MED1stMR
Mixed Reality Training

TRAIN
[SKILLS. RESILIENCE. PERFORMANCE]
SAVE LIVES

D4.4

Physiological Signals Acquisition Hardware and Software Framework

Version
V1.0

Authors

Pedro Duque (PLUX)
Katrin Mrotzeck (PLUX)
Patricia Gamboa (PLUX)
Guilherme Ramos (PLUX)

Project
MED1stMR

Project number
101021775

Type of Action
RIA

Start date of project
01.06.2021

Duration
36 months

Deliverable
D4.4

Deliverable Lead
PLUX

Related work package
WP4

Dissemination level
Public

Due submission date
31.05.2023

Actual submission
31.05.2023

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Versions

Version	Date	Author(s)	Description
V0.1	24/03/2023	Patricia Gamboa (PLUX)	First Draft
V0.2	11/04/2023	Katrin Mrotzeck (PLUX)	Extension of the structure and additions to the content
V0.3	03/05/2023	Guilherme Ramos (PLUX)	Extension of the structure and additions to the content
V0.4	08/05/2023	Pedro Duque (PLUX)	Review and extension of the structure and additions to the content
V0.5	22/05/2023	Pedro Duque (PLUX)	Review and formatting
V0.6	24/05/2023	Pedro Duque (PLUX)	Revision and incorporation of comments from internal reviewers
V1.0	31/05/2023	Helmut Schrom-Feiertag (AIT) Vendula Rajdlova (AIT)	Final formatting and submission

Report Review

Version	Date	Reviewer(s)	Statement
V0.5	23/05/2023	Katrin Mrotzeck (PLUX) Patricia Gamboa (PLUX) Helmut Schrom-Feiertag (AIT)	I miss a clear structure in some chapters, notes made in the document.
V1.0	30/05/2023	Helmut Schrom-Feiertag (AIT) Vendula Rajdlova (AIT)	Report ok.

HSchrom
31.05.2023

RajdlovaV
31.05.2023

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List of Acronyms and Abbreviations

Acronym/ Abbreviation	
ACC	Accelerometer
ADC	Analogue to Digital Converter
API	Application Programming Interface
BLE	Bluetooth Low Energy
BPM	Beats per Minute
BR	Breathing Rate
BT	Bluetooth
ECG	Electrocardiogram
EDA	Electrodermal Activity
EEG	Electroencephalography
HR	Heart Rate
HRV	Heart Rate Variability
LA	Left Arm
LF	Left Foot
MAG	Magnetometer
MCI	Mass Casualty Incident
MFR	Medical First Responder
MR	Mixed Reality
RA	Right Arm
SCR	Skin Conductance Response
VR	Virtual Reality

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Terms and Definitions

Term	
API	Software interface for two or more computer programs to communicate with each other.

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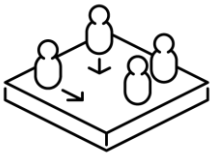
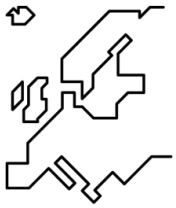
Relation to Objectives

Objective	Description
	**Obj. 1: Pioneering MR training approach for enhanced realism** This deliverable will contribute to this objective as the hardware and software development will allow for the acquisition of real-time physiological data of MFRs in a non-invasive way (through comfortable easy-to-wear wearables).
	**Obj. 2: Effective training scenarios and a training curriculum** The developed hardware and software described in this deliverable allows the physiological signals acquisition of multiple trainees in real-time and contributes to better training scenarios adapted to the needs of the trainees. The display of the physiological data into a dashboard will add a new layer of information and allow trainers to have a more in-depth knowledge of their trainees' stress levels and objective information on how to adjust the training scenario.
	**Obj. 3: Physiological signal and trainee behaviour feedback loop and smart scenario control** This deliverable contributes directly to this objective since it pertains to the development of the hardware and software of the sensors that will collect physiological data from the trainees. These data will then be important for the integration into the trainer dashboard and build the basis for the development of the AI-assisted smart scenario control.
	**Obj. 4: Position the pioneering MR training approach across Europe** With the integration of physiological data into the Med1stMR system we are realizing a pioneering approach, contributing to effective training with new wearable technologies. This innovative system will generate interest by MFRs organizations across Europe, stimulating the exchange of knowledge between countries.

