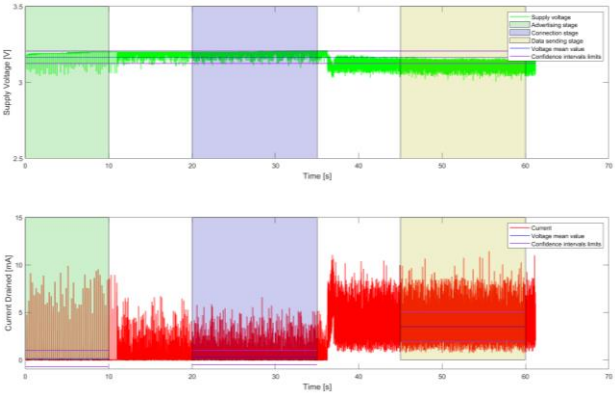

Figure 7.2.6.5 – Voltage and current plot.

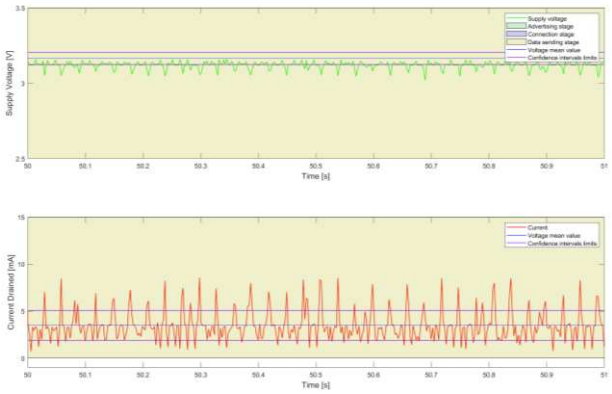

Figure 7.2.6.6 – Current and voltage 1s plot.

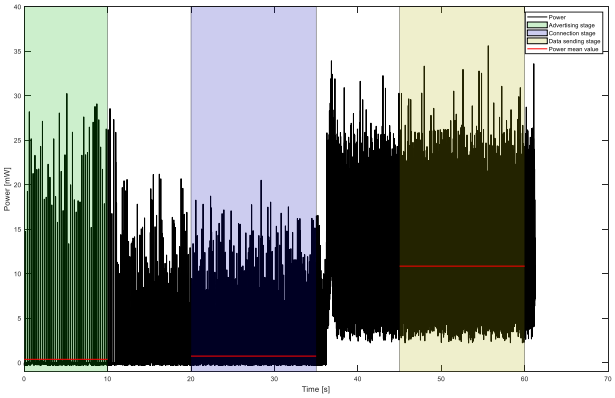

Figure 7.2.7.7 – Calculated power plot.

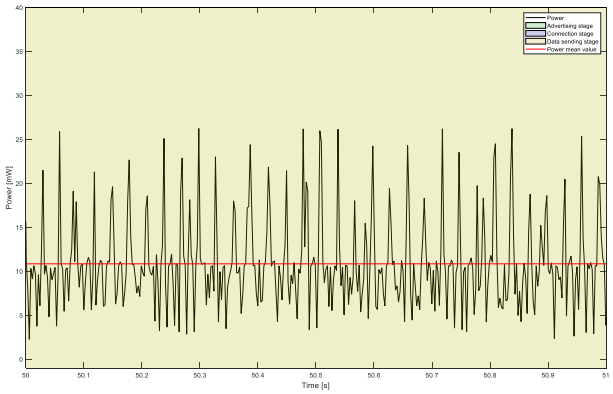

Figure 7.2.7.8 – Power data 1s plot.

For repetition number 3 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.7.9 and Figure 7.2.7.10 shows a second of the data transmission interval while Figure 7.2.7.11 shows the power calculated and Figure 7.2.7,12 shows a second of the power calculated in the same second of data transmission interval.

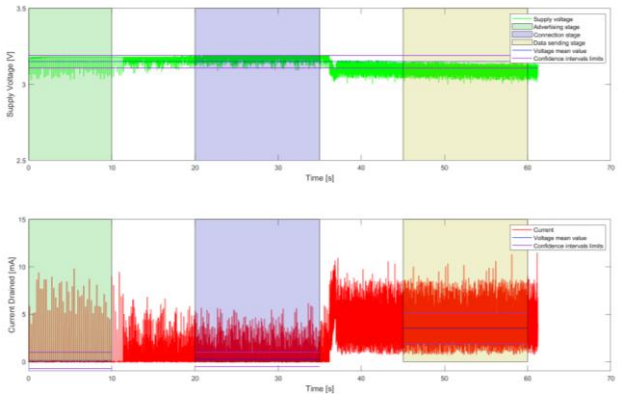

Figure 7.2.7.9 – Voltage and current plot.

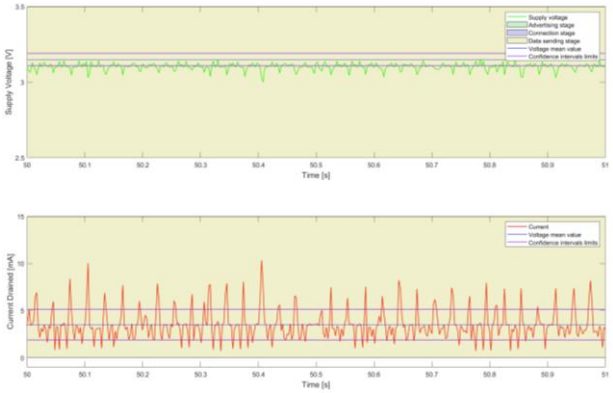

Figure 7.2.7.10 – Current and voltage 1s plot.

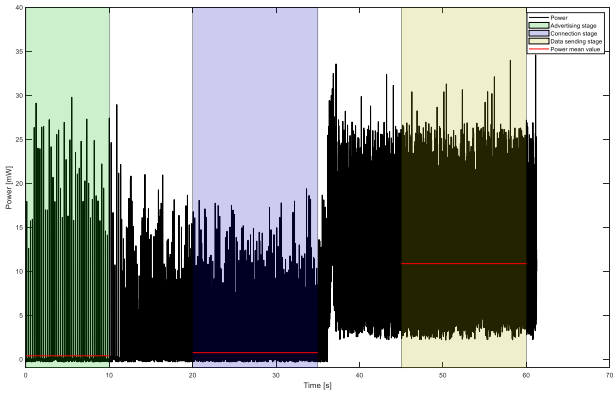

Figure 7.2.7.11 – Calculated power data plot.

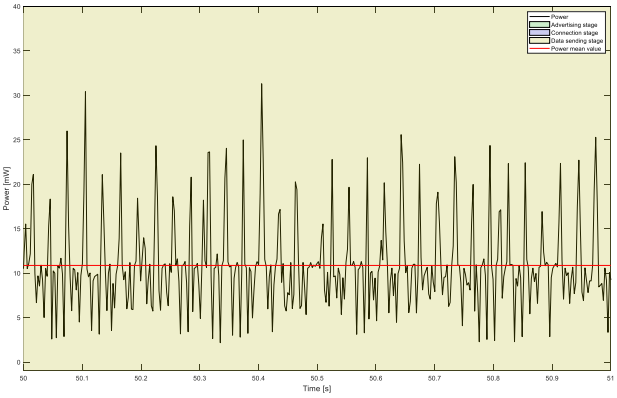

Figure 7.2.7.12 – Power data 1s plot.

For repetition number 4 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.7.13 and Figure 7.2.7.14 shows a second of the data transmission interval while Figure 7.2.7.15 shows the power calculated and Figure 7.2.7.16 shows a second of the power calculated in the same second of data transmission interval.

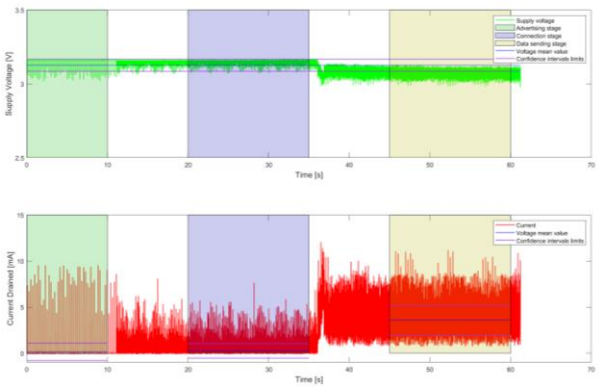

Figure 7.2.7.13 – Voltage and current plot.

Figure 7.2.7.14 – Current and voltage 1s plot.

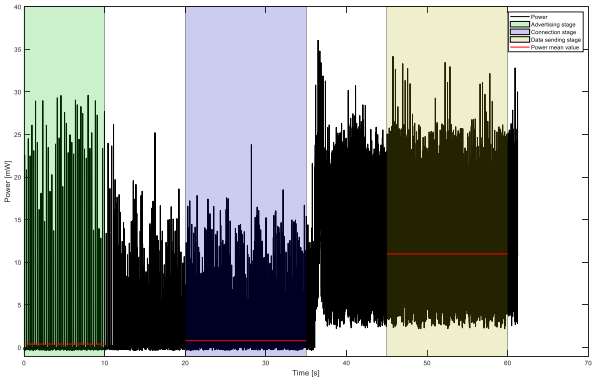

Figure 7.2.7.15 – Calculated power data plot.

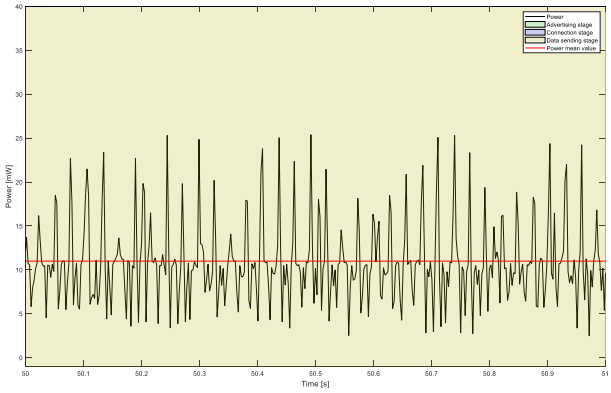

Figure 7.2.7.16 – Power data 1s plot.

For repetition number 5 when accelerometer and pedometer sensors are active voltage and current measured data is shown in Figure 7.2.7.17 and Figure 7.2.7.18 shows a second of the data transmission interval while Figure 7.2.7.19 shows the power calculated and Figure 7.2.7.20 shows a second of the power calculated in the same second of data transmission interval.

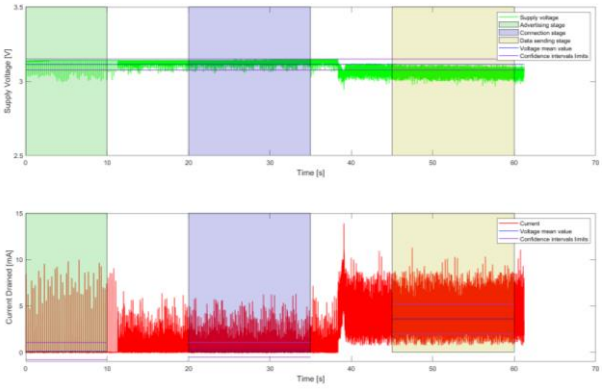

Figure 7.2.7.17 – Voltage and current plot.

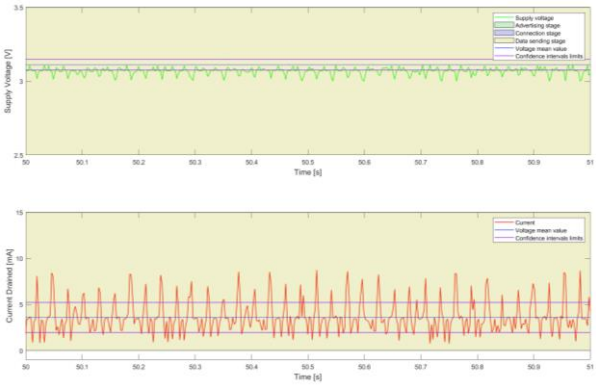

Figure 7.2.7.18 – Current and voltage 1s plot.

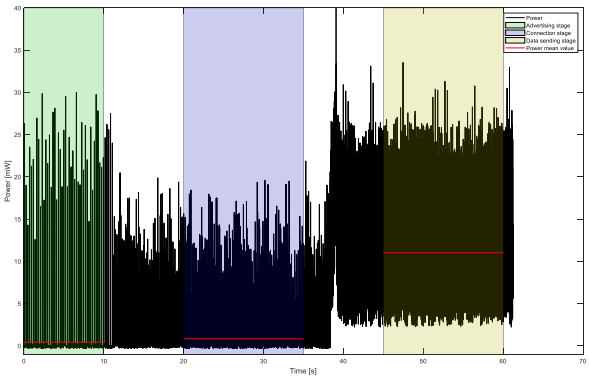

Figure 7.2.7.19 – Calculated power data plot.

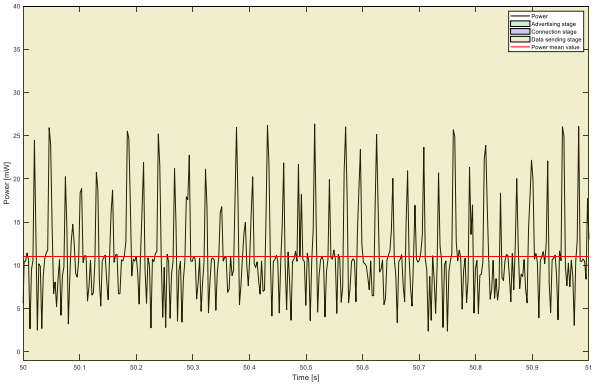

Figure 7.2.7.20 – Power data 1s plot.

Table 7.2.7.1 presents a summary of the main values obtained during the five repetitions performed with the actual enable sensors configuration.

Table 7.2.7.1 – Electrical values with just the accelerometer sensor active.

	Advertising			Connecting			Transmitting		
Test	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.123	10.046	3.26	0.229	7.361	3.26	3.498	11.136	3.22
2	0.123	9.903	3.20	0.233	6.585	3.20	3.486	11.456	3.16
3	0.124	9.813	3.18	0.234	6.164	3.19	3.509	11.308	3.15
4	0.131	9.559	3.16	0.256	7.641	3.17	3.575	11.212	3.13
5	0.137	9.969	3.14	0.265	6.289	3.15	3.597	11.279	3.12

7.3. Electrical power results analysis

After having performed all the tests with the different active sensors combinations and for both data acquisition rates it is possible to identify from the plots obtained from MATLAB that the data transmission stage is always where the mean power value is higher from the other two stages. To calculate the mean amount of power needed to operate the board for this application during data transmission stage the values of mean current and voltage obtained from the previous tests are considered. Table 7.3.1 and Table 7.3.2 show the mean power value calculated for every test and a mean of them for an output data rate of 25Hz and 120Hz respectively.

Table 7.3.1 – Mean power values by test for all data transmission stage with different sensors active configurations at 25Hz.

Sensors enabled	Test 1	Test 2	Test 3	Test 4	Test 5	Tests mean	Unit
All on	4.79	4.82	4.83	4.78	4.80	4.80	mW
Acc + Press	3.26	3.25	3.41	3.36	3.37	3.33	
Acc + Hum	3.55	3.43	3.39	3.40	3.40	3.43	
Acc + Mag	4.82	4.78	4.75	4.73	4.73	4.76	
Acc + Prox	3.37	3.34	3.32	3.31	3.30	3.32	
Acc + Pedom	3.47	3.45	3.43	3.42	3.40	3.43	
Just Acc on	3.41	3.42	3.42	3.40	3.35	3.40	

Table 7.3.2 – Mean power values by test for all data transmission stage with different sensor active configurations at 120Hz.

Sensors enabled	Test 1	Test 2	Test 3	Test 4	Test 5	Tests mean	Unit
All on	13.52	13.47	13.64	13.56	13.45	13.52	mW
Acc + Press	11.02	11.10	11.03	10.93	10.91	10.99	
Acc + Hum	11.24	11.23	11.12	10.96	11.07	11.12	
Acc + Mag	14.22	14.20	14.07	13.81	13.93	14.04	
Acc + Prox	10.76	10.68	10.80	10.79	10.81	10.76	
Acc + Pedom	11.10	10.79	11.06	10.85	11.02	10.96	
Just Acc on	11.04	10.85	10.86	10.99	11.01	10.95	

Figure 7.3.1 shows a graphics of the comparison between the mean power values calculated for each active sensor configuration for both data acquisition rates showing better the difference in the amount of energy demanded from the battery.

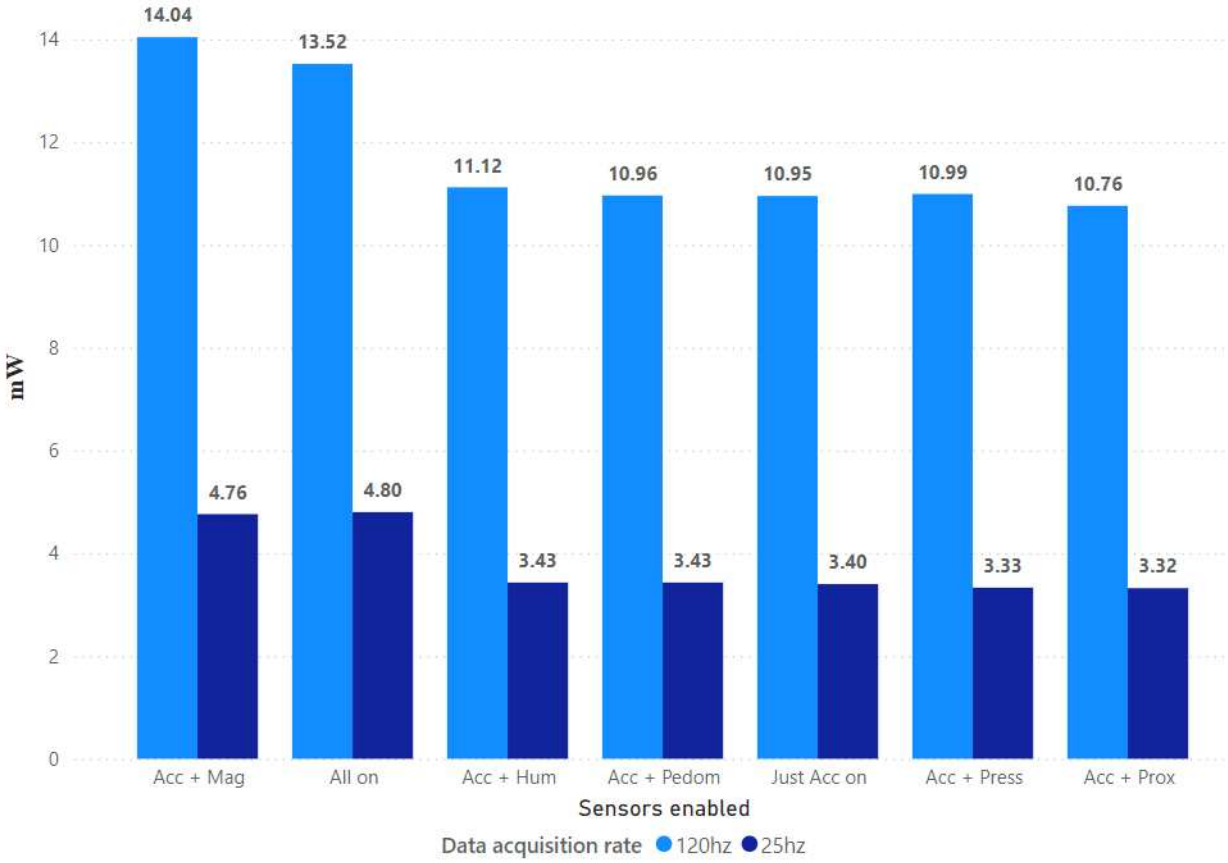

Figure 7.3.1 – Mean power values with different active sensor configuration during all data transmission stage for different data acquisition rates.

Considering just a second of every test in the data transmission stage it is possible to repeat the analysis to obtain a value of a mean just for this period to try to approximate a rate of power needed per second. Table 7.3.3 and Table 7.3.4 show the values of power per second calculated considering the 50th second of each test and active sensors configuration for tests performed at 25Hz and 120Hz respectively and Figure 7.3.2 shows the comparison between mean power obtained in a second of time during data transmission stage for both data acquisition rates.

Table 7.3.3 – Mean power values by test for one second of data transmission stage with different sensors active configurations at 25Hz.

Sensors enabled	Test 1	Test 2	Test 3	Test 4	Test 5	Tests mean	Unit
All on	4.72	4.74	4.80	4.73	4.81	4.77	mW
Acc + Press	3.36	3.22	3.63	3.42	3.54	3.43	
Acc + Hum	3.54	3.39	3.33	3.36	3.57	3.43	
Acc + Mag	4.71	4.84	4.81	4.71	4.82	4.77	
Acc + Prox	3.36	3.34	3.22	3.27	3.31	3.30	
Acc + Pedom	3.64	3.37	3.41	3.63	3.22	3.45	
Just Acc on	3.52	3.56	3.72	3.22	3.50	3.50	

Table 7.3.4 – Mean power values by test for one second of data transmission stage with different sensors active configurations at 120Hz.

