APPENDIX E - MEASUREMENTS ON THE SimMan SIMULATOR

The prototype developed to carry out measurements on the simulator is composed of the following components:

a) ESP32:

Development board with 30 pins of which 25 are digital input/output, Clock up to 240MHz, 520KB RAM memory and 4MB FLASH memory.

b) AD8232 cardiac monitoring sensor:

Capable of measuring the electrical activity of the heart which can be mapped as an ECG and generated as an analog reading. This sensor performs a pre-filtering in order to clean the signal from possible noise.

c) Cable with electrode pads.

They are used to connect the electrodes to the AD8232 sensor.

d) ECG electrodes with a disposable surface.

These are the devices that connect the patient with the cardiac sensor, where electrical information is obtained for printing and analyzing the ECG.

e) Protoboard and jumpers.

They carry out the electrical connections of the prototype components.

f) USB cable type A-B:

It has the function of connecting the computer with a digital output from ESP32, in order to allow the sending of data worked on the development board to the computer for future analysis.

g) ADS1115 analog-digital converter:

Its purpose is to convert the analog signal from the heart monitor to digital in order to be treated by ESP32. It has 16-bit precision at 860 samples/second. Its interface is via I2C protocol. Furthermore, it can be configured as 4 single-ended input channels or two differential channels. Its use in the prototype was necessary because the ESP32's A/D converter does not have the required quality expected for sampling and analog signal conversion.

h) Tactile key with 4 terminals:

Its function is to indicate the start of recording an exam when it is pressed. It works by sending to a digital pin of ESP32 a logic state that indicates whether it was pressed or not. The debounce technique was used in order to avoid possible problems with undefined transitions in moments of pressure due to mechanical or physical failures.

The main connections between the components listed above are described below:

Connecting the AD8232 heart monitor to the ADS1115:

Table I – AD8232 Heart Monitor Connections with ADS1115 Component

Pin name on AD8232 board	Pin functions	Connection on ADS1115
GND	Ground	Ground
3.3V	3.3V power	3.3V
OUTPUT	output analog signal	A0 pin
LO -	lead detection -	NC
LO +	lead detection +	NC
SDN	turn off	NC

Connection of ADS1115 analog-digital converter with ESP32:

Table II – ADS1115 Analog-to-Digital Converter Connections with ESP32

ADS1115	Connection on ESP32
GND	Ground
3.3V	3.3V
SCL	SCL pin (22)
SDA	DAS pin (21)
ADDR	Ground
ALRT	NC
A0	NC
A1	NC
A2	NC
A3	NC

The schematic with the connection between the three components mentioned above is shown below:

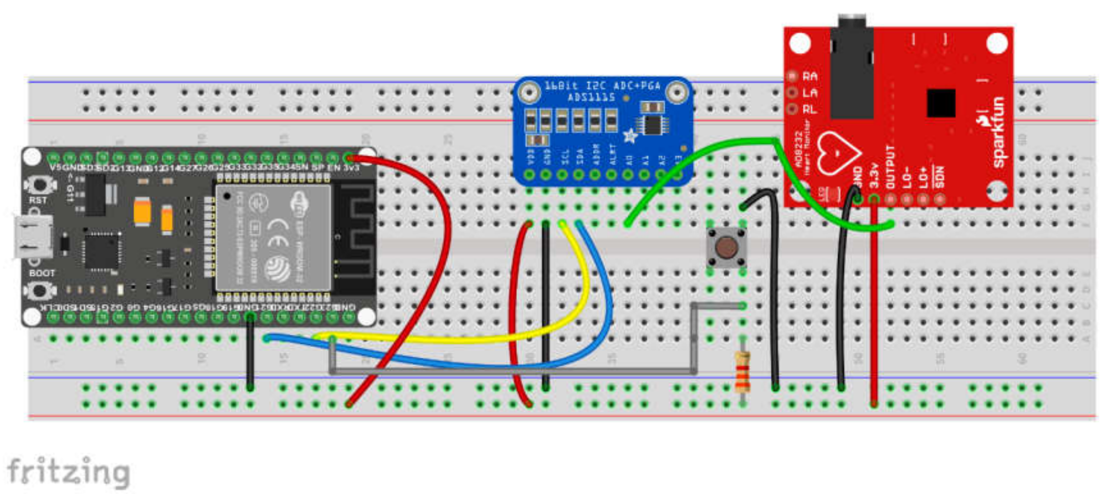

Fig. 1: Prototype assembly schematic.
Source: Fritzing, 2021.