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Executive Summary

This deliverable D4.4 - Physiological signals acquisition hardware and software framework describe the framework for the integration of physiological data into the MED1stMR system.

This deliverable defines the final specifications for the development of an easy-to-use wearable with miniaturized sensors for acquisition and processing of MFR's physiological signals (focussing on the hardware and software). This was done closely with the requirements' definition by end users and with the integration of the model and physiological measurements defined by research partners (WP2 and WP3).

The deliverable also presents the PLUX Hardware and Software Framework which is composed by the wearable devices (Hardware Component) and by the Python Server and Unity Client APPs (Software Component).

The wearable devices will allow access to the physiological data of MFRs that will be integrated into the smart scenario control dashboard (allowing real-time assessment of stress levels) and it will also be relevant for debriefing purposes (as the information gathered reflects on stress periods of MFRs).

Relation to other deliverables and tasks in MED1stMR

Table 1: The work and the document build on results from the following deliverables.

No.	Title	Information on which to build
D2.2	End Users Perspective: Requirements Report, Stakeholder Map and Expectation Summary for Smart Wearables, MR Training Framework and Curriculum	In D2.2 the needs of the end users are summarized. These are the basis for all further developments to meet the demanded requirements. D2.2 provides input into what physiological signals are needed to achieve the learning objectives for medical training.
D2.4	High-Level System Architecture	High level system architecture describes the integration of the modules that integrate the MR training system: the VR training system, manikin ADAM-X, PLUX wearable sensors, and the dashboard application.
D3.3	Concept for Physiological Measurement Suite for Stress Assessment	The stress measurement indicators (e.g., heart rate variability, skin conductance etc.) for real-time tracking the effectiveness of introduced strain through VR simulations are based on the physiological data retrieved from trainees.

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D3.4	Real-Time Training Progress Assessment Tool	The display of psychophysiological outcomes (i.e., data gathered from sensors) embedded into the dashboard provides the trainer insights on the stress level of trainees in real-time.

Table 2: The results of this work will be incorporated into following work and developments.

No.	Title	Basis for
D4.3	Activity Recording for the Exercise Debriefing	All physiological data of trainees will be recorded and communicated over the API and must be saved for debriefing to be able to integrate this information that reflects on the stress periods of the MFRs.
D4.5	Smart Wearables for First Responder Monitoring	The wearable prototype for MFR monitoring during training will provide all physiological data from the trainee.
D5.2	MR Trainings Environment, Trainings-Scenarios and MR Live Editor infrastructure for conducting the Evaluations	The integration of trainees' physiological data is done via API and is essential to allow a visual display of information into the dashboard application.
D5.4	Integrated Sensorics for Physiological Measurement of Trainees	The physiological assessment of stress (gathered by biosignals) and the assessment of trainee behaviour will be integrated in the MR training environment.
D5.5	Smart Scenario Control Module	The integration of the MFRs' physiological data done through API will allow the scenario to have access to the stress levels of trainees.

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1 Introduction

In the MED1stMR project, the recording of physiological signals from the MFRs during training represents an essential component to gather data from trainees' psychophysiological state. The acquisition of these physiological signals is made through wearable devices, developed in order to meet the requirements defined by end users and the MED1stMR system constraints. These physiological signals are integrated into a dashboard that presents in real time the information regarding trainees' physiological parameters and a stress level derived from those parameters.

2 Physiological Signals

This part of the deliverable focuses on the physiological signals choice that was based on the past deliverables' information regarding the end users' perspective and PLUX's expert view.