Sensors enabled	Test 1	Test 2	Test 3	Test 4	Test 5	Tests mean	Unit
All on	13.64	13.39	13.72	13.44	13.45	13.52	mW
Acc + Press	10.92	10.94	10.73	10.88	10.68	10.83	
Acc + Hum	10.97	11.47	11.17	10.78	10.86	11.05	
Acc + Mag	13.93	13.85	13.59	13.73	13.87	13.79	
Acc + Prox	10.86	10.86	10.64	10.72	10.28	10.67	
Acc + Pedom	10.77	10.86	11.30	11.01	10.92	10.97	
Just Acc on	11.08	10.83	10.92	10.79	11.27	10.97	

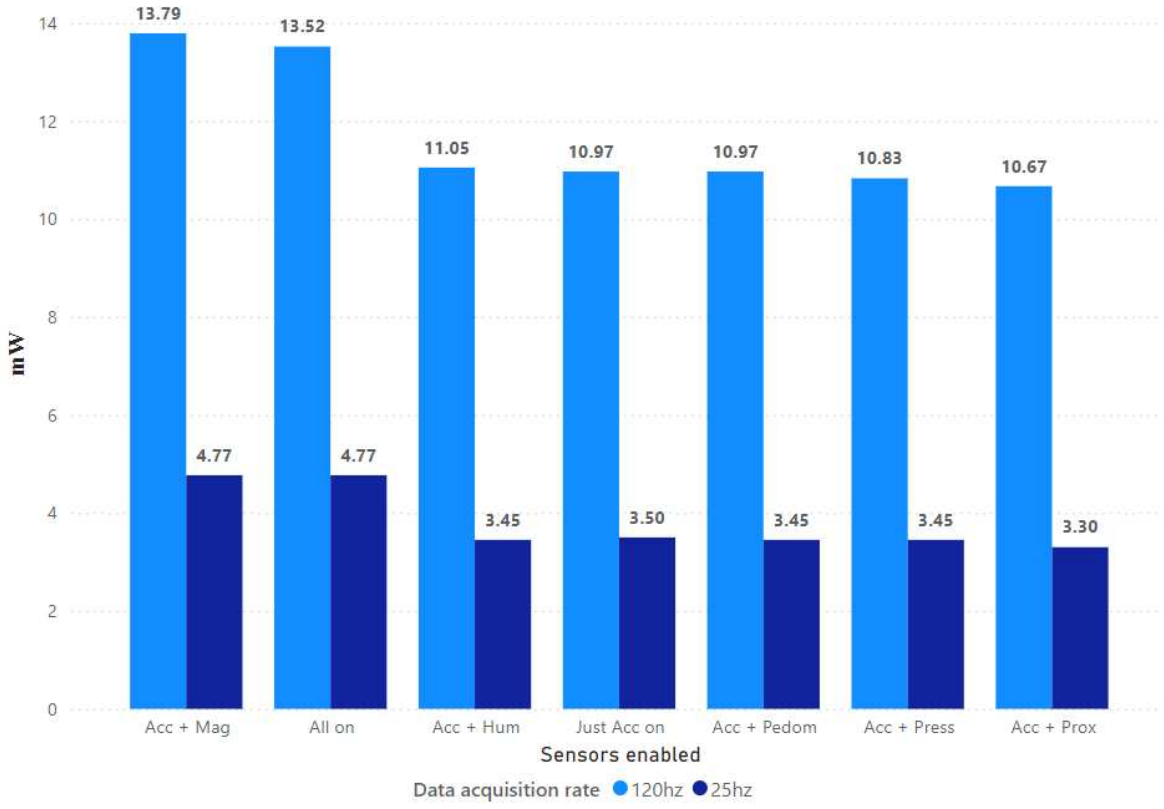

Figure 7.3.2 – Mean power values with different active sensor configuration during a second of data transmission stage for different data acquisition rates.

8. On-body accelerometer testing

The many analyses of energy consumption presented in previous chapters were done using the sensor board in non-realistic situations as part of the developing process. Now, a test using the STEVAL-BCN002V1B in a more intuitive application was performed to collect the acceleration and power consumption data defining some controlled conditions. The test consists in positioning the device, Arduino and PCB designed board, inside a bag strapped to a person's leg while walking on a treadmill at different speeds while obtaining the energy consumption data using a PC and the accelerations obtained using the mobile app.

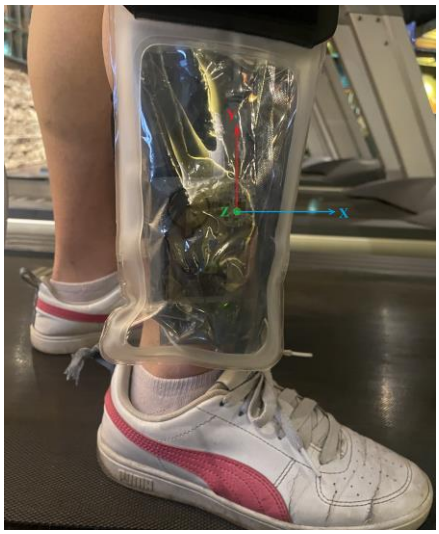

Figure 8.1 – Treadmill test fist parameters settings.

8.1. First speed configuration test

The test consists in collecting power data while a person is walking on a treadmill. The sensor's linear acceleration sensitivity was set to ±16 g and the times to change between advertising, connection and data transmission stages are the same as described in section 6.5. The treadmill settings used by the user for the first test can be observed in Figure 8.1.1.

Figure 8.1.1 – Treadmill test fist parameters settings.

8.1.1 Accelerometer data acquisition at 25Hz

For repetition number 1 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.1.1 and Figure 8.1.1.2 shows a second of the data transmission interval while Figure 8.1.1.3 shows the power calculated, Figure 8.1.1.4 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.1.1.5.

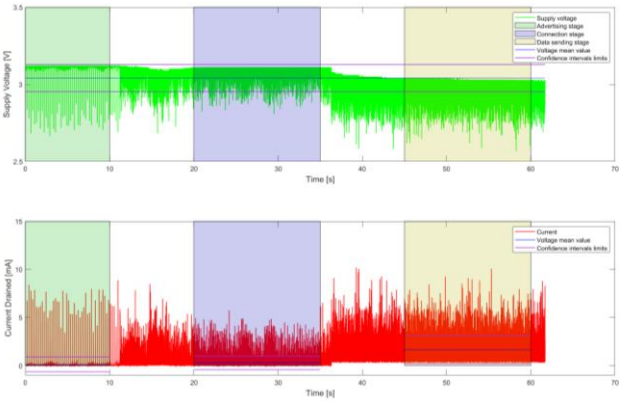

Figure 8.1.1.1 – Voltage and current plot.

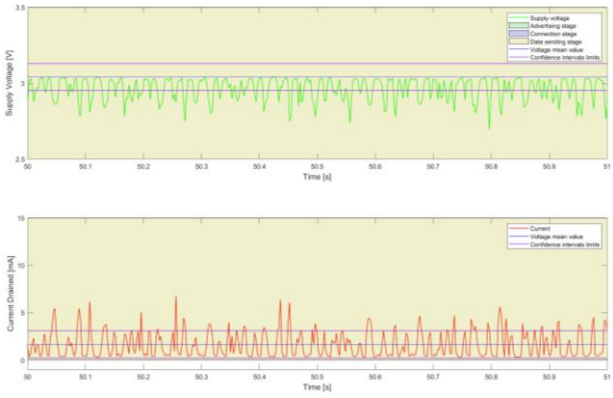

Figure 8.1.1.2 – Current and voltage 1s plot.

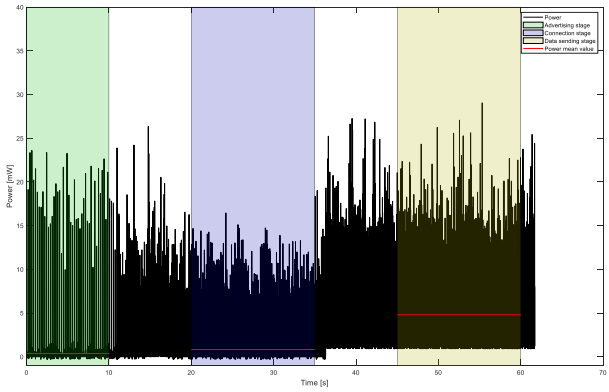

Figure 8.1.1.3 – Calculated power data plot.

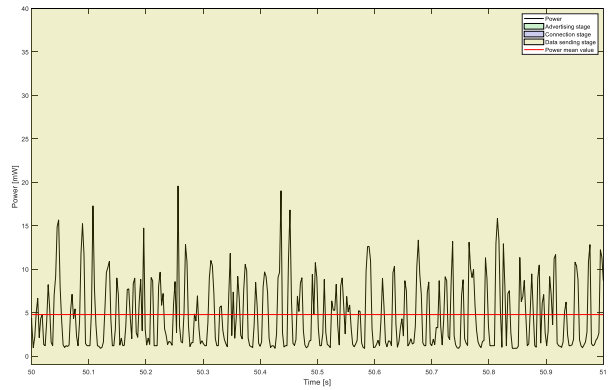

Figure 8.1.1.4 – Power data 1s plot.

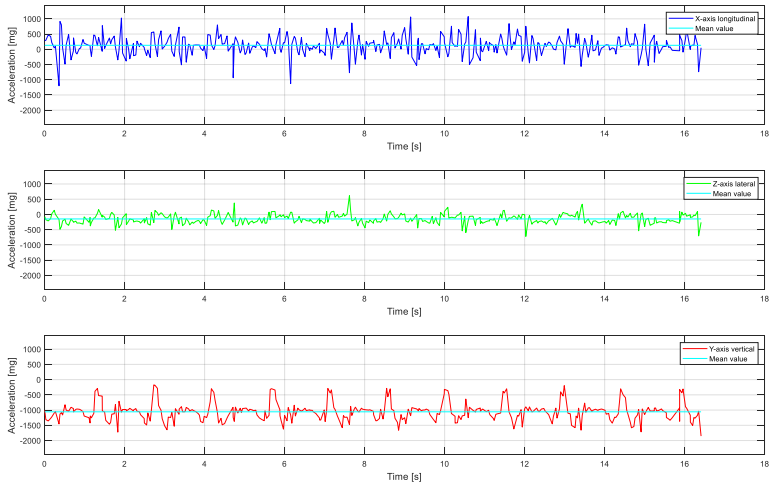

Figure 8.1.1.5 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 2 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.1.6 and Figure 8.1.1.7 shows a second of the data transmission interval while Figure 8.1.1.8 shows the power calculated, Figure 8.1.1.9 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.1.1.10.

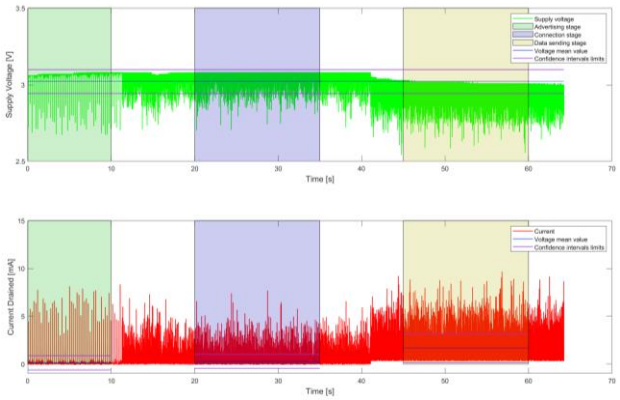

Figure 8.1.1.6 – Voltage and current plot.

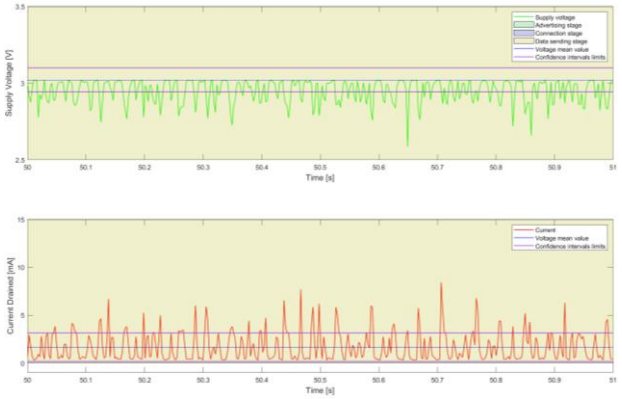

Figure 8.1.1.7 – Current and voltage 1s plot.

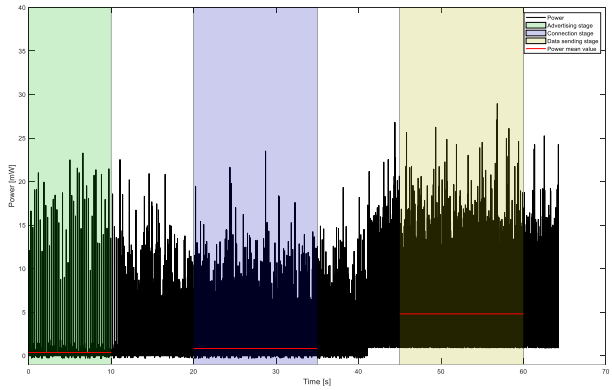

Figure 8.1.1.8 – Calculated power data plot.

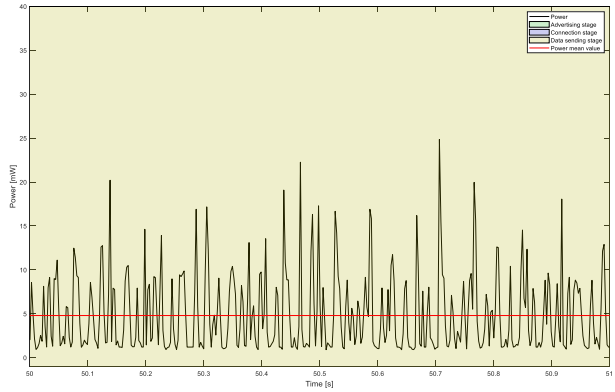

Figure 8.1.1.9 – Power data 1s plot.

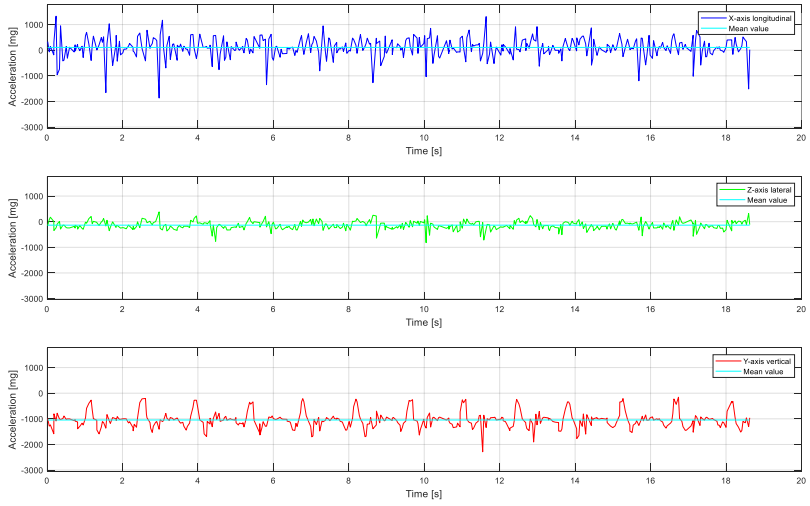

Figure 8.1.1.10 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 3 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.1.11 and Figure 8.1.1.12 shows a second of the data transmission interval while Figure 8.1.1.13 shows the power calculated, Figure 8.1.1.14 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.1.1.15.

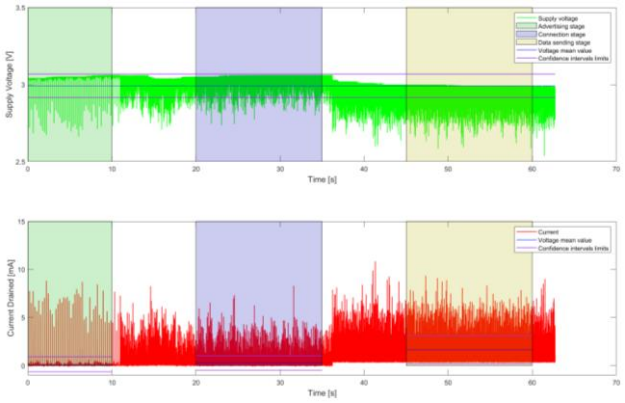

Figure 8.1.1.11 – Voltage and current plot.

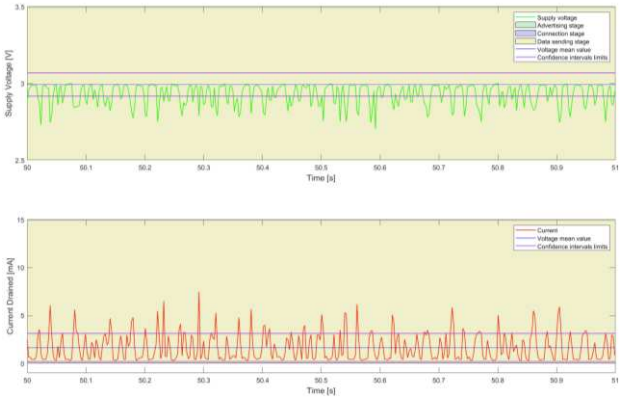

Figure 8.1.1.12 – Current and voltage 1s plot.

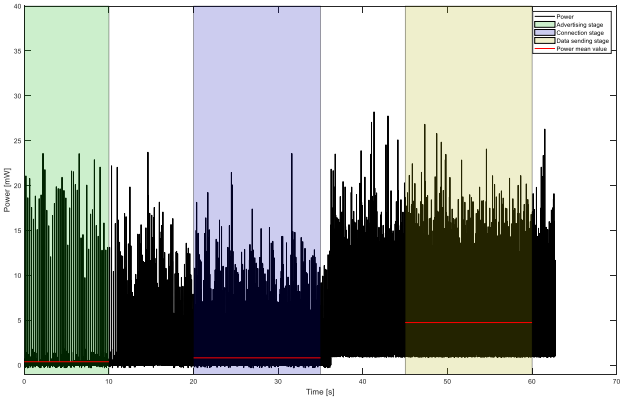

Figure 8.1.1.13 – Calculated power data plot.

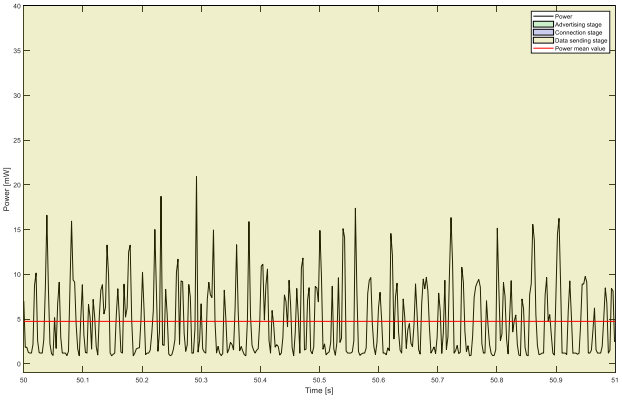

Figure 8.1.1.14 – Power data 1s plot.

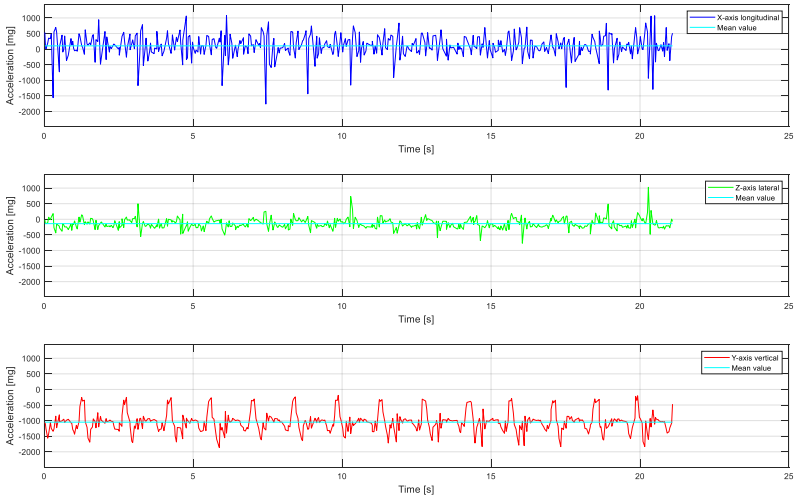

Figure 8.1.1.15 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 4 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.1.16 and Figure 8.1.1.17 shows a second of the data transmission interval while Figure 8.1.1.18 shows the power calculated, Figure 8.1.1.19 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.1.1.20.

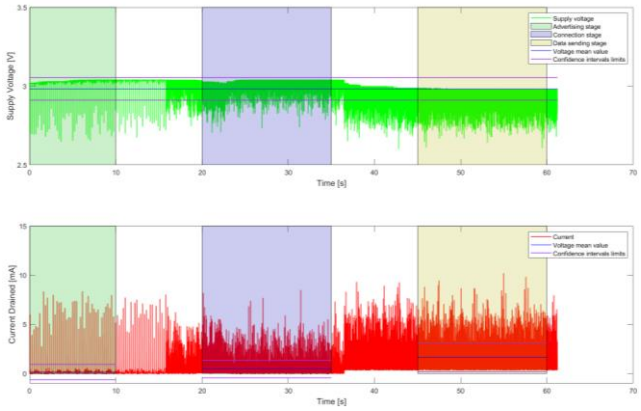

Figure 8.1.1.16 – Voltage and current plot.

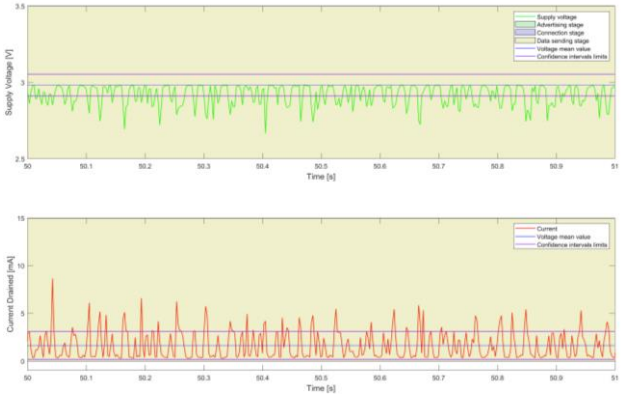

Figure 8.1.1.17 – Current and voltage 1s plot.

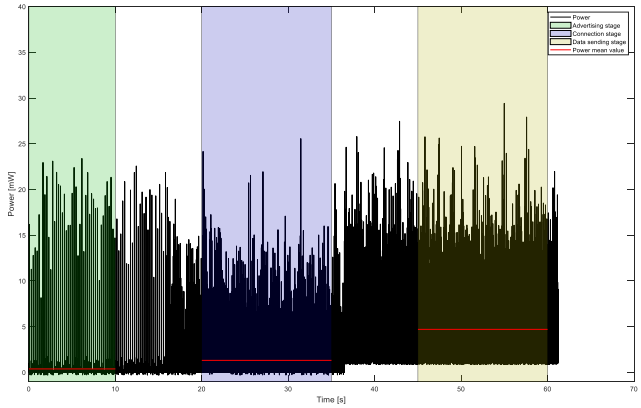

Figure 8.1.1.18 – Calculated power data plot.

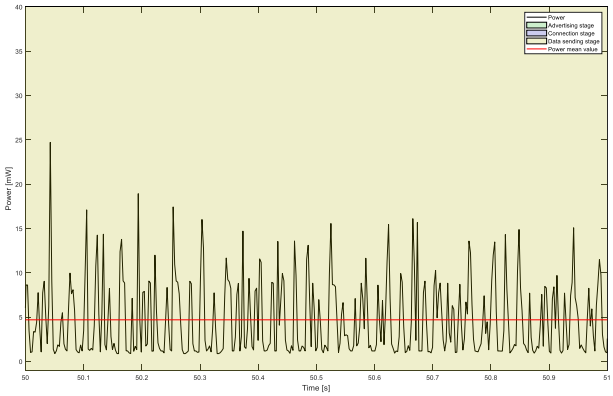

Figure 8.1.1.19 – Power data 1s plot.