The connection of the electrode pads with the signals to be sampled from the body according to the type I lead is given by:

Table III – Connections of the electrode pads to the body

Cable color	Signal
Green	LA (*Left Arm*)
Red	RA (*Right Arm*)
Yellow	RL (*Right Leg*)

The layout of the type I lead reading in the human body is exemplified in the image below:

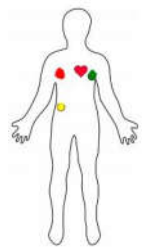

Fig. 2: Positioning the electrode pads on the human body.
Source: Author, 2021.

The arrangement of connections already in the simulator is shown in the figures below:

Fig. 3: Prototype layout in SimMan.
Source: Author, 2021.

Fig. 4: Prototype layout in SimMan.
Source: Author, 2021.

As described in the article, once the prototype had already been assembled, several AFIB and SR signals were started to be applied to the simulator, with or without noise. Shown below are some of these already filtered signals obtained.

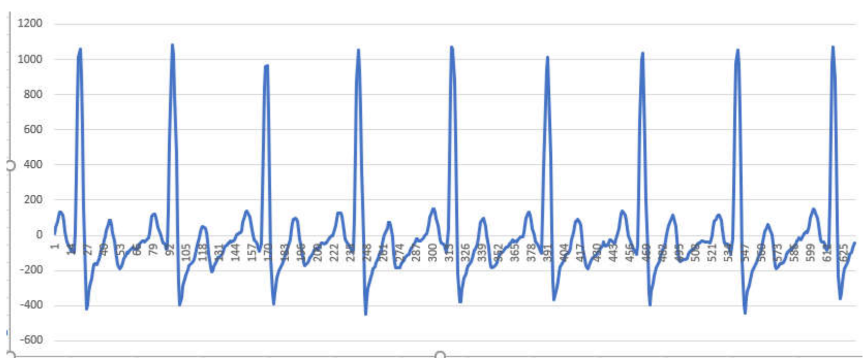

Fig. 5: Signal from a noiseless SR ECG record.
Source: Author, 2021.

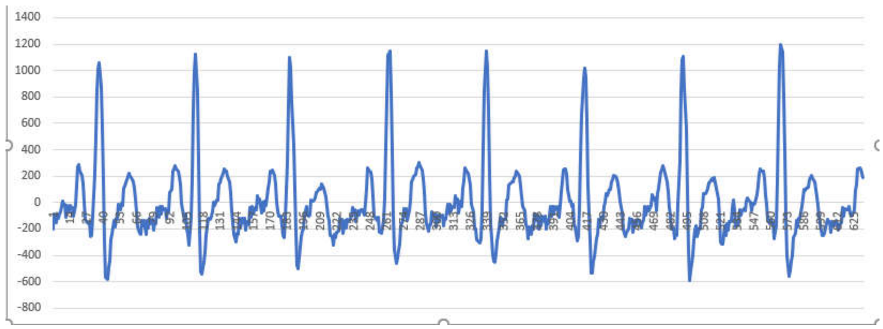

Fig. 6: Signal from a noisy SR ECG record.
Source: Author, 2021.

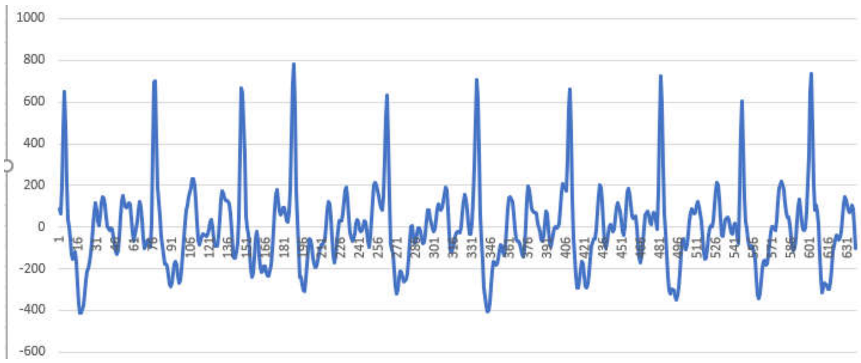

Fig. 7: Signal from a noiseless AFIB ECG record.
Source: Author, 2021.