2.1 End users' requirements

In D2.2 - *End Users Perspective: Requirements Report, Stakeholder Map and Expectation Summary for Smart Wearables, MR Training Framework and Curriculum* - end users identified that it would be relevant for the smart wearables developed in the MED1atMR system to assess different biosignals (electrocardiogram - ECG, breathing rate - BR, electroencephalography - EEG or electrodermal activity - EDA) in order to provide stress measurements. They considered it relevant as it allows the trainers to gather useful information regarding the mass casualty incident (MCI) training (understanding when and why are the MFRs stressed and to assist in the handling of psychological strain) and, furthermore, to intervene if needed (e.g., if the stress levels are too high).

Further information was provided in the deliverable D3.3 - *Concept for Physiological Measurement Suite for Stress Assessment* - where the stress measurement indicators that will provide useful information regarding trainees during the MCI training were identified. The document pinpointed the ECG features that will be important for the stress analysis, namely, heart rate, heart rate variability and breathing rate (HR, HRV, BR). EDA was also considered a biosignal pertinent for the stress measurement.

EEG was not considered for integration in the system since from the point of view of usability it would be rather complex to make the set-up (the MFRs will be using a helmet which would difficult the placement of electrodes on the head).

In summary, end users identified as pertinent physiological signals the ECG (which allows the extraction of HR, HRV and BR) and the EDA. This was also explored in the deliverable D3.4 - *Real-Time Training Progress Assessment Tool* - where a real time training dashboard that combines various measurement tools was presented. This tool provides a stress level assessment derived from the indicators of stress - HRV and EDA - physiological parameters retrieved from the trainees. The

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visualization of the physiological data in a dashboard allows trainers to have a better understanding of the trainees' data and the team's real-time status (see D3.4 for the dashboard).

2.2 Wearable Development

Regarding the requirements for the wearable development, in the deliverable D2.2, end users identified that wearables should allow free movement and should not be "felt" thus, being comfortable to wear during the training session. End users also considered that the wearable could be a wristband/smartwatch or a suit/vest. Essentially, they focused that it should be a one-piece wearable.

When considering the development of a wearable, PLUX excluded the possibility of this being a wrist-band or a smartwatch as these would not have ECG as a continuous available signal (and this was considered an extremely important signal for stress measurement) and would possibly restrain the movements since MFRs already have other elements in their hands, when conducting the training.

The development of a vest/suit was considered but it derived into a strap that stretches in order to fit tightly. This tightness is needed so that sensors are in close contact with the skin, and this would be much harder to achieve with a vest or suit (this knowledge derives from an H2020 project in which PLUX is also involved in - IM-TWIN [1]). This strap is easy to wear and allows the free movement of MFRs. The integration of a device - cardioBAN - into the strap allows for the collection of ECG data. Another device is being considered for the acquisition of EDA and it can also be integrated into the back side of the strap. Like this, the wearable would be a strap/belt that integrates two devices - one in the front, collecting ECG, and the other in the back, collecting EDA.

2.2.1 EDA wearable

The development of an EDA wearable was achieved through the exploration of EDA signals in different locations since the gold standard position (the fingers or the palm of the hand) is a location that will not be available due to usability issues (MFRs will have other elements in their hands during training).

For the study of the EDA positioning, PLUX conducted a study that involved 25 healthy participants (18 to 51 years-old; 14 female).

The following locations were explored: (1) Fingers (Standard Position) non-dominant hand; (2) *Rectus Abdominus*, (3) Back (inferior zone of Trapezius), (4) Forehead, (5) Armpit (lower, in the line of the cardioBAN belt). To mention that for the last location the data was collected from only 7 participants. The following figure (Figure 1) illustrates the location of the EDA sensors' electrodes.

[1] From Intrinsic Motivations to Transitional Wearable INtelligent companions for autism spectrum disorder (H2020 #952095). https://im-twin.eu/