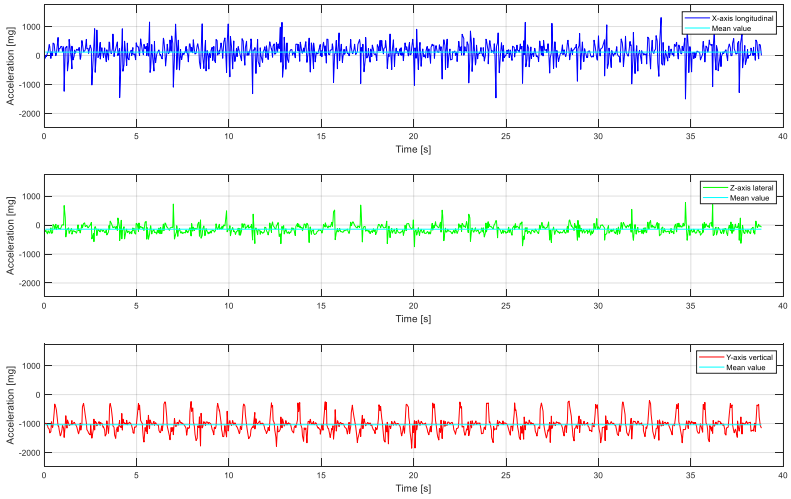

Figure 8.1.1.20 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 5 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.1.21 and Figure 8.1.1.22 shows a second of the data transmission interval while Figure 8.1.1.23 shows the power calculated, Figure 8.1.1.24 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.1.1.25.

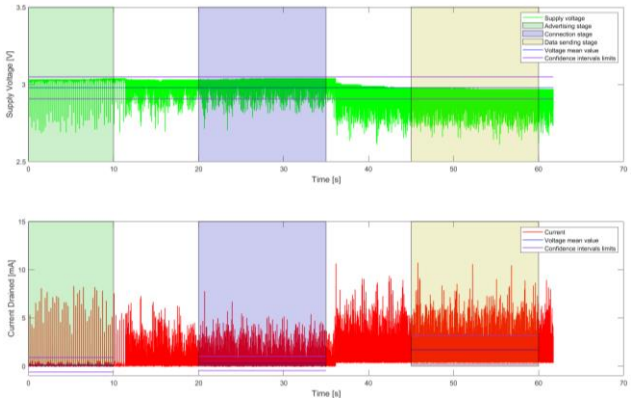

Figure 8.1.1.21 – Voltage and current plot.

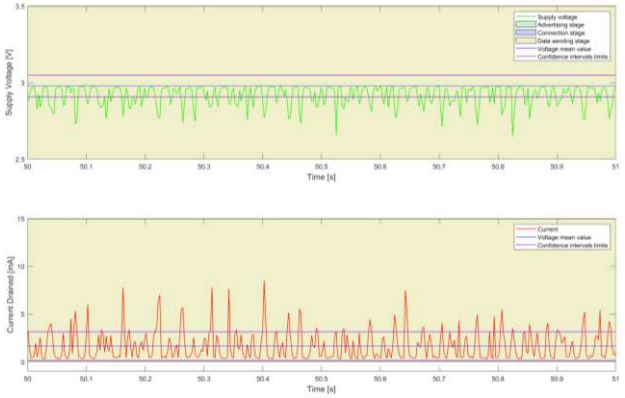

Figure 8.1.1.22 – Current and voltage 1s plot.

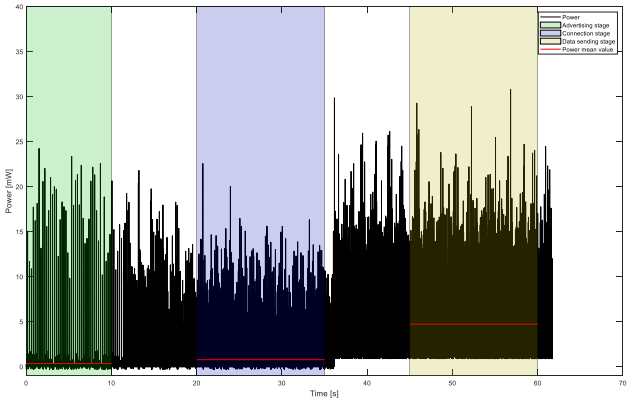

Figure 8.1.1.23 – Calculated power data plot.

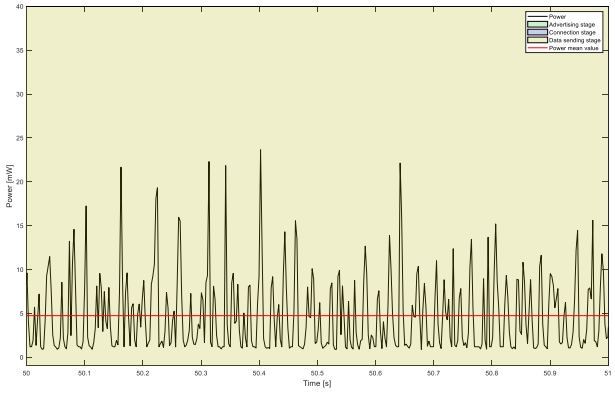

Figure 8.1.1.24 – Power data 1s plot.

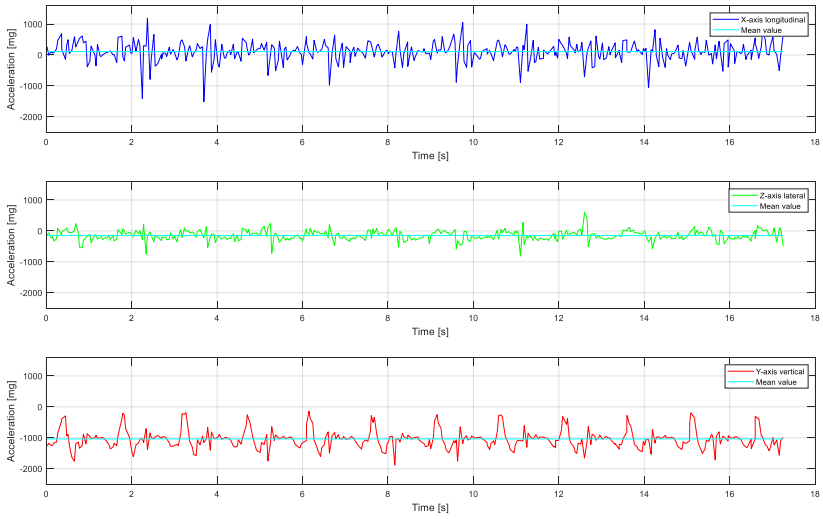

Figure 8.1.1.25 – Acceleration values for the last 15 seconds using the mobile app.

The obtained data for the five repetitions of the test performed are shown in Table 8.1.1.1.

Table 8.1.1.1 – Electrical values from walking at fist speed and data collected at 25Hz.

	Advertising			Connecting			Transmitting		
Repetition	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.126	8.398	3.12	0.268	5.737	3.11	1.646	10.082	3.04
2	0.128	8.126	3.08	0.273	7.685	3.08	1.655	9.679	3.03
3	0.130	8.828	3.06	0.270	8.300	3.06	1.644	9.360	3.00
4	0.132	8.359	3.04	0.440	8.492	3.04	1.635	10.194	2.99
5	0.123	8.296	3.04	0.263	7.767	3.04	1.647	10.722	2.98

8.1.2 Accelerometer data acquisition at 120Hz

For repetition number 1 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.2.1 and Figure 8.1.2.2 shows a second of the data transmission interval while Figure 8.1.2.3 shows the power calculated, Figure 8.1.2.4 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.1.2.5.

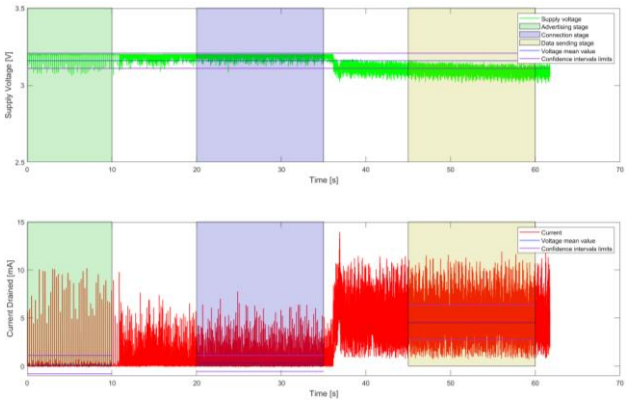

Figure 8.1.2.1 – Voltage and current plot.

Figure 8.1.2.2 – Current and voltage 1s plot.

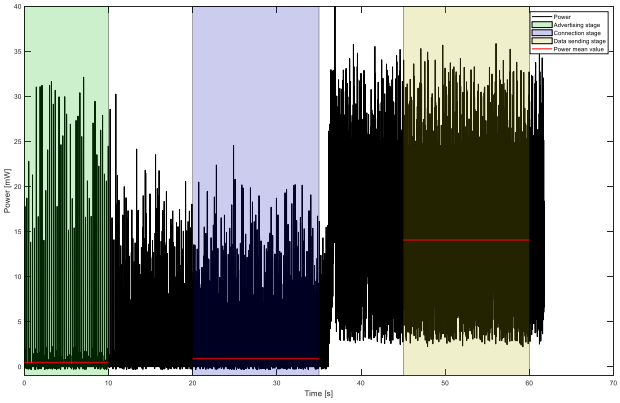

Figure 8.1.2.3 – Calculated power data plot.

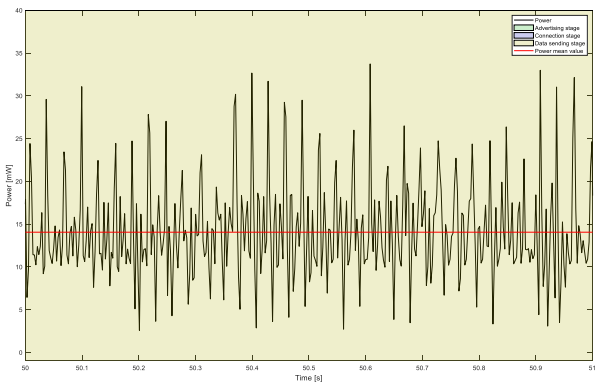

Figure 8.1.2.4 – Power data 1s plot.

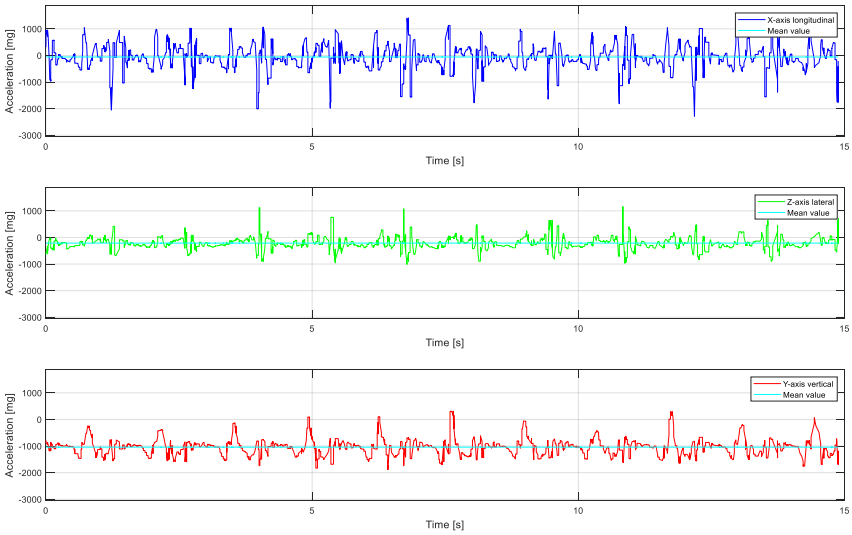

Figure 8.1.2.5 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 2 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.2.6 and Figure 8.1.2.7 shows a second of the data transmission interval while Figure 8.1.2.8 shows the power calculated, Figure 8.1.2.9 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.1.2.10.

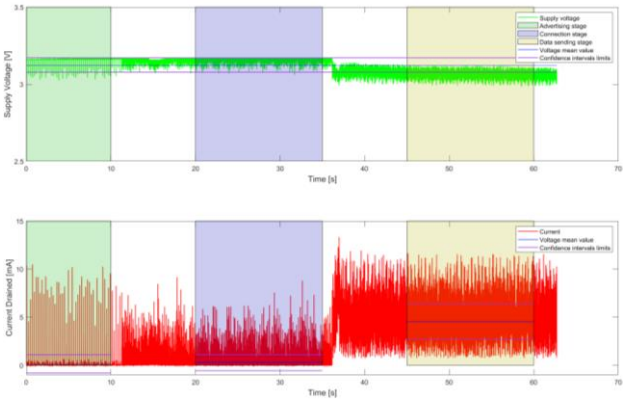

Figure 8.1.2.6 – Voltage and current plot.

Figure 8.1.2.7 – Current and voltage 1s plot.

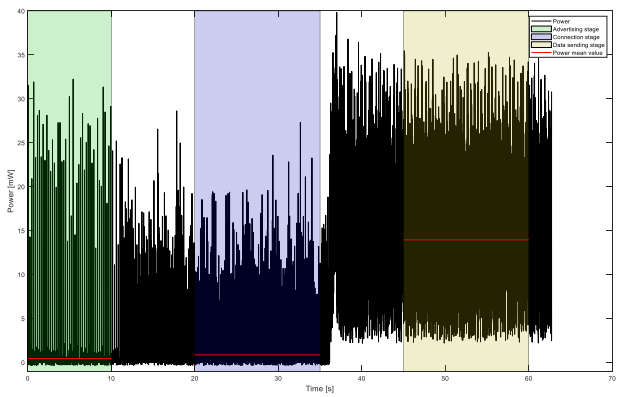

Figure 8.1.2.8 – Calculated power data plot.

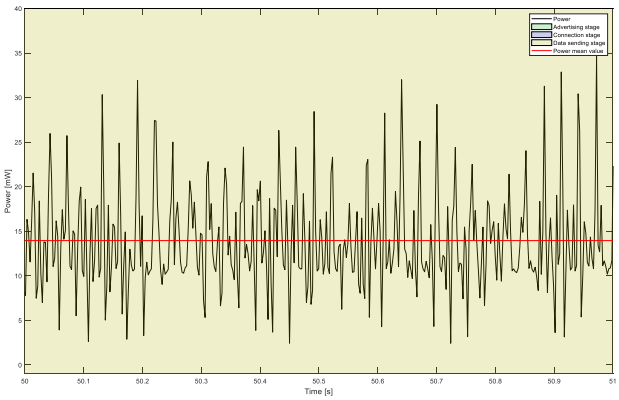

Figure 8.1.2.9 – Power data 1s plot.

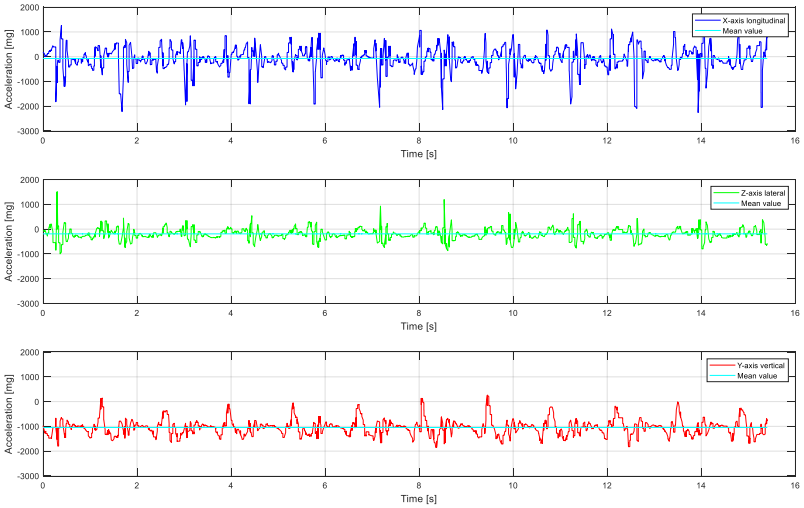

Figure 8.1.2.10 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 3 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.1.11 and Figure 8.1.1.12 shows a second of the data transmission interval while Figure 8.1.1.13 shows the power calculated, Figure 8.1.1.14 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.1.1.15.

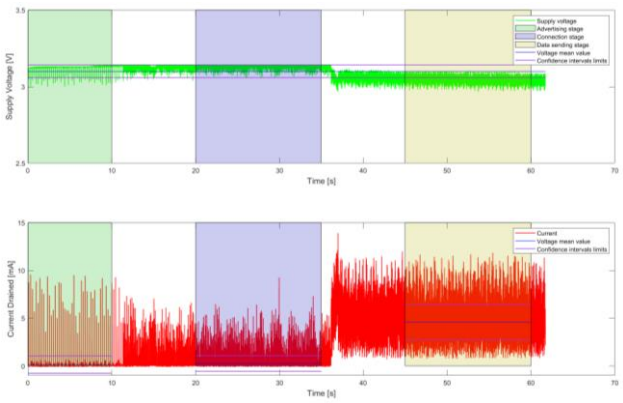

Figure 8.1.2.11 – Voltage and current plot.

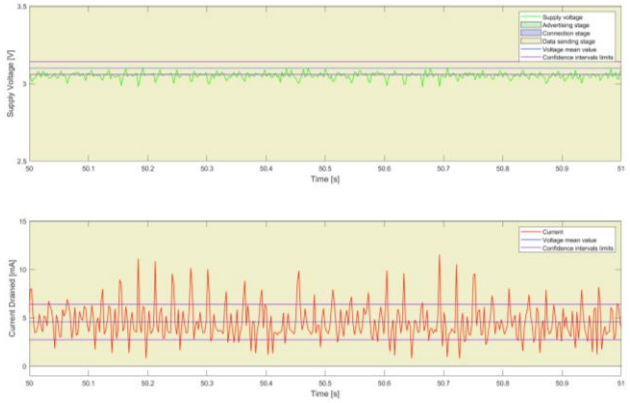

Figure 8.1.2.12 – Current and voltage 1s plot.

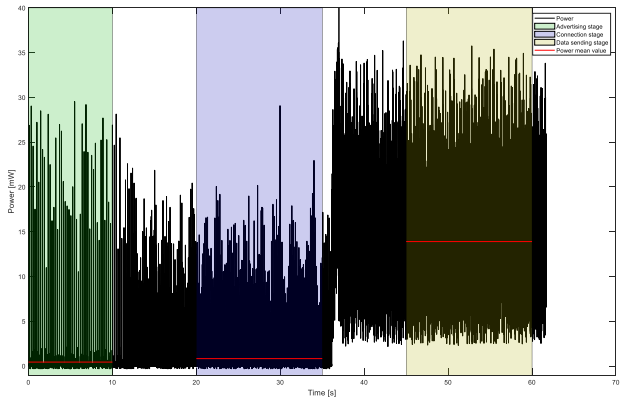

Figure 8.1.2.13 – Calculated power data plot.

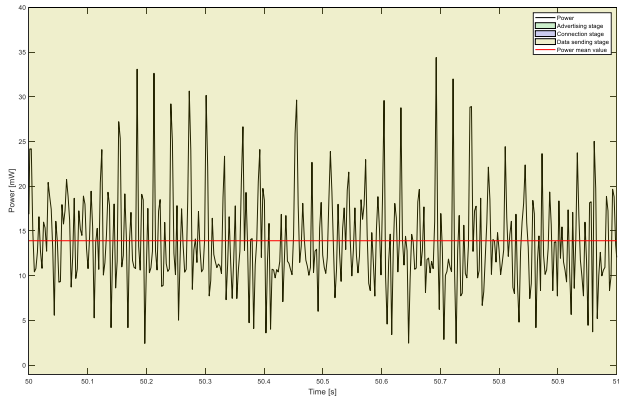

Figure 8.1.2.14 – Power data 1s plot.

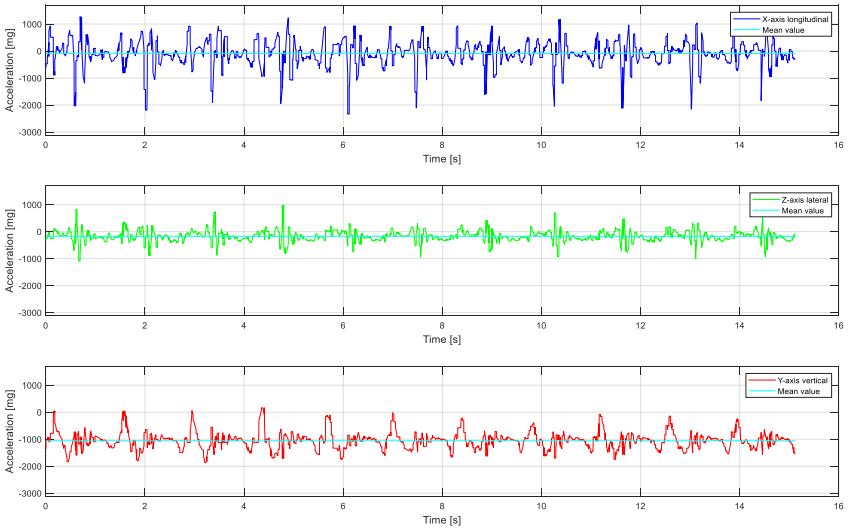

Figure 8.1.2.15 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 4 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.2.16 and Figure 8.1.2.17 shows a second of the data transmission interval while Figure 8.1.2.18 shows the power calculated, Figure 8.1.2.19 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.1.2.20.

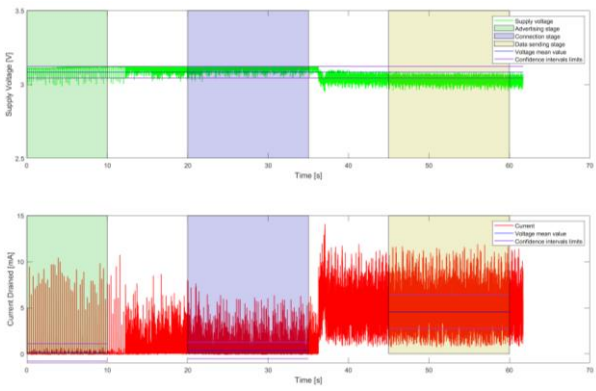

Figure 8.1.2.16 – Voltage and current plot.

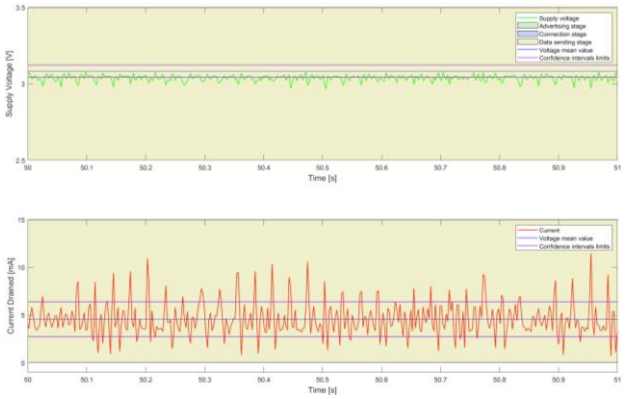

Figure 8.1.2.17 – Current and voltage 1s plot.