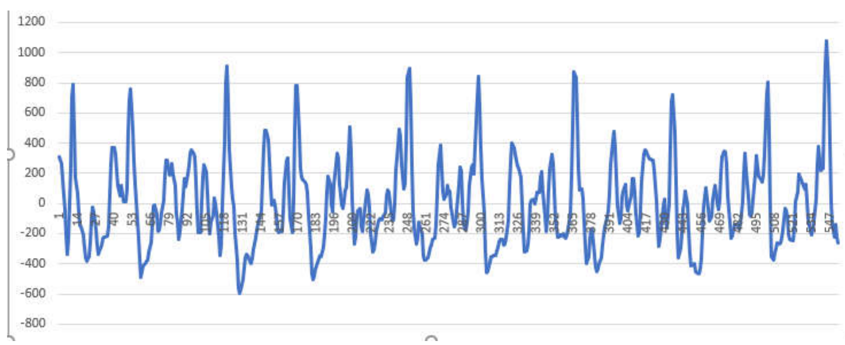

Fig. 8: Signal from a noisy AFIB ECG record.
Source: Author, 2021.

About the classifications themselves, it is attested that they last an average of 8ms, as shown in the image below, that is, this is the duration of the model inference. This constant is close to that estimated by Edge Impulse, which was 10ms.

```
Edge Impulse standalone inferencing (Arduino)
run_classifier returned: 0
Predictions (DSP: 0 ms., Classification: 8 ms., Anomaly: 0 ms.):
[0.90234, 0.09766]
    afib: 0.90234
    sr: 0.09766
Edge Impulse standalone inferencing (Arduino)
run_classifier returned: 0
Predictions (DSP: 0 ms., Classification: 8 ms., Anomaly: 0 ms.):
[0.90234, 0.09766]
    afib: 0.90234
    sr: 0.09766
```

Fig. 9: Records of model classification parameters.
Source: Author, 2021.

Finally, an idealization of how it is expected in the future to transform the prototype into a single board capable of performing both the sampling, treatment, classification and display of data and results is presented below. It will have many of the components mentioned above for the construction of the original prototype with the addition of the display, although the ESP32 will be replaced by a microcontroller with an even smaller size, containing just what is necessary to run the machine learning model and treatment of the ECG data. There is also the addition of an external battery, in order to make the ECG measurement safer, since it will not be necessary to connect directly to the electrical network.

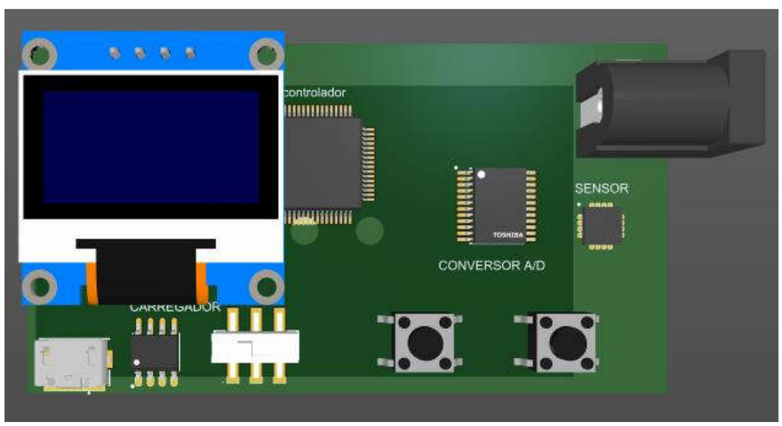

Fig. 10: Idealization of the final prototype of the project (front of the board).
Source: Author, 2021.

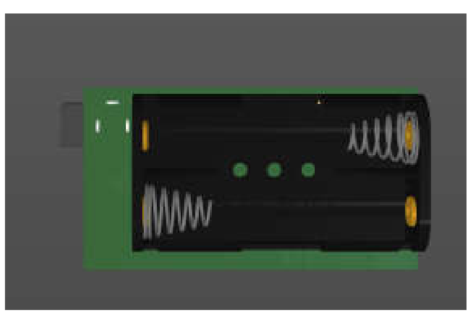

Fig. 11: Idealization of the final prototype of the project (behind the board).
Source: Author, 2021.