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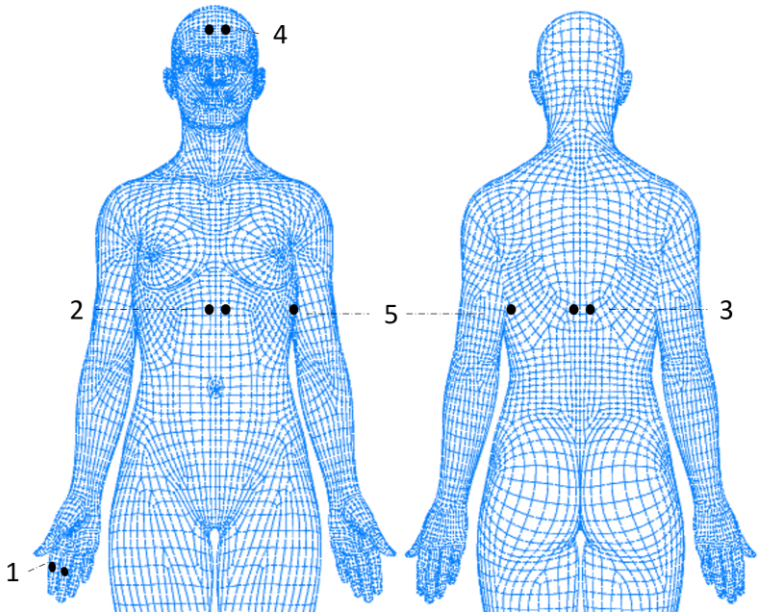

Figure 1: EDA sensors' positioning 1: finger, 2: chest, 3: back, 4: forehead, 5: armpit.

The study consisted of the following steps. First, we placed the sensors (the standard position and the abdomen) and started with 5 minutes of rest after the electrodes' placement and the establishment of a baseline (3 minutes acquisition). Then, the following tasks were performed (with 30 seconds of rest in between tasks): touch of the back of the hand into a cup containing hot water; touch of the back of the hand into an ice package (cold stimulus); rubbing the back of the hand with cotton; rubbing the back of the hand with sandpaper; poking the back of the hand with a needle (the largest part); and holding the breath as long as possible. Afterwards, the repetition of this protocol followed since we needed to compare different zones: the standard position with the back, the standard position with the forehead and the standard position with the armpit. There was a resting time at the beginning of 3 minutes.

The tools used for EDA analysis were NeuroKit2 (SCR onset, peak, recovery) and the features SCR peak amplitude, with 0.04µS and 0.02µS as thresholds. Onset within a specific time window of stimuli was considered.

The next figure represents an example signal of the chest, compared with the standard position (fingers). The red line represents the alternating phases of activities being performed and resting stages (where the baseline represents the latter) and the yellow line represents the raw EDA signal obtained. The black intermittent line represents detected responses to stimuli.

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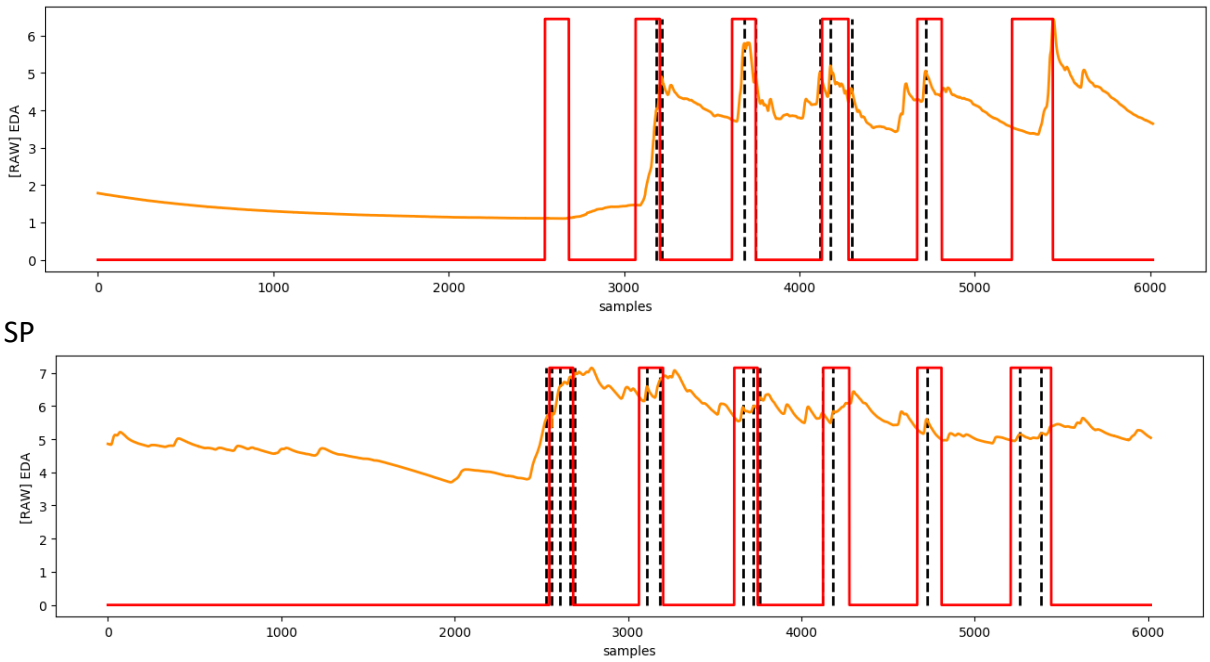