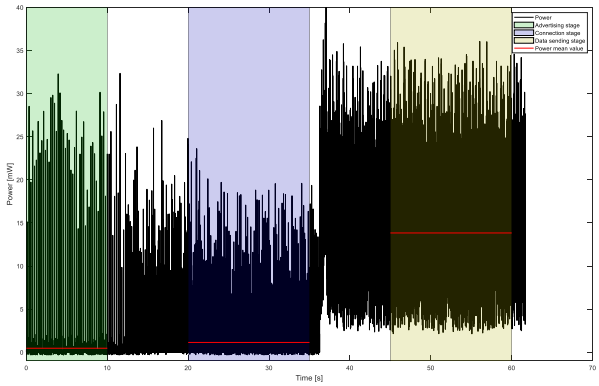

Figure 8.1.2.18 – Calculated power data plot.

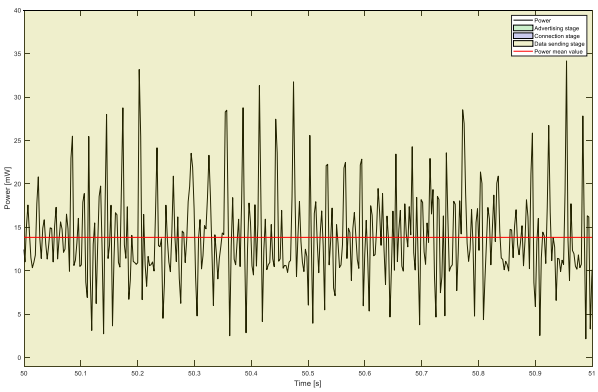

Figure 8.1.2.19 – Power data 1s plot.

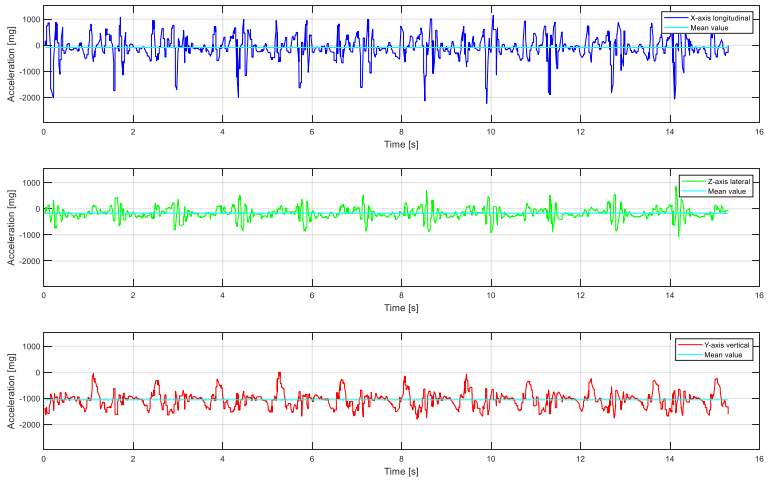

Figure 8.1.2.20 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 5 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.1.2.21 and Figure 8.1.2.22 shows a second of the data transmission interval while Figure 8.1.2.23 shows the power calculated, Figure 8.1.2.24 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.1.2.25.

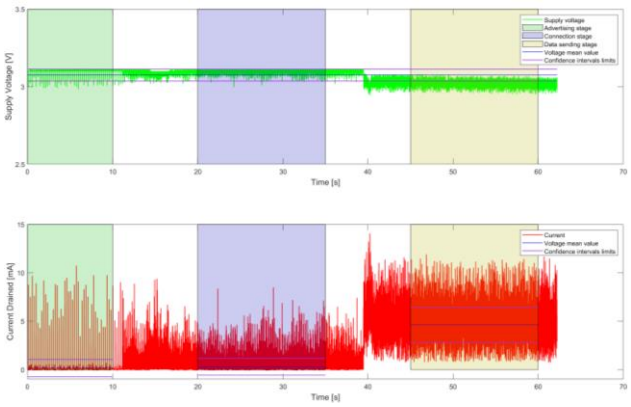

Figure 8.1.1.21 – Voltage and current plot.

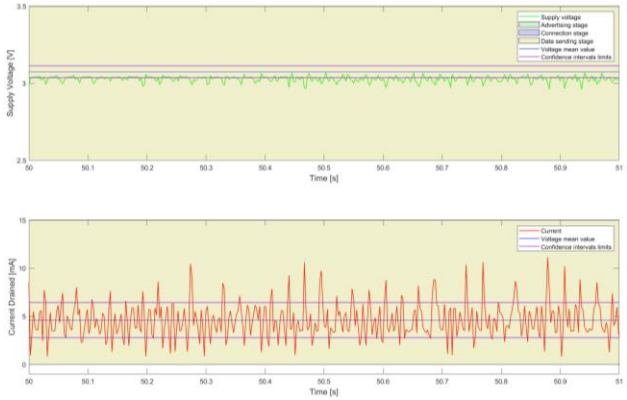

Figure 8.1.1.22 – Current and voltage 1s plot.

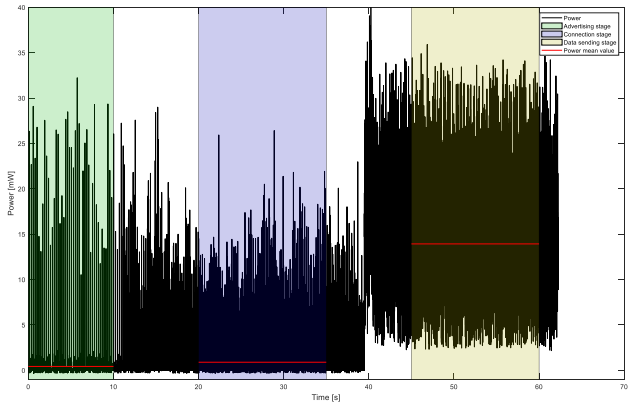

Figure 8.1.2.23 – Calculated power data plot.

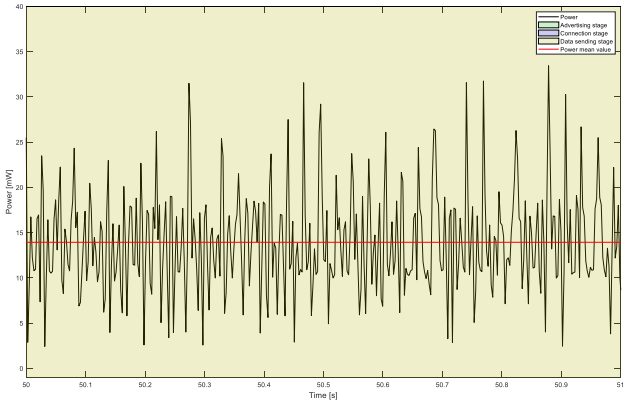

Figure 8.1.2.24 – Power data 1s plot.

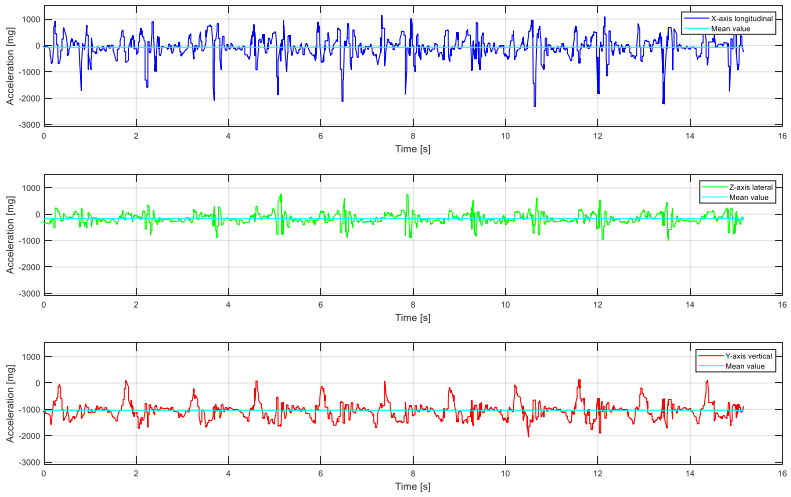

Figure 8.1.2.25 – Acceleration values for the last 15 seconds using the mobile app.

The obtained data for the five repetitions of the test performed are shown in Table 8.1.2.1.

Table 8.1.2.1 – Electrical values from walking at fist speed and data collected at 120Hz.

	Advertising			Connecting			Transmitting		
Repetition	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.151	10.184	3.20	0.274	7.750	3.20	4.541	11.902	3.16
2	0.145	10.495	3.17	0.274	8.801	3.17	4.551	11.686	3.12
3	0.144	9.565	3.14	0.266	9.261	3.14	4.563	11.848	3.10
4	0.152	10.432	3.12	0.367	7.916	3.12	4.562	11.911	3.09
5	0.140	10.744	3.11	0.287	8.498	3.11	4.608	11.908	3.08

8.2. Second speed configuration test

The test consists in collecting power data while a person is walking on a treadmill. The sensor's linear acceleration sensitivity was set to ±16 g and the times to change between advertising, connection and data transmission stages are the same as described in section 6.5. The treadmill settings used by the user for the first test can be observed in Figure 8.2.1.

Figure 8.2.1 – Treadmill test second parameters settings.

8.2.1 Accelerometer data acquisition at 25Hz

For repetition number 1 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.1.1 and Figure 8.2.1.2 shows a second of the data transmission interval while Figure 8.2.1.3 shows the power calculated, Figure 8.2.1.4 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.2.1.5.

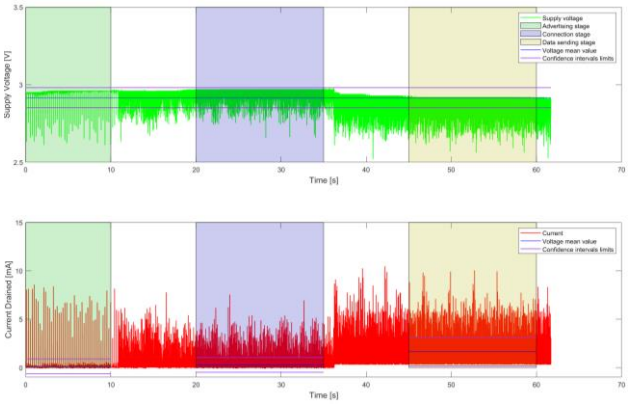

Figure 8.2.1.1 – Voltage and current plot.

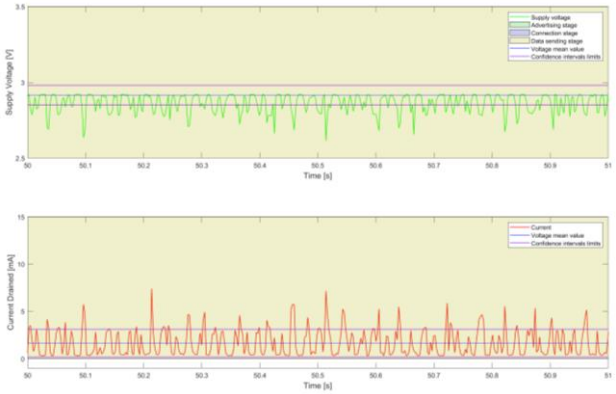

Figure 8.2.1.2 – Current and voltage 1s plot.

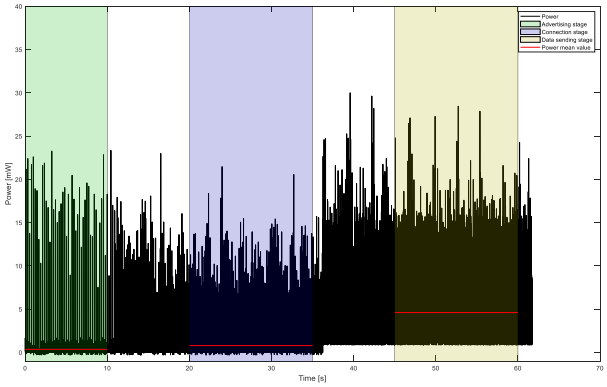

Figure 8.2.1.3 – Calculated power data plot.

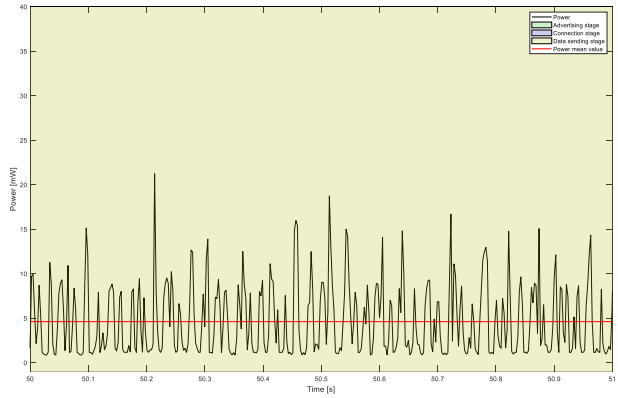

Figure 8.2.1.4 – Power data 1s plot.

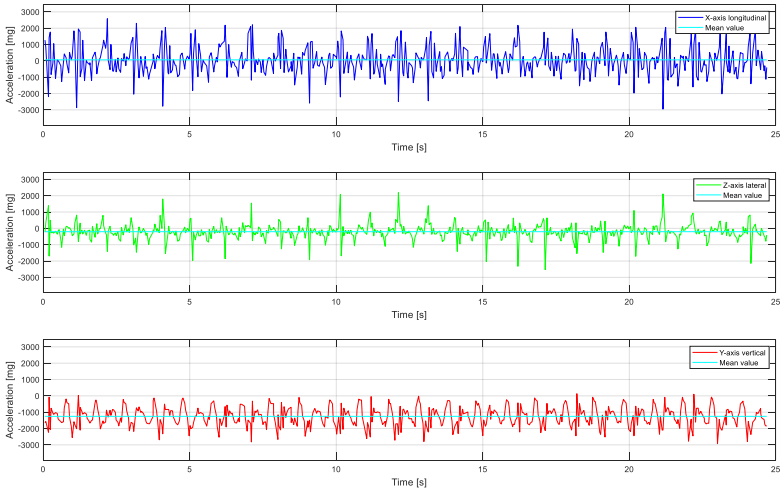

Figure 8.2.1.5 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 2 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.1.6 and Figure 8.2.1.7 shows a second of the data transmission interval while Figure 8.2.1.8 shows the power calculated, Figure 8.2.1.9 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.2.1.10.

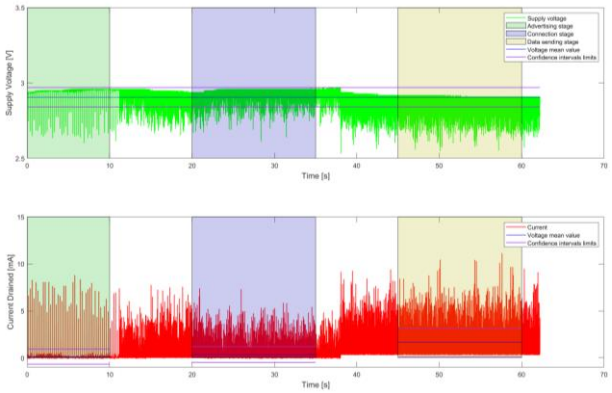

Figure 8.2.1.6 – Voltage and current plot.

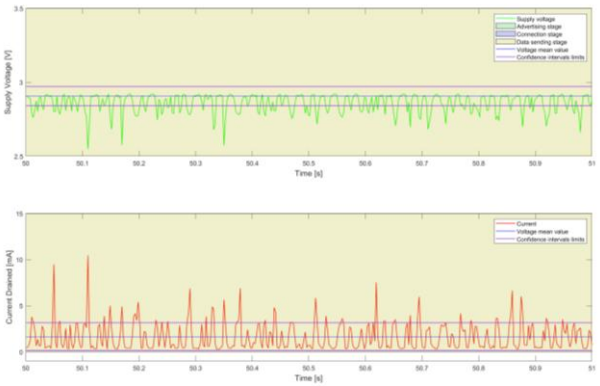

Figure 8.2.1.7 – Current and voltage 1s plot.

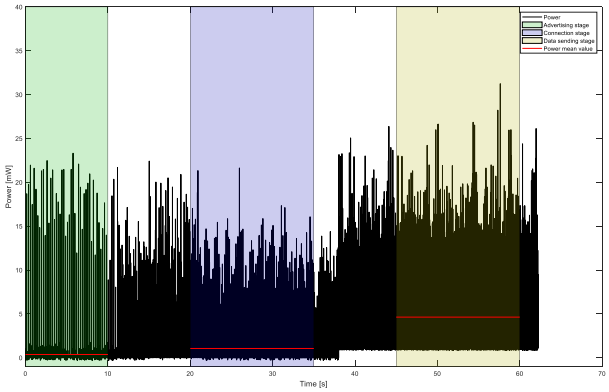

Figure 8.2.1.8 – Calculated power data plot.

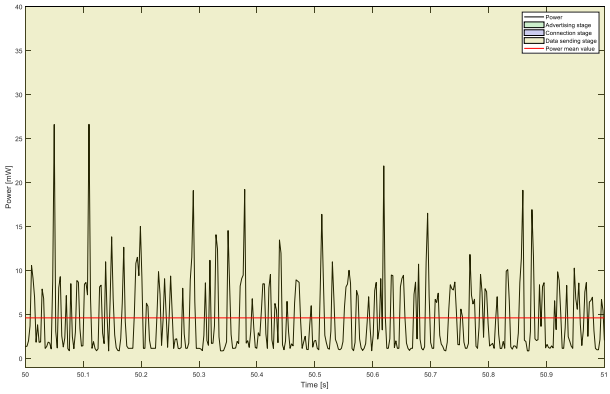

Figure 8.2.1.9 – Power data 1s plot.

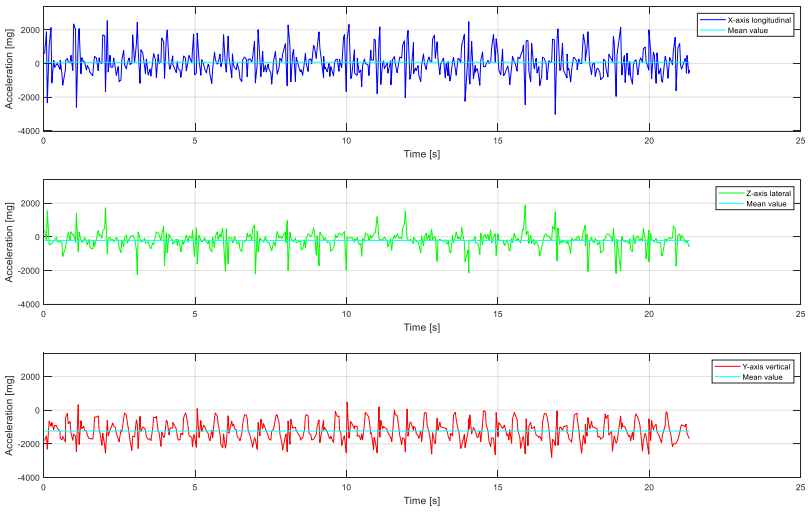

Figure 8.2.1.10 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 3 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.1.11 and Figure 8.2.1.12 shows a second of the data transmission interval while Figure 8.2.1.13 shows the power calculated, Figure 8.2.1.14 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.2.1.15.

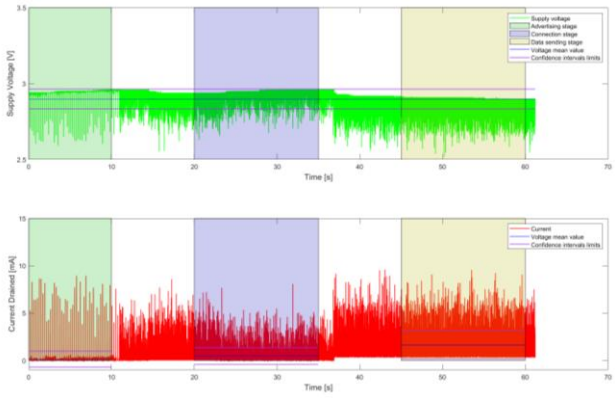

Figure 8.2.1.11 – Voltage and current plot.

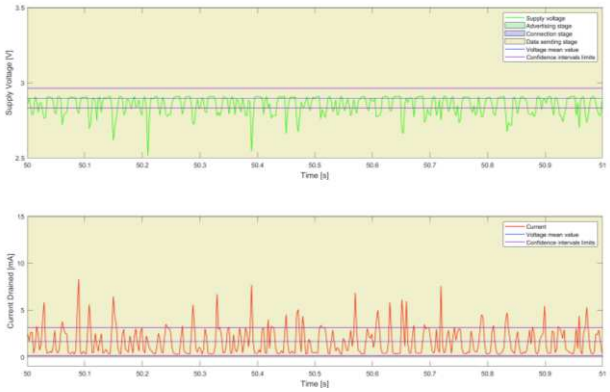

Figure 8.2.1.12 – Current and voltage 1s plot.

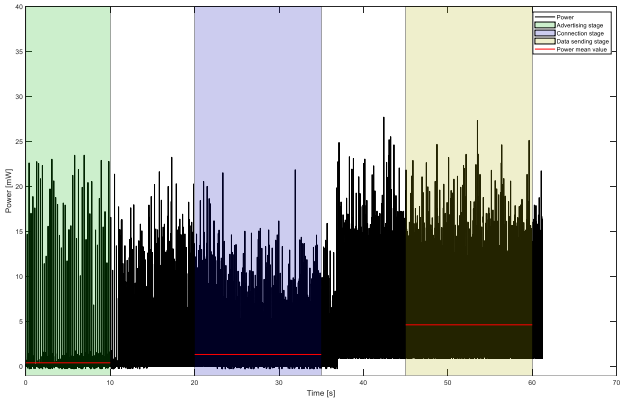

Figure 8.2.1.13 – Calculated power data plot.

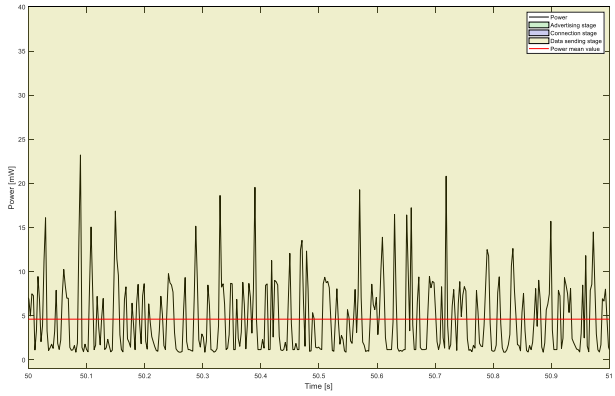

Figure 8.2.1.14 – Power data 1s plot.