Figure 2: Example of raw EDA signals (orange) from chest and fingers (SP).

For a threshold of 0.04µS, the mean and standard deviation of the peak amplitude for all participants for the different positions are presented in the table below (Table 3).

Table 3: Mean and standard deviation of the SCR peak amplitude (Threshold of 0.04µS).

Round	Position	SCR_MEAN [µS]	SCR_STD [µS]
1	Chest	0.239	0.431
1	SP	0.583	1.092
2	Back	0.238	0.363
2	SP	0.634	1.135
3	Forehead	0.231	0.326
3	SP	0.625	0.957
4	Armpit	0.027	0.068
4	SP	0.515	0.545

The difference of the mean amplitude between the back and the standard position is similar to the difference of the mean amplitude between the chest and the standard position.

The following boxplot (Figure 3) illustrates the median and the spread of the amplitude for each position, compared with the standard position, for all participants, for a threshold of 0.04µS.

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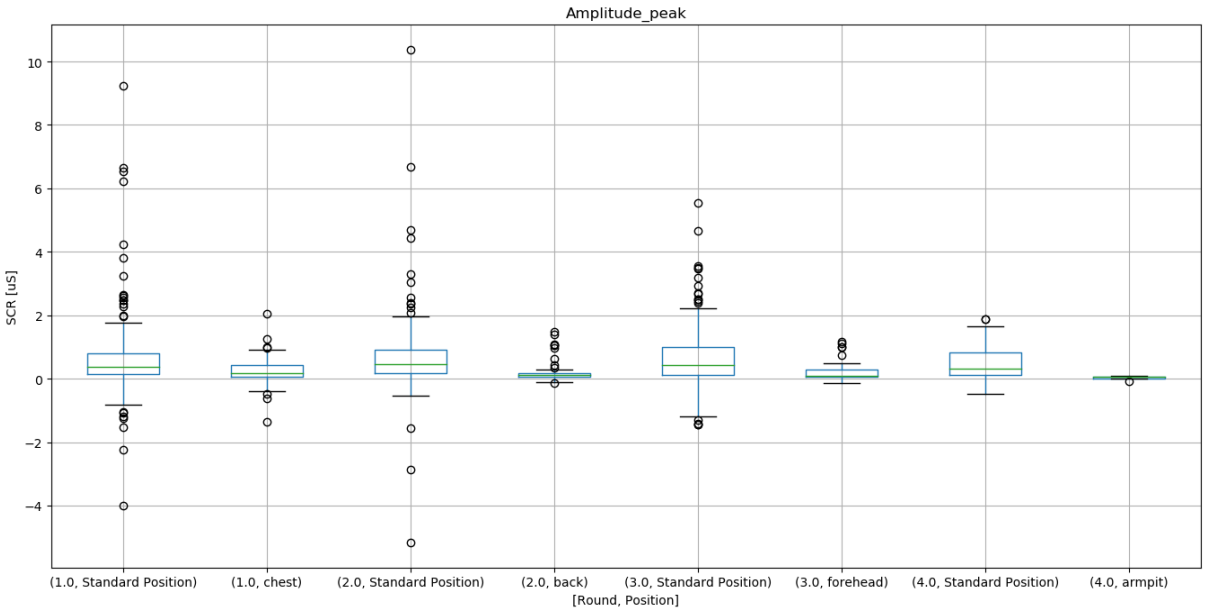

Figure 3: Boxplot with median and spread of the SCR amplitude (Threshold of 0.04µS).