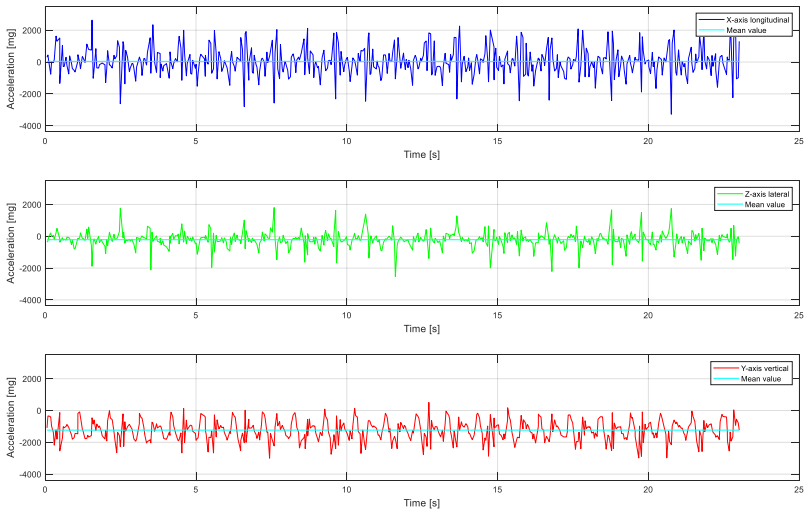

Figure 8.2.1.15 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 4 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.1.16 and Figure 8.2.1.17 shows a second of the data transmission interval while Figure 8.2.1.18 shows the power calculated, Figure 8.2.1.19 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.2.1.20.

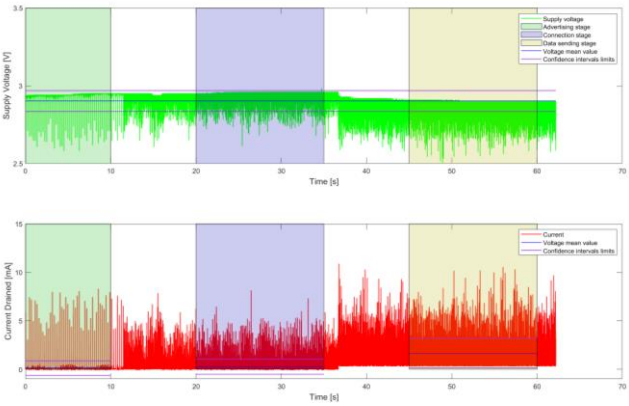

Figure 8.2.1.16 – Voltage and current plot.

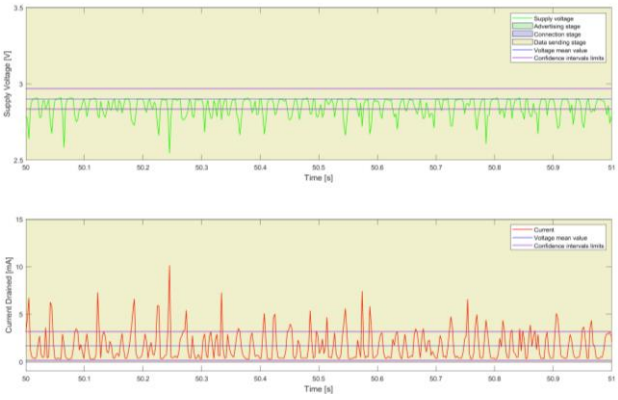

Figure 8.2.1.17 – Current and voltage 1s plot.

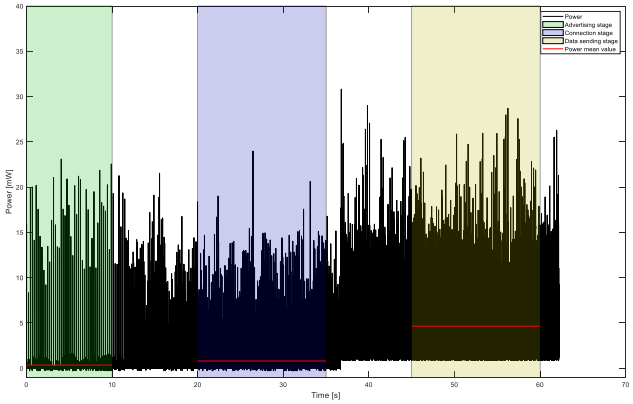

Figure 8.2.1.18 – Calculated power data plot.

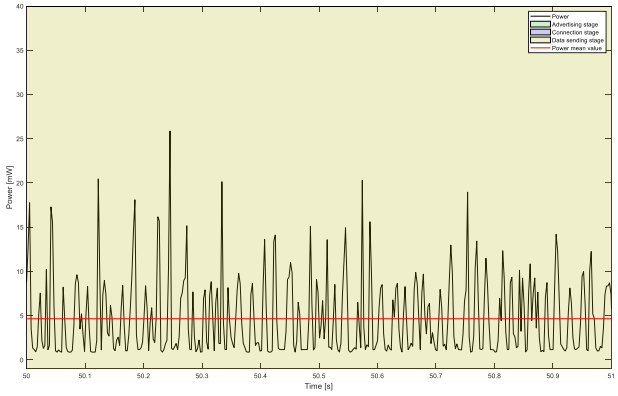

Figure 8.2.1.19 – Power data 1s plot.

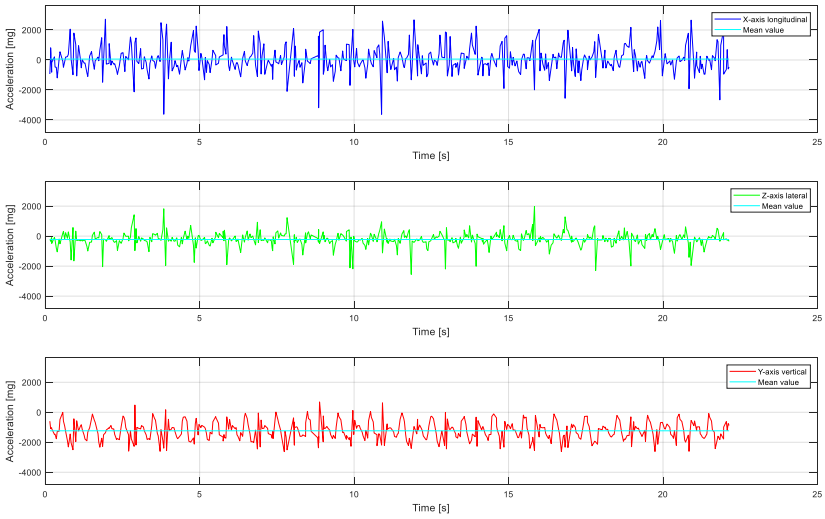

Figure 8.2.1.20 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 5 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.1.21 and Figure 8.2.1.22 shows a second of the data transmission interval while Figure 8.2.1.23 shows the power calculated, Figure 8.2.1.24 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.2.1.25.

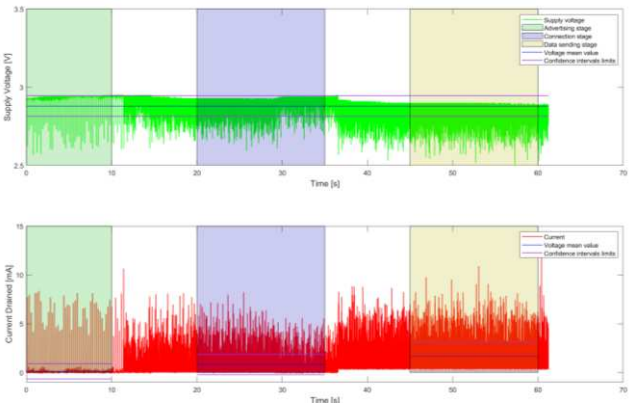

Figure 8.2.1.21 – Voltage and current plot.

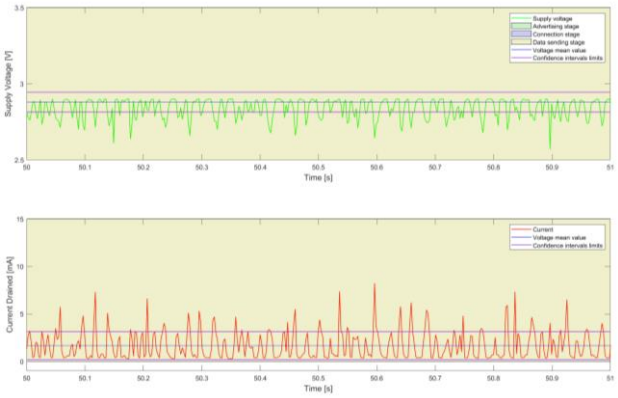

Figure 8.2.1.22 – Current and voltage 1s plot.

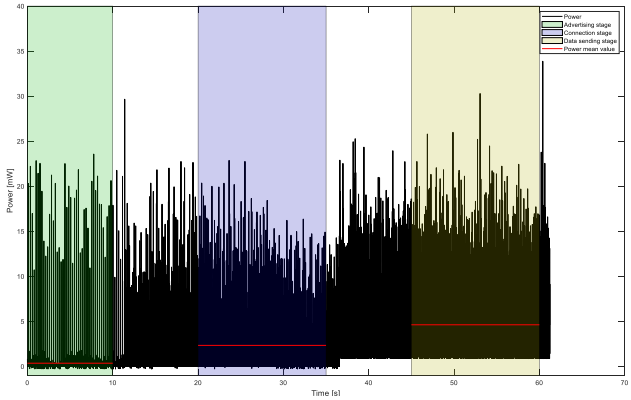

Figure 8.2.1.23 – Calculated power data plot.

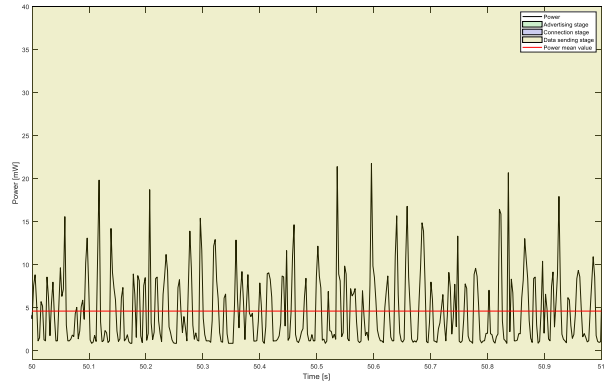

Figure 8.2.1.24 – Power data 1s plot.

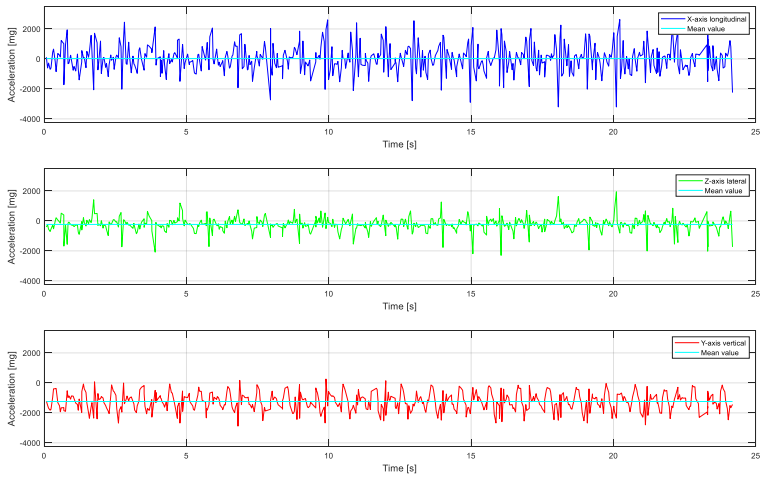

Figure 8.2.1.25 – Acceleration values for the last 15 seconds using the mobile app.

The obtained data for the five repetitions of the test performed are shown in Table 8.2.1.1.

Table 8.2.1.1 – Electrical values from running test.

	Advertising			Connecting			Transmitting		
Repetition	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.126	8.585	2.96	0.272	7.546	2.97	1.635	10.042	2.93
2	0.131	8.813	2.96	0.364	7.413	2.97	1.644	11.129	2.92
3	0.139	8.955	2.96	0.457	8.081	2.96	1.642	9.564	2.92
4	0.126	8.315	2.95	0.276	8.130	2.98	1.656	10.554	2.91
5	0.126	8.374	2.95	0.817	8.216	2.94	1.651	10.903	2.90

8.2.2 Accelerometer data acquisition at 120Hz

For repetition number 1 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.2.1 and Figure 8.2.2.2 shows a second of the data transmission interval while Figure 8.2.2.3 shows the power calculated, Figure 8.2.2.4 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.2.2.5.

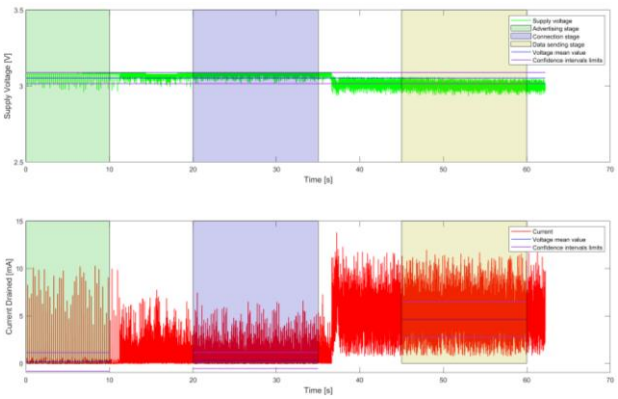

Figure 8.2.2.1 – Voltage and current plot.

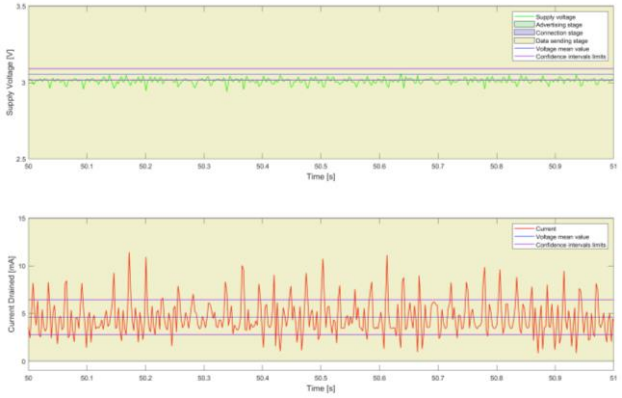

Figure 8.2.2.2 – Current and voltage 1s plot.

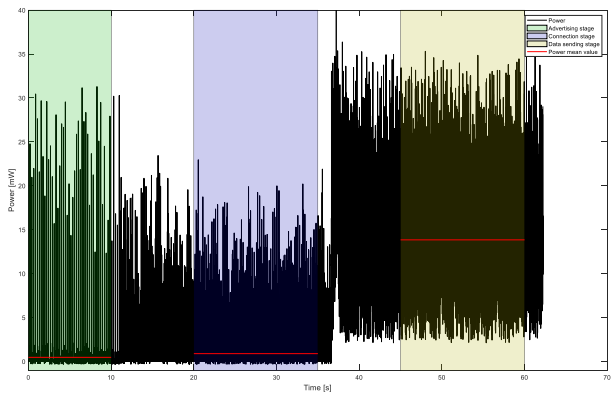

Figure 8.2.2.3 – Calculated power data plot.

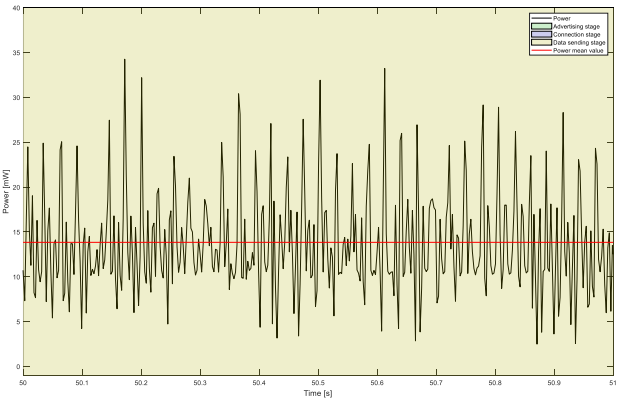

Figure 8.2.2.4 – Power data 1s plot.

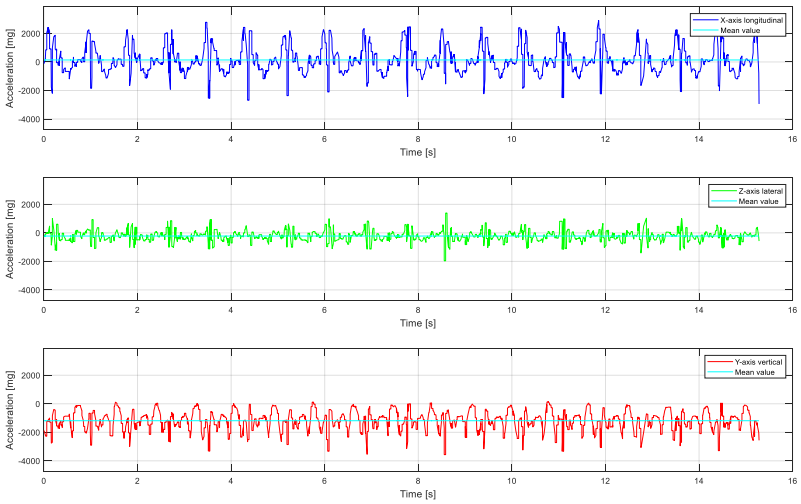

Figure 8.2.2.5 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 2 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.2.6 and Figure 8.2.2.7 shows a second of the data transmission interval while Figure 8.2.2.8 shows the power calculated, Figure 8.2.2.9 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.2.2.10.

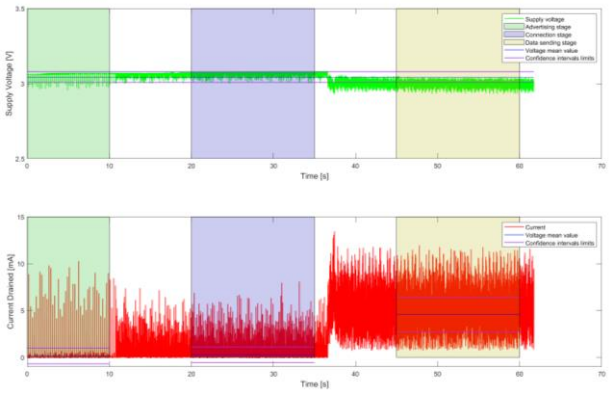

Figure 8.2.2.6 – Voltage and current plot.

Figure 8.2.2.7 – Current and voltage 1s plot.

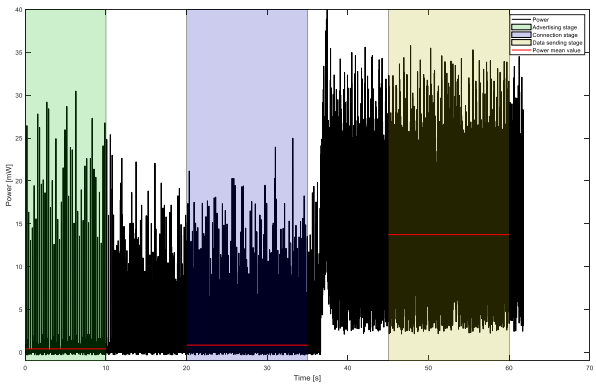

Figure 8.2.2.8 – Calculated power data plot.

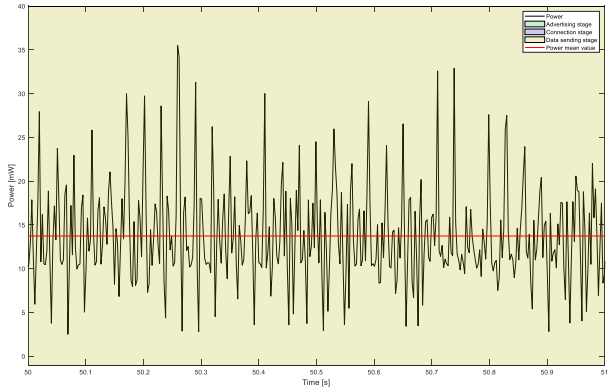

Figure 8.2.2.9 – Power data 1s plot.

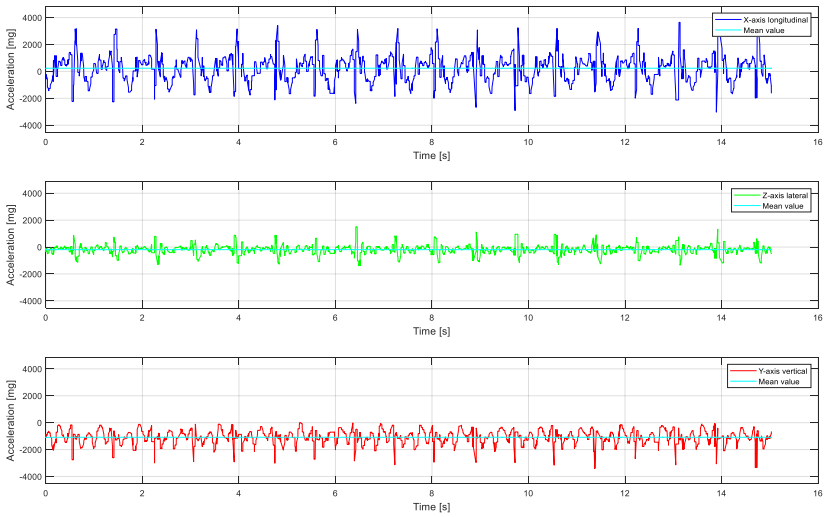

Figure 8.2.2.10 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 3 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.2.11 and Figure 8.2.2.12 shows a second of the data transmission interval while Figure 8.2.2.13 shows the power calculated, Figure 8.2.2.14 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.2.2.15.

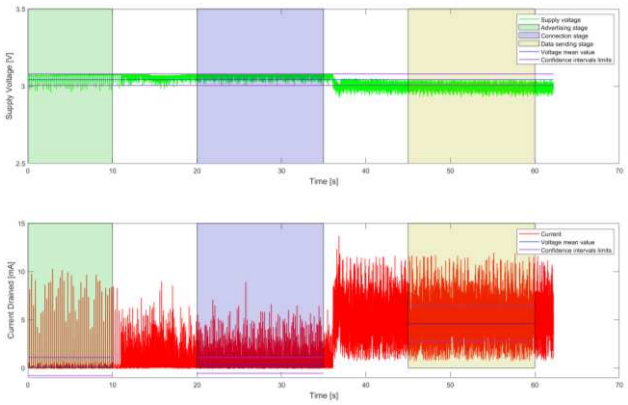

Figure 8.2.2.11 – Voltage and current plot.

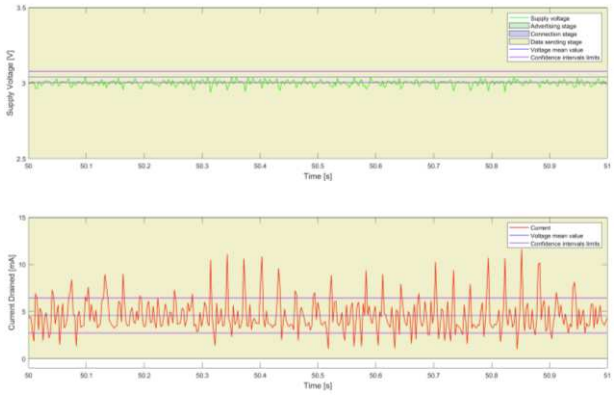

Figure 8.2.2.12 – Current and voltage 1s plot.

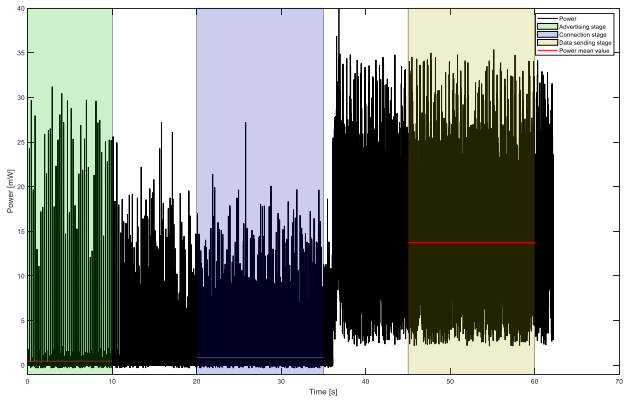

Figure 8.2.2.13 – Calculated power data plot.

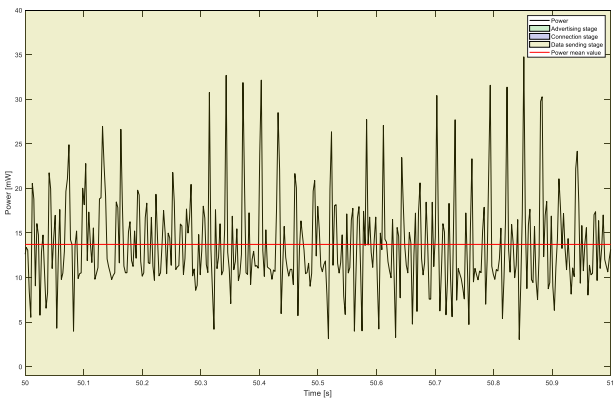

Figure 8.2.2.14 – Power data 1s plot.

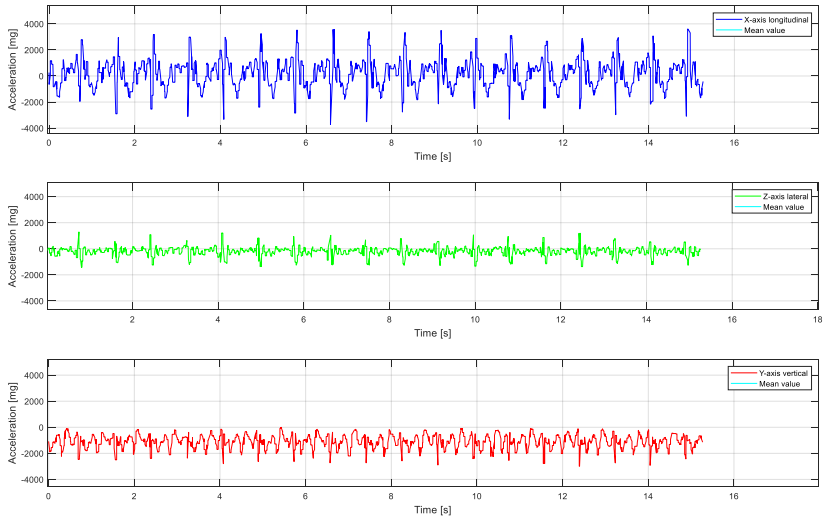

Figure 8.2.2.15 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 4 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.2.16 and Figure 8.2.2.17 shows a second of the data transmission interval while Figure 8.2.2.18 shows the power calculated, Figure 8.2.2.19 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.2.2.20.

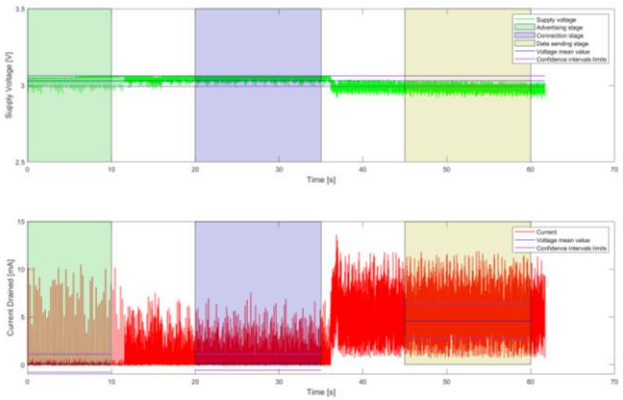

Figure 8.2.2.16 – Voltage and current plot.

Figure 8.2.2.17 – Current and voltage 1s plot.

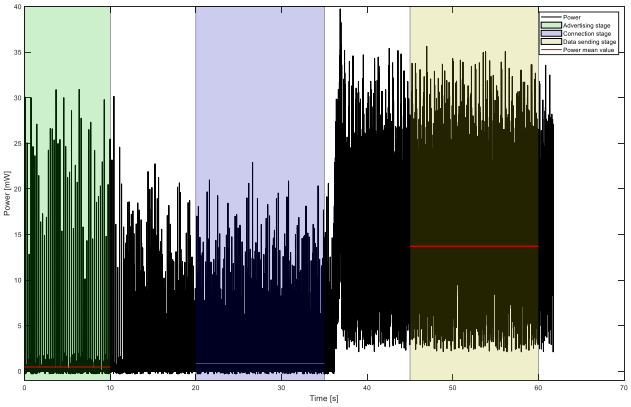

Figure 8.2.2.18 – Calculated power data plot.

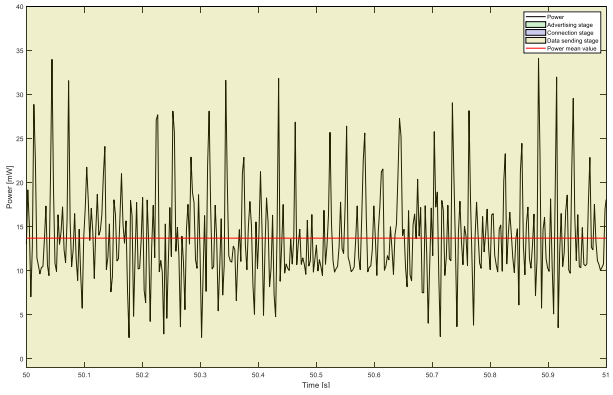

Figure 8.2.2.19 – Power data 1s plot.

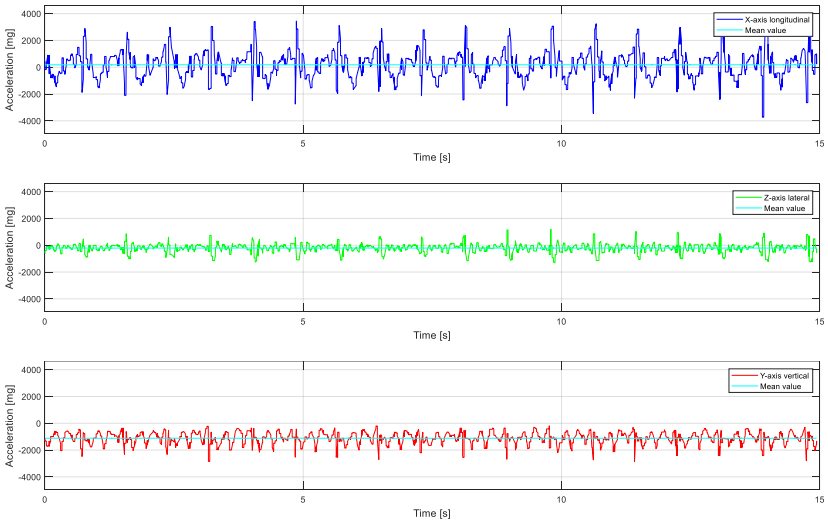

Figure 8.2.2.20 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 5 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.2.2.21 and Figure 8.2.2.22 shows a second of the data transmission interval while Figure 8.2.2.23 shows the power calculated, Figure 8.2.2.24 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.2.2.25.

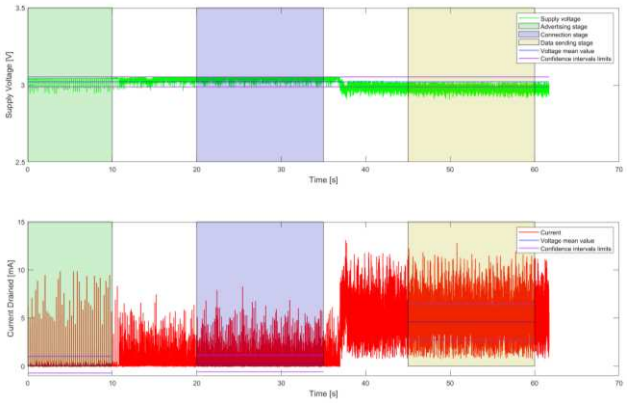

Figure 8.2.2.21 – Voltage and current plot.

Figure 8.2.2.22 – Current and voltage 1s plot.

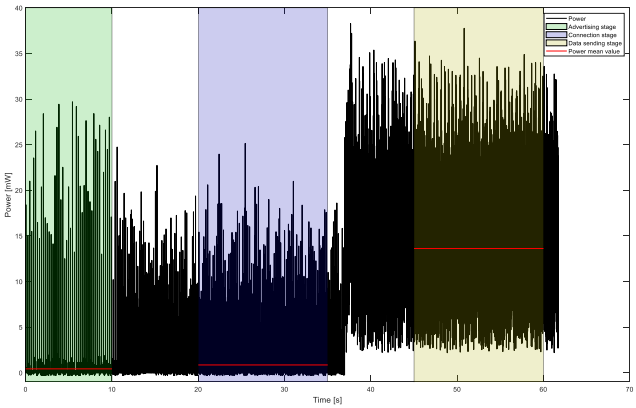

Figure 8.2.2.23 – Calculated power data plot.

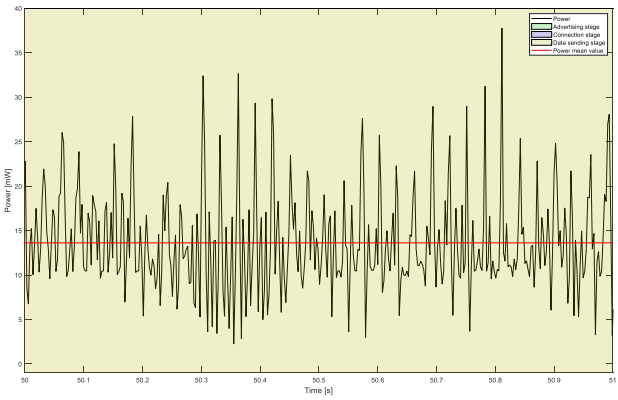

Figure 8.2.2.24 – Power data 1s plot.

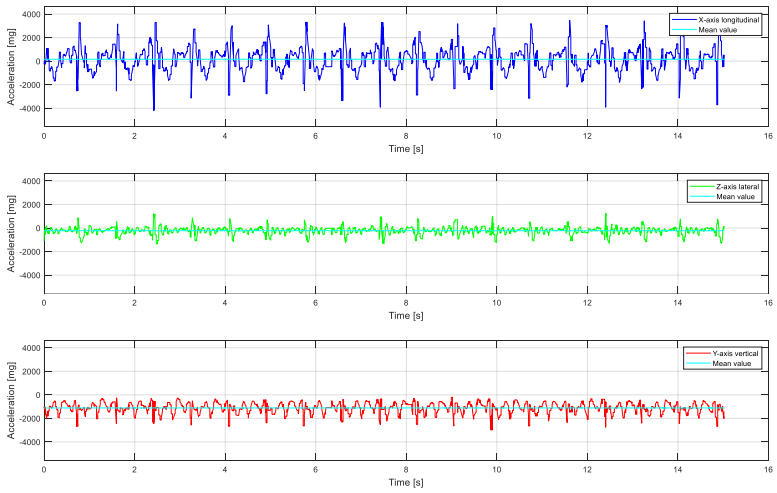

Figure 8.2.2.25 – Acceleration values for the last 15 seconds using the mobile app.

The obtained data for the five repetitions of the test performed are shown in Table 8.2.2.1.

Table 8.2.2.1 – Electrical values from running test.

	Advertising			Connecting			Transmitting		
Repetition	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.156	10.291	3.09	0.290	7.433	3.09	4.605	11.968	3.06
2	0.135	10.281	3.07	0.276	8.113	3.08	4.581	11.969	3.05
3	0.148	10.295	3.08	0.276	8.937	3.08	4.580	11.947	3.04
4	0.153	10.476	3.06	0.277	7.562	3.06	4.590	11.883	3.03
5	0.142	9.870	3.05	0.282	8.268	3.05	4.572	12.789	3.02

8.3. Third speed configuration test

The test consists in collecting power data while a person is walking on a treadmill. The sensor's linear acceleration sensitivity was set to ±16 g and the times to change between advertising, connection and data transmission stages are the same as described in section 6.5. The treadmill settings used by the user for the first test can be observed in Figure 8.3.1.

Figure 8.3.1 – Treadmill test third parameters settings.

8.3.1 Accelerometer data acquisition at 25Hz

For repetition number 1 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.1.1 and Figure 8.3.1.2 shows a second of the data transmission interval while Figure 8.3.1.3 shows the power calculated, Figure 8.3.1.4 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.3.1.5.

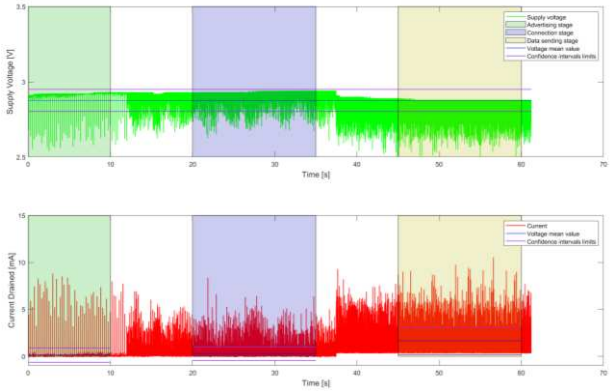

Figure 8.3.1.1 – Voltage and current plot.

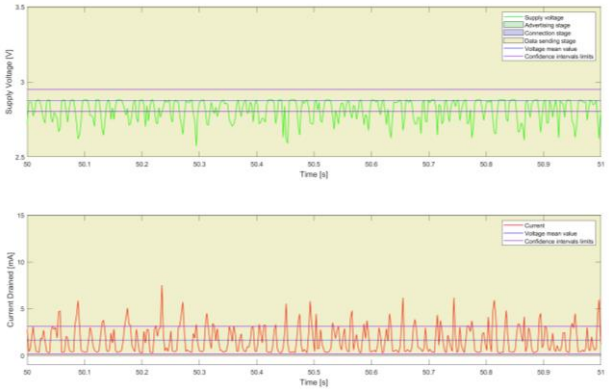

Figure 8.3.1.2 – Current and voltage 1s plot.

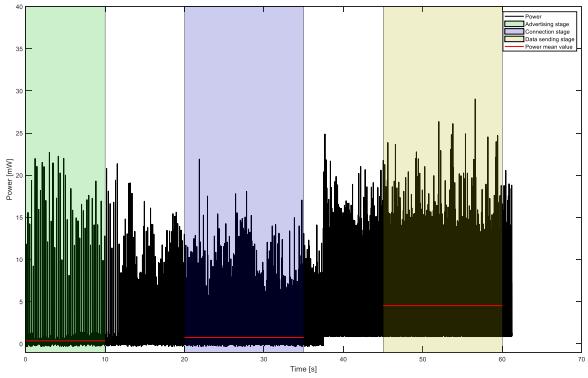

Figure 8.3.1.3 – Calculated power data plot.

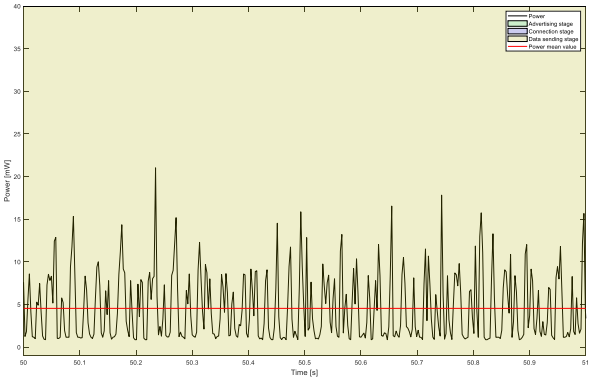

Figure 8.3.1.4 – Power data 1s plot.

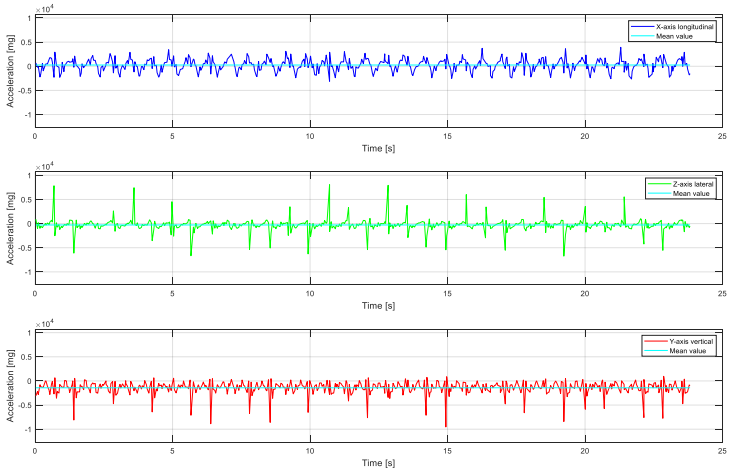

Figure 8.3.1.5 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 2 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.1.6 and Figure 8.3.1.7 shows a second of the data transmission interval while Figure 8.3.1.8 shows the power calculated, Figure 8.3.1.9 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.3.1.10.

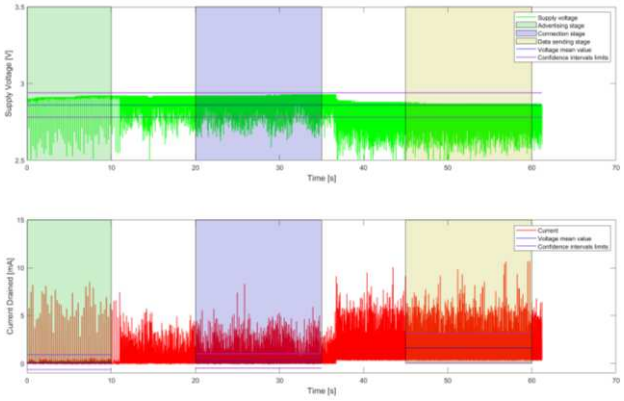

Figure 8.3.1.6 – Voltage and current plot.

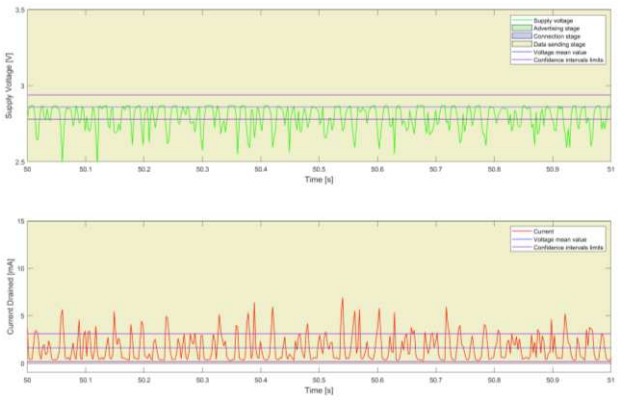

Figure 8.3.1.7 – Current and voltage 1s plot.

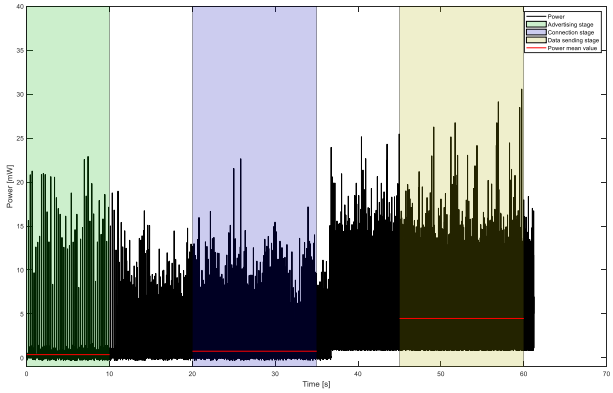

Figure 8.3.1.8 – Calculated power data plot.

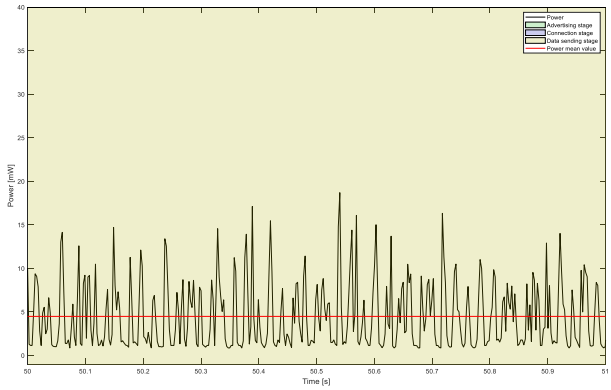

Figure 8.3.1.9 – Power data 1s plot.

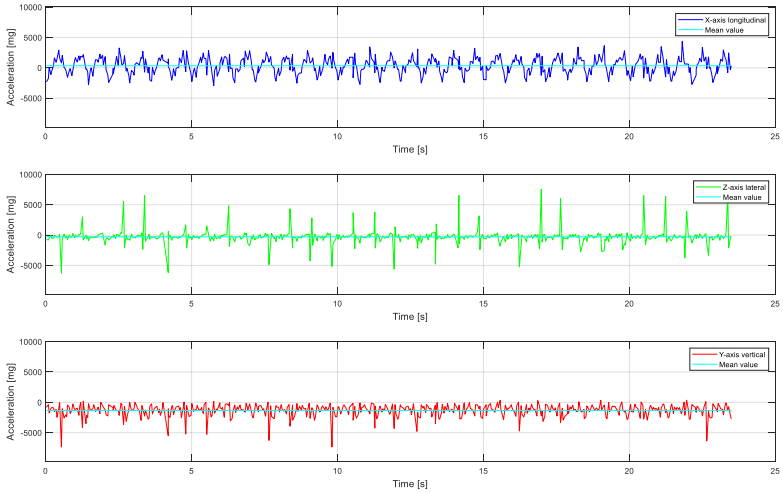

Figure 8.3.1.10 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 3 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.1.11 and Figure 8.3.1.12 shows a second of the data transmission interval while Figure 8.3.1.13 shows the power calculated, Figure 8.3.1.14 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.3.1.15.

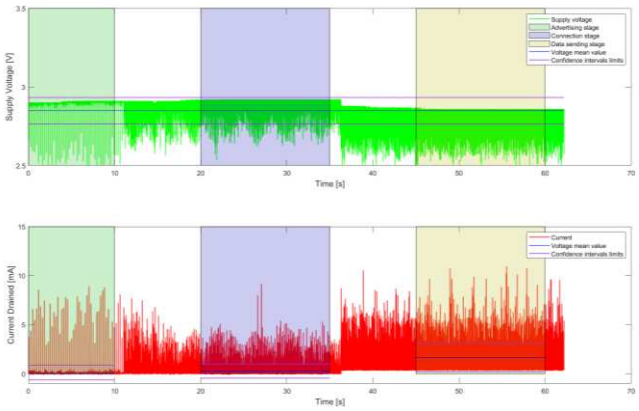

Figure 8.3.1.11 – Voltage and current plot.

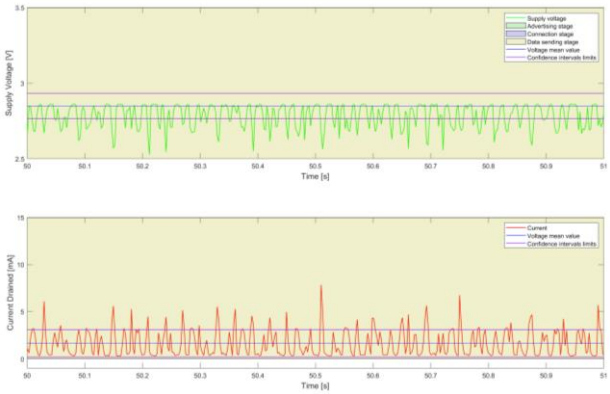

Figure 8.3.1.12 – Current and voltage 1s plot.

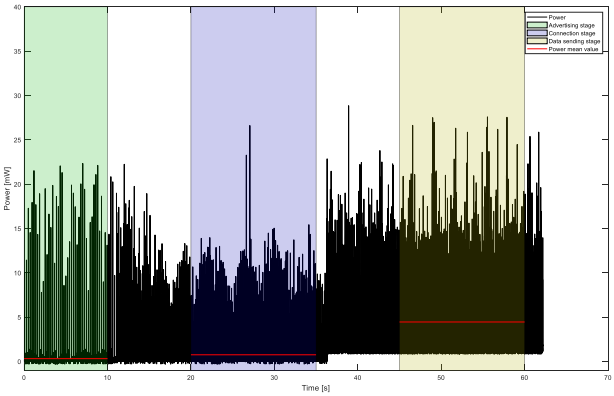

Figure 8.3.1.13 – Calculated power data plot.

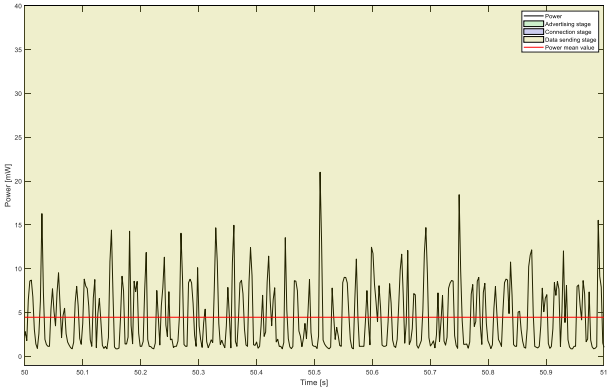

Figure 8.3.1.14 – Power data 1s plot.

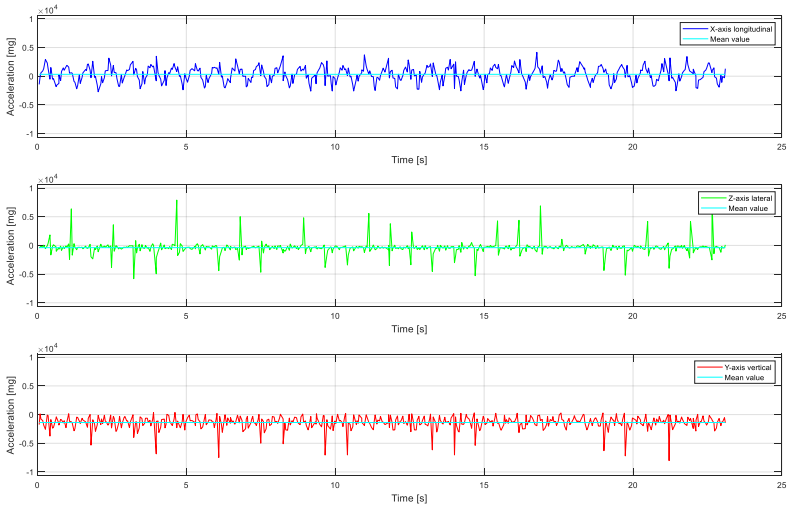

Figure 8.3.1.15 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 4 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.1.16 and Figure 8.3.1.17 shows a second of the data transmission interval while Figure 8.3.1.18 shows the power calculated, Figure 8.3.1.19 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.3.1.20.

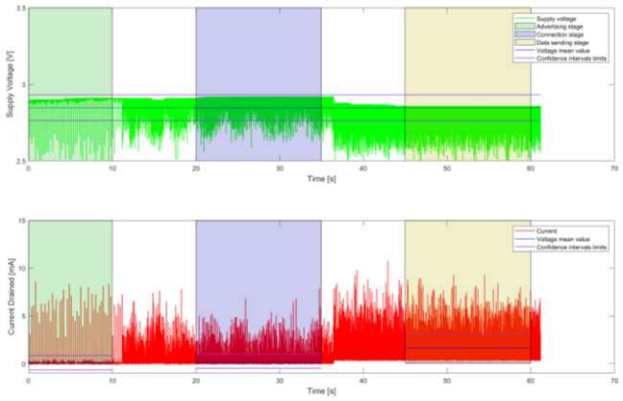

Figure 8.3.1.16 – Voltage and current plot.

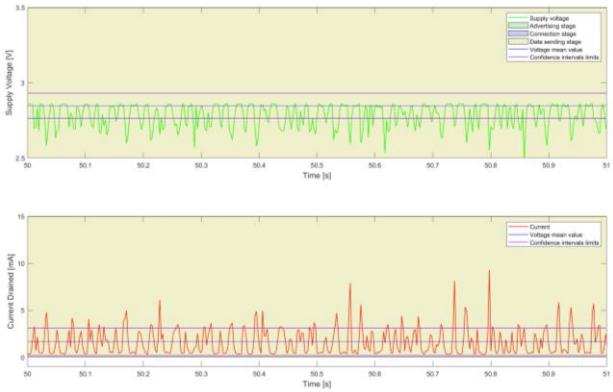

Figure 8.3.1.17 – Current and voltage 1s plot.

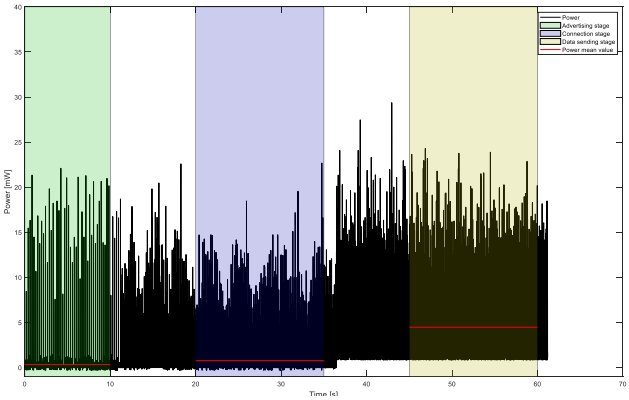

Figure 8.3.1.18 – Calculated power data plot.

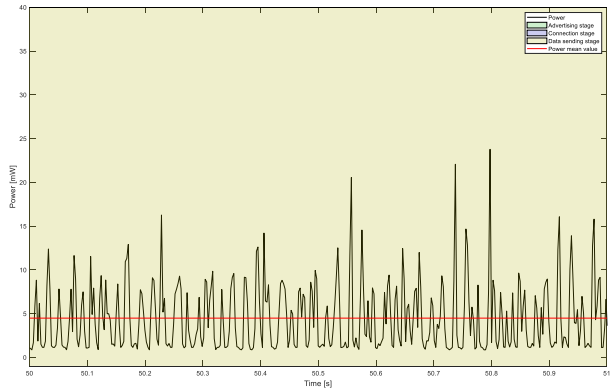

Figure 8.3.1.19 – Power data 1s plot.

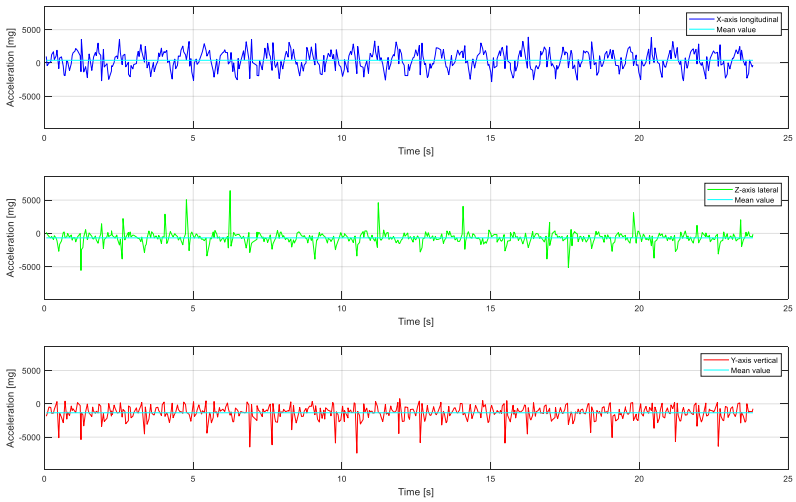

Figure 8.3.1.20 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 5 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.1.21 and Figure 8.3.1.22 shows a second of the data transmission interval while Figure 8.3.1.23 shows the power calculated, Figure 8.3.1.24 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 25Hz is shown in Figure 8.3.1.25.

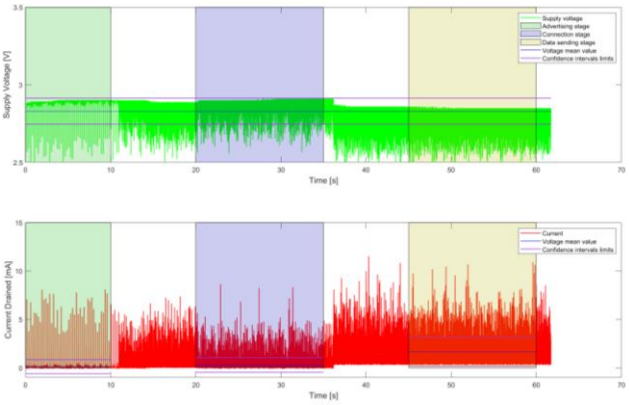

Figure 8.3.1.21 – Voltage and current plot.

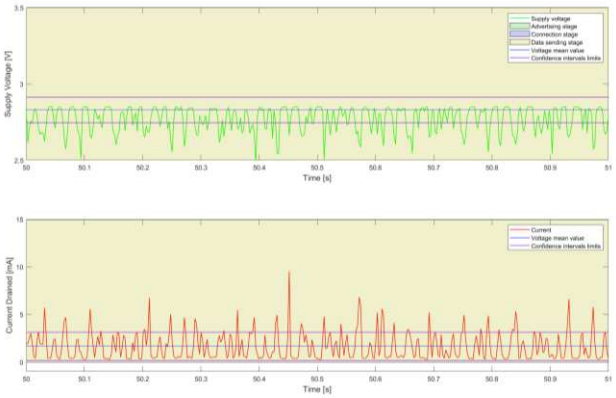

Figure 8.3.1.22 – Current and voltage 1s plot.

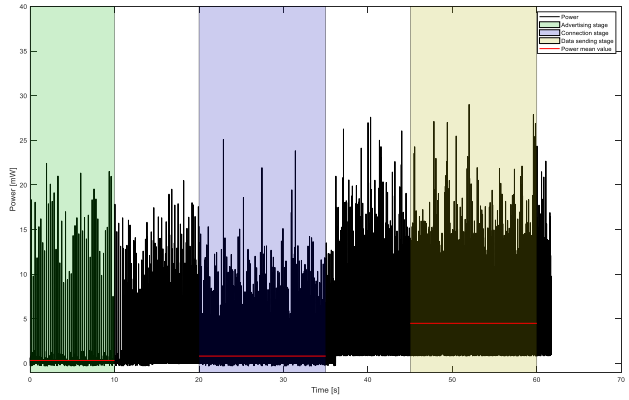

Figure 8.3.1.23 – Calculated power data plot.

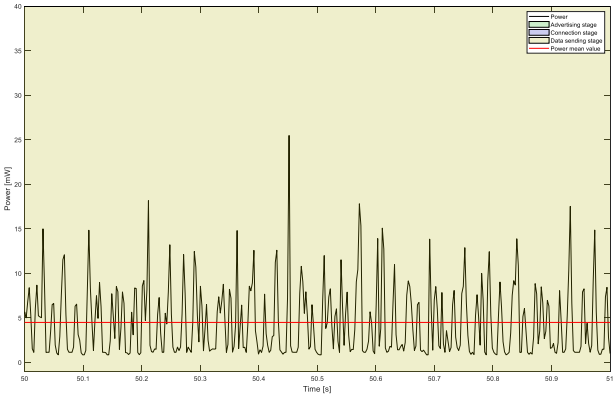

Figure 8.3.1.24 – Power data 1s plot.

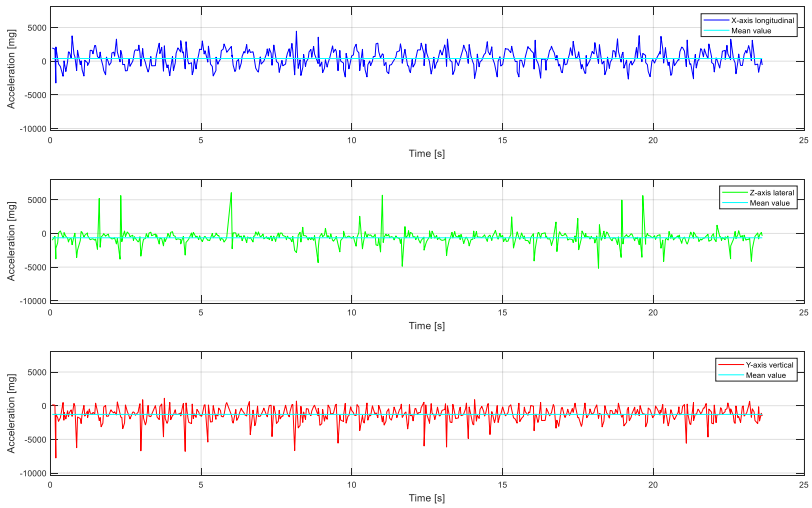

Figure 8.3.1.25 – Acceleration values for the last 15 seconds using the mobile app.

The obtained data for the five repetitions of the test performed are shown in Table 8.3.1.1.

Table 8.3.1.1 – Electrical values from running test.

	Advertising			Connecting			Transmitting		
Repetition	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.130	8.827	2.93	0.266	8.346	2.94	1.641	10.529	2.89
2	0.135	8.542	2.92	0.266	8.324	2.93	1.634	10.709	2.88
3	0.120	8.950	2.91	0.268	9.151	2.92	1.633	10.941	2.87
4	0.123	8.628	2.91	0.273	7.874	2.92	1.642	9.320	2.86
5	0.122	8.107	2.90	0.292	8.653	2.91	1.654	10.616	2.86

8.3.2 Accelerometer data acquisition at 120Hz

For repetition number 1 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.2.1 and Figure 8.3.2.2 shows a second of the data transmission interval while Figure 8.3.2.3 shows the power calculated, Figure 8.3.2.4 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.3.2.5.

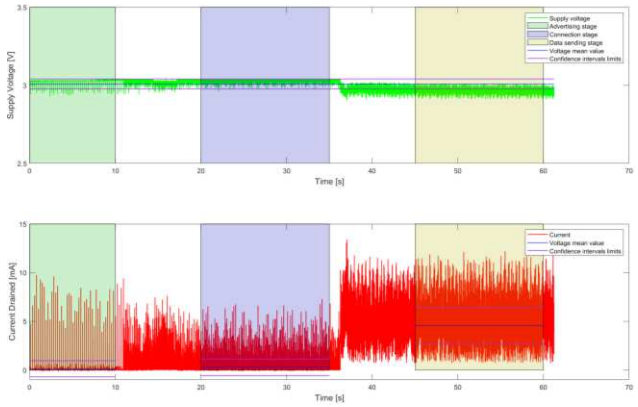

Figure 8.3.2.1 – Voltage and current plot.

Figure 8.3.2.2 – Current and voltage 1s plot.

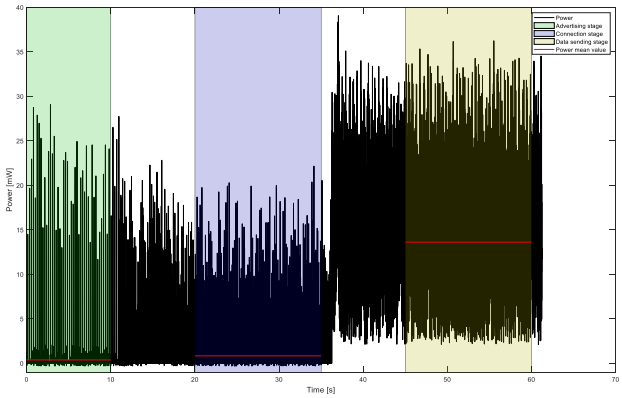

Figure 8.3.2.3 – Calculated power data plot.

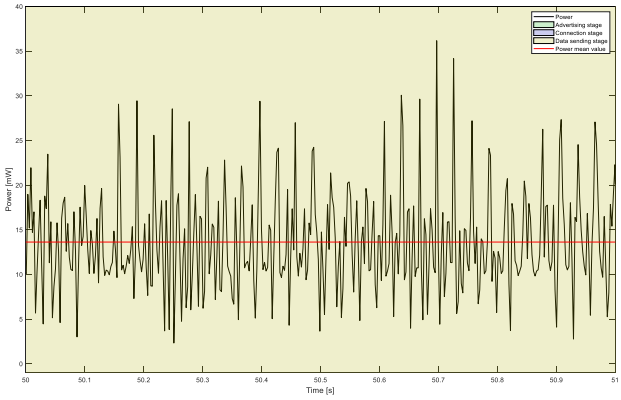

Figure 8.3.2.4 – Power data 1s plot.

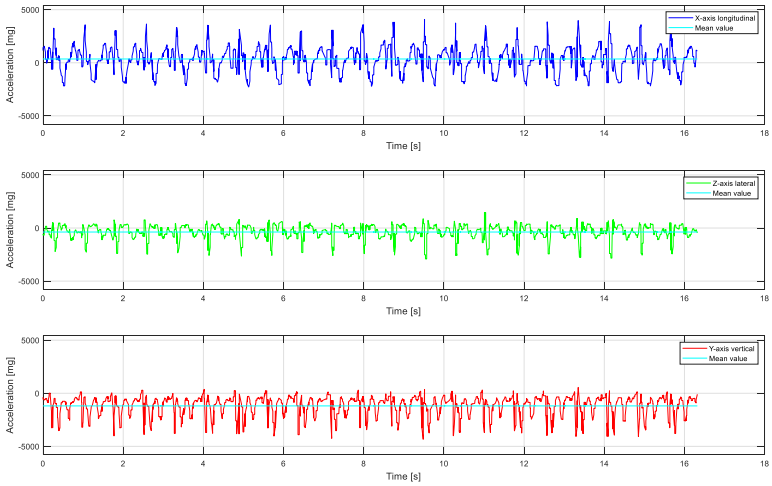

Figure 8.3.2.5 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 2 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.2.6 and Figure 8.3.2.7 shows a second of the data transmission interval while Figure 8.3.2.8 shows the power calculated, Figure 8.3.2.9 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.3.2.10.

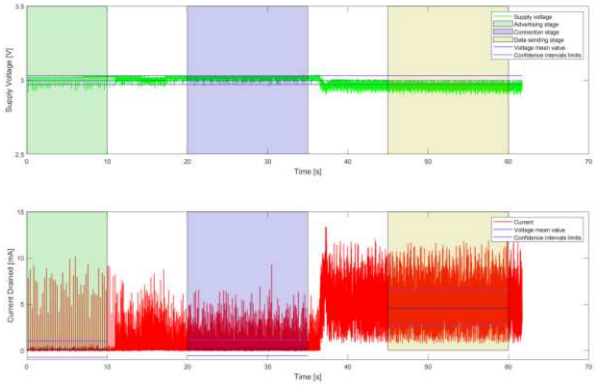

Figure 8.3.2.6 – Voltage and current plot.

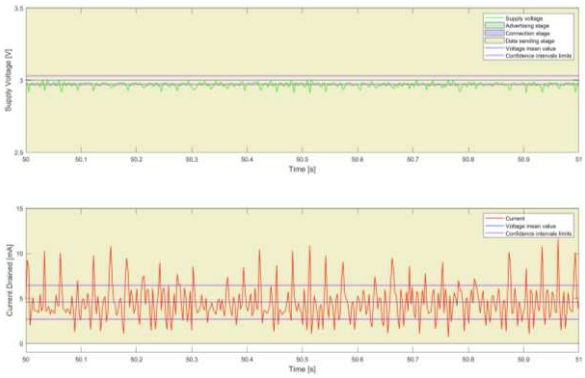

Figure 8.3.2.7 – Current and voltage 1s plot.

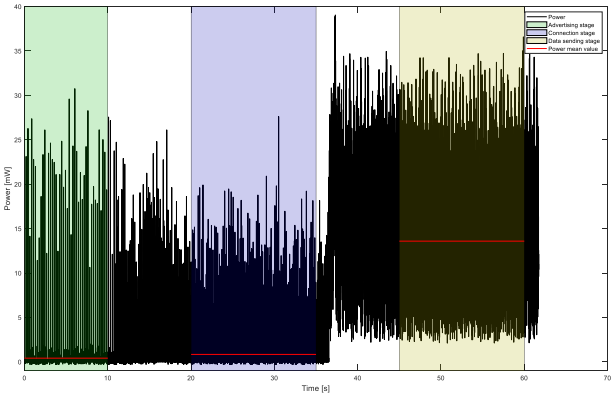

Figure 8.3.2.8 – Calculated power data plot.

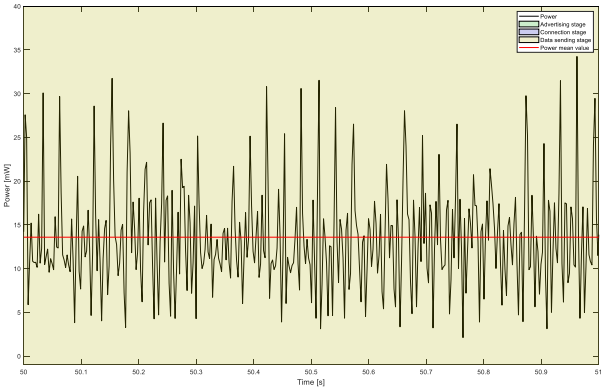

Figure 8.3.2.9 – Power data 1s plot.

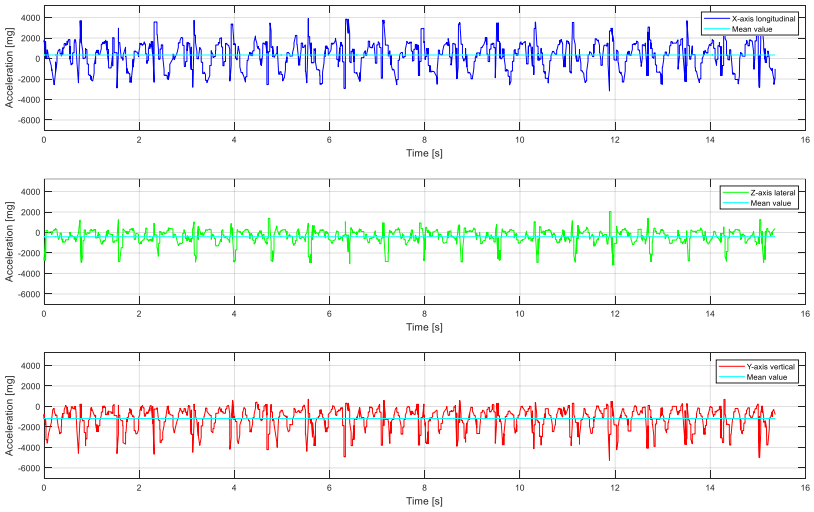

Figure 8.3.2.10 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 3 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.2.11 and Figure 8.3.2.12 shows a second of the data transmission interval while Figure 8.3.2.13 shows the power calculated, Figure 8.3.2.14 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.3.2.15.

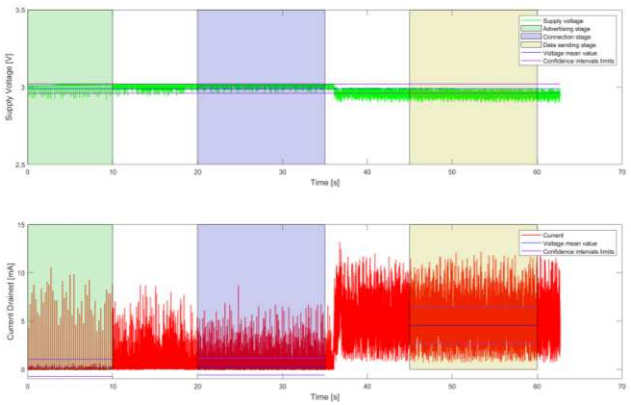

Figure 8.3.2.11 – Voltage and current plot.

Figure 8.3.2.12 – Current and voltage 1s plot.

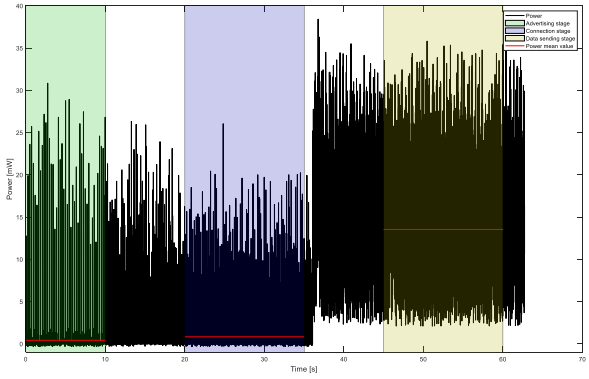

Figure 8.3.2.13 – Calculated power data plot.

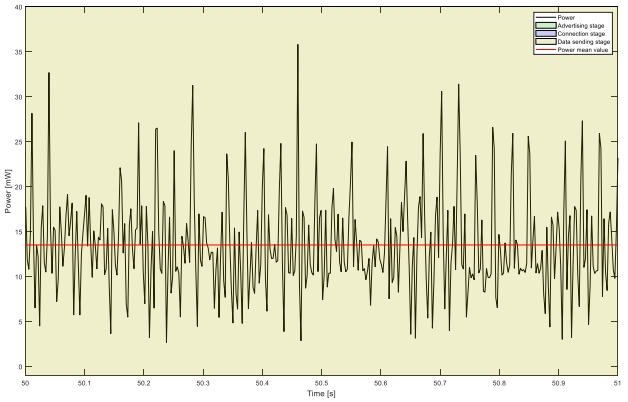

Figure 8.3.2.14 – Power data 1s plot.

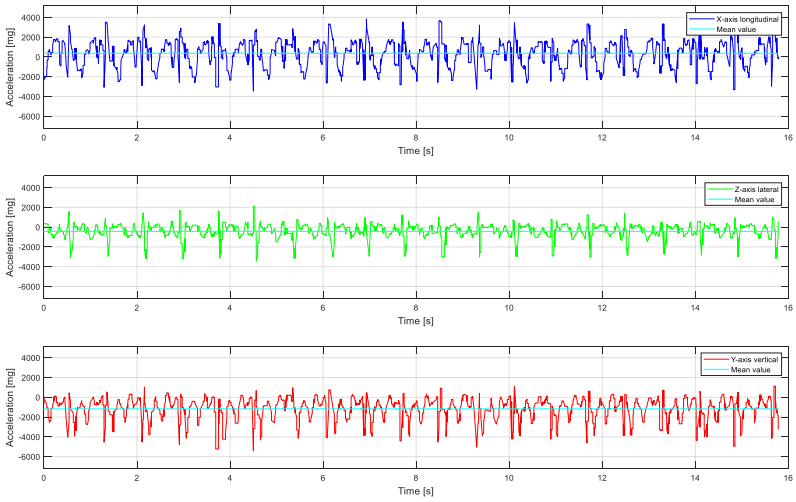

Figure 8.3.2.15 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 4 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.2.16 and Figure 8.3.2.17 shows a second of the data transmission interval while Figure 8.3.2.18 shows the power calculated, Figure 8.3.2.19 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.3.2.20.

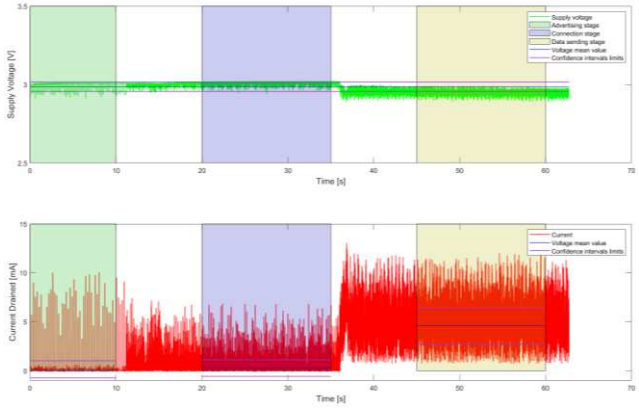

Figure 8.3.2.16 – Voltage and current plot.

Figure 8.3.2.17 – Current and voltage 1s plot.

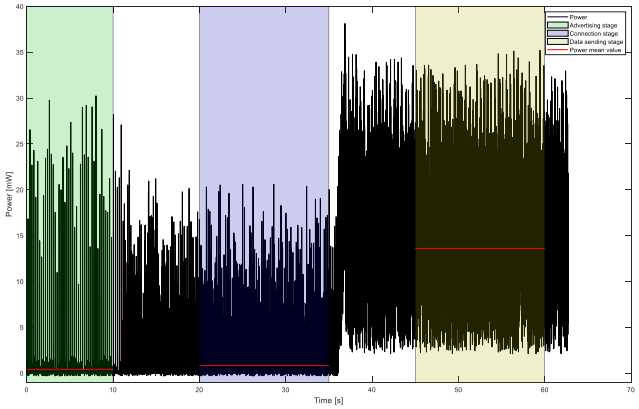

Figure 8.3.2.18 – Calculated power data plot.

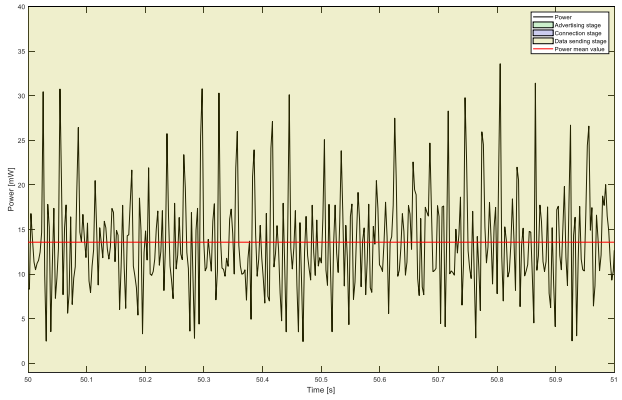

Figure 8.3.2.19 – Power data 1s plot.

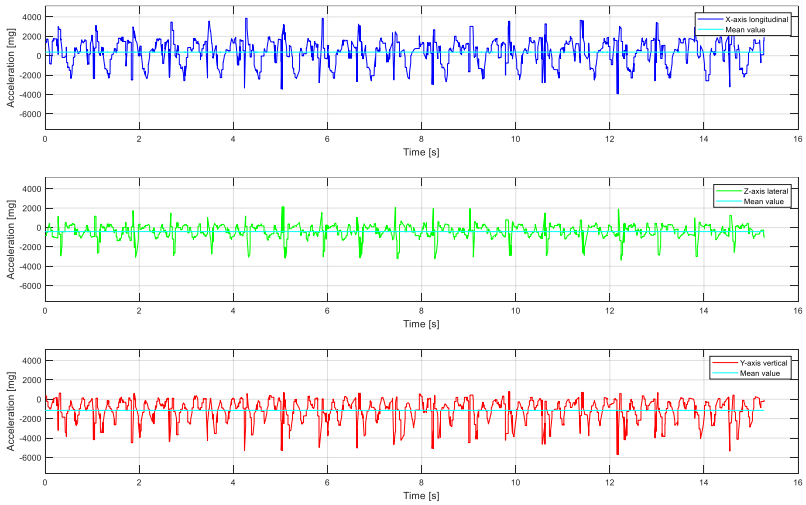

Figure 8.3.2.20 – Acceleration values for the last 15 seconds using the mobile app.

For repetition number 5 when the person is walking at first speed and all sensors are active in the board, voltage and current measured data is shown in Figure 8.3.2.21 and Figure 8.3.2.22 shows a second of the data transmission interval while Figure 8.3.2.23 shows the power calculated, Figure 8.3.2.24 shows a second of the power calculated in the same second of data transmission interval and acceleration data obtained values at 120Hz is shown in Figure 8.3.2.25.

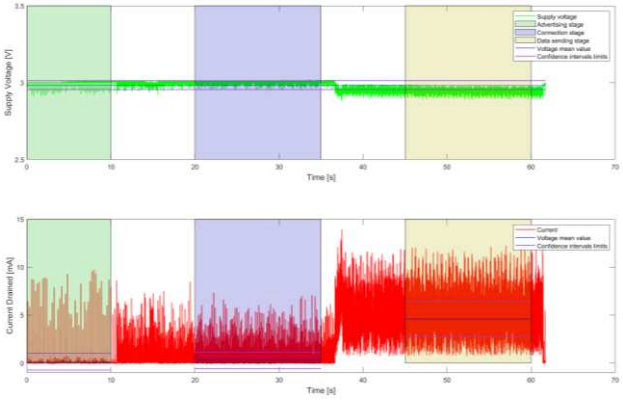

Figure 8.3.2.21 – Voltage and current plot.

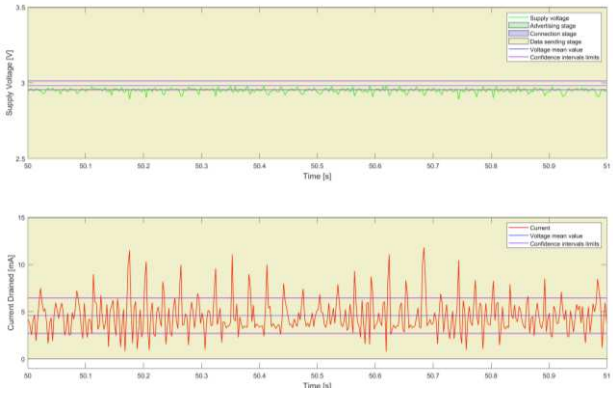

Figure 8.3.2.22 – Current and voltage 1s plot.

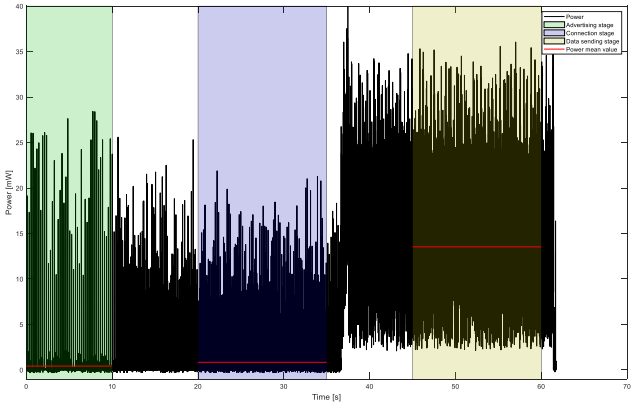

Figure 8.3.2.23 – Calculated power data plot.

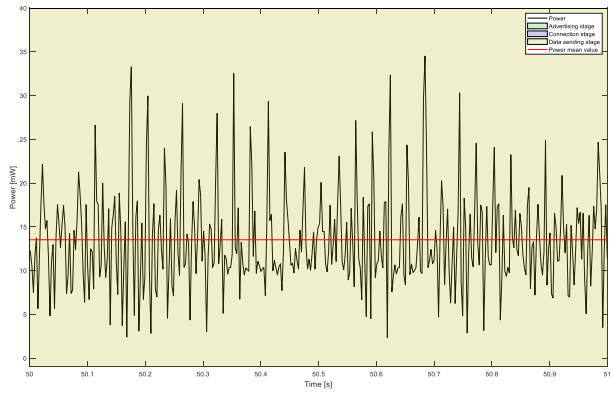

Figure 8.3.2.24 – Power data 1s plot.

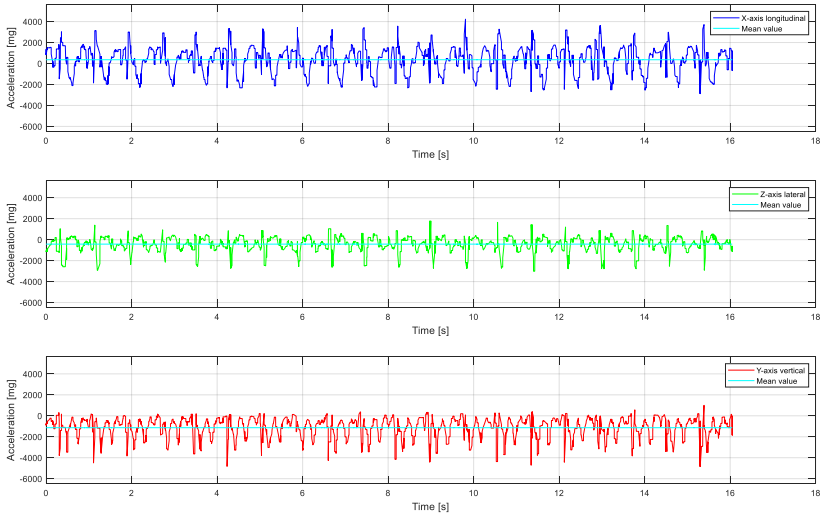

Figure 8.3.2.25 – Acceleration values for the last 15 seconds using the mobile app.

The obtained data for the five repetitions of the test performed are shown in Table 8.3.2.1.

Table 8.3.2.1 – Electrical values from running test.

	Advertising			Connecting			Transmitting		
Repetition	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]	Mean current [mA]	Max current [mA]	Max voltage [V]
1	0.128	9.741	3.04	0.279	7.288	3.04	4.587	12.180	3.01
2	0.139	10.189	3.03	0.278	9.289	3.03	4.585	12.527	3.00
3	0.141	10.555	3.02	0.276	8.704	3.02	4.581	12.189	3.00
4	0.139	10.054	3.01	0.274	6.861	3.02	4.605	12.127	2.99
5	0.142	9.722	3.01	0.279	7.333	3.02	4.590	2.989	2.98

8.4. Tests result comparison

Table 8.4.1 and Table 8.4.2 present the power values measured during the data transmission stage for an acquisition frequency of 25Hz and 120Hz respectively while Figure 8.4.1 shows a graphic comparing the mean power values with both acquisition frequencies.

Table 8.4.1 – Mean power values by test for all data transmission stage at 25Hz.

Speed config.	Test 1	Test 2	Test 3	Test 4	Test 5	Test mean	Unit
1	4.79	4.79	4.74	4.70	4.73	4.75	mW
2	4.61	4.62	4.61	4.64	4.61	4.61	
3	4.53	4.48	4.46	4.48	4.49	4.48	

Table 8.4.2 – Mean power values by test for all data transmission stage at 120Hz.

Speed config.	Test 1	Test 2	Test 3	Test 4	Test 5	Test mean	Unit
1	14.05	13.95	13.90	13.83	13.93	13.93	mW
2	13.84	13.73	13.71	13.70	13.62	13.72	
3	13.61	13.59	13.56	13.58	13.52	13.57	

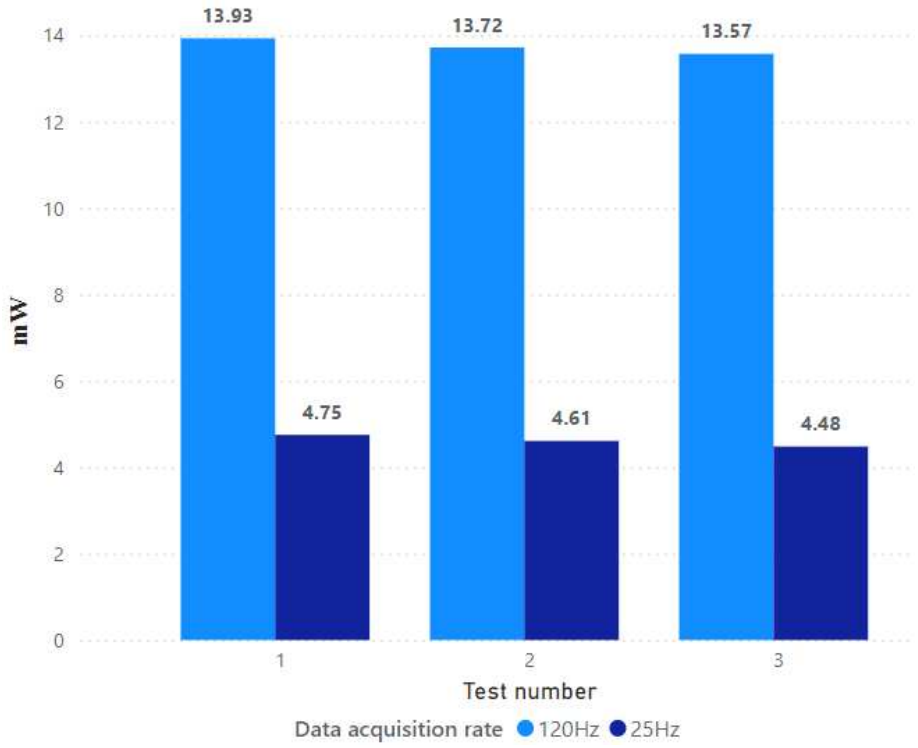

Figure 8.4.1 – Mean power values with different active sensor configuration during all data transmission stage for different data acquisition rates in on-body test.

Conclusions

After analysing the structure and operation of the STEVAL-BCN002V1B sensor board, with special emphasis on the use of the integrated LSM6DSO accelerometer and its corresponding energy consumption, it can be concluded that the energy demanded from the 3.3V battery is significantly affected by the sensor configuration selected by the user. Factors such as enabling or disabling certain sensors and the data acquisition rate chosen to have a direct impact on the board's energy consumption.

Although the system developed for measuring energy consumption has some limitations regarding the sampling rate, which could be faster, this does not prevent performing an energy analysis that provides relevant numerical data based on the usage conditions of the sensor board. If a higher sampling rate is desired during energy consumption measurements, it is recommended to use specialized instruments, such as a data acquisition board (DAQ).

The user responsible for developing a specific application for the sensor board has the option to modify the application provided by the manufacturer or create a new one based on it, considering the project's objectives when configuring the sensors integrated into the board.

Wireless data transmission using the manufacturer’s mobile application is useful as it works in conjunction with the software executed by the board. For the development of a more specific application, both programs, the one used by the board and the one responsible for reading the data, should be developed together to ensure proper handling of the information packets transmitted via Bluetooth.

Although the accelerometer is designed to perform measurements at high sampling frequencies, it is necessary to consider the execution time of the board’s application and the other sensors setup to determine the actual sampling rate, which was found to be lower than the one configured in the sensor.

The electric energy harvester device, even if it can save energy in a capacitor, due to its working mode is not able to power an electronic device such as the sensor board previously studied because the outputs cannot bring the amount of voltage needed for a typical and correctly use of them, also, it cannot retain the energy for a useful time so it has to be constantly powered by a constant signal, not pulses. The use of a lithium base battery is recommended for these kinds of purposes.

Reference

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