The following plot (Figure 4) illustrates the boxplot of the sum of peaks, with median (green) and outliers (o). 75% of the participants have less than 7 peaks, for the chest. 75% of the participants have less than 3 peaks, for the back. For the forehand, 75% of the participants present less than 2 peaks. For all four positions, the median is zero (no peak) so, on average, there was no response.

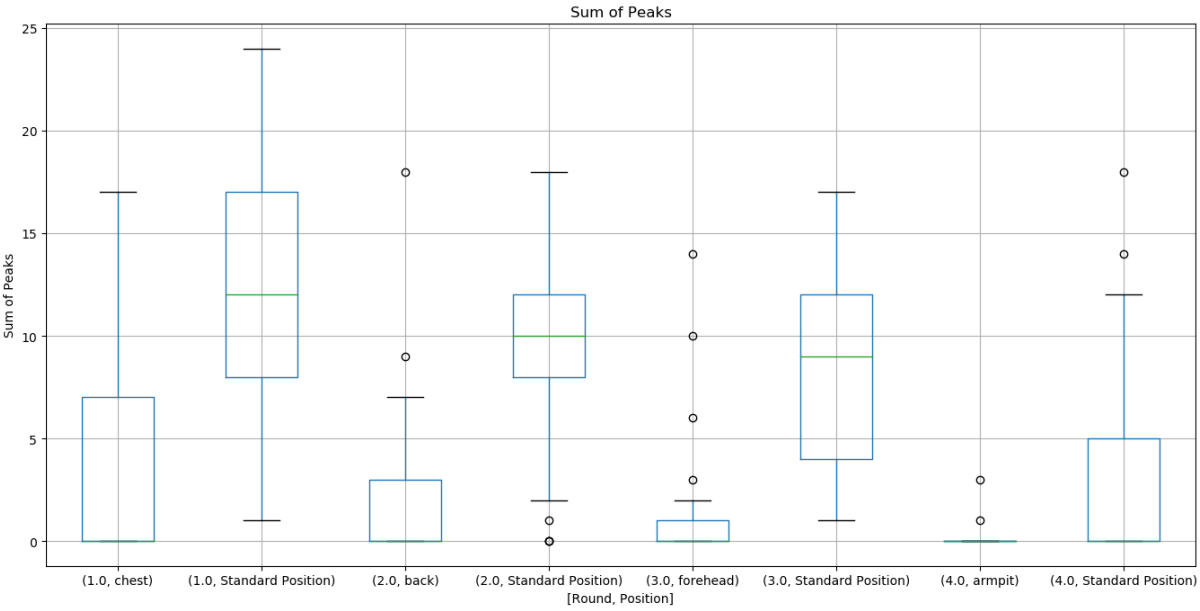

Figure 4: Boxplot of the sum of peaks (Threshold of 0.04µS).

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For a threshold of 0.02µS, the mean and standard deviation of the peak amplitude for all participants for the different positions are presented in the table below (Table 4).

Table 4: Mean and standard deviation of the peak amplitude (Threshold of 0.02µS).

Round	Position	SCR_MEAN [µS]	SCR_STD [µS]
1	Chest	0.182	0.388
1	SP	0.559	1.075
2	Back	0.182	0.325
2	SP	0.591	1.106
3	Forehead	0.154	0.281
3	SP	0.598	0.944
4	Armpit	0.029	0.053
4	SP	0.489	0.542

The difference of the mean amplitude between the back and the standard position is also similar to the difference of the mean amplitude between the chest and the standard position.

The difference of the mean amplitude between the chest and the standard position is the smallest for both thresholds.

The following boxplot (Fig 5) illustrates the median and the spread of the amplitude for each position, compared with the standard position, for all participants, for a threshold of 0.02µS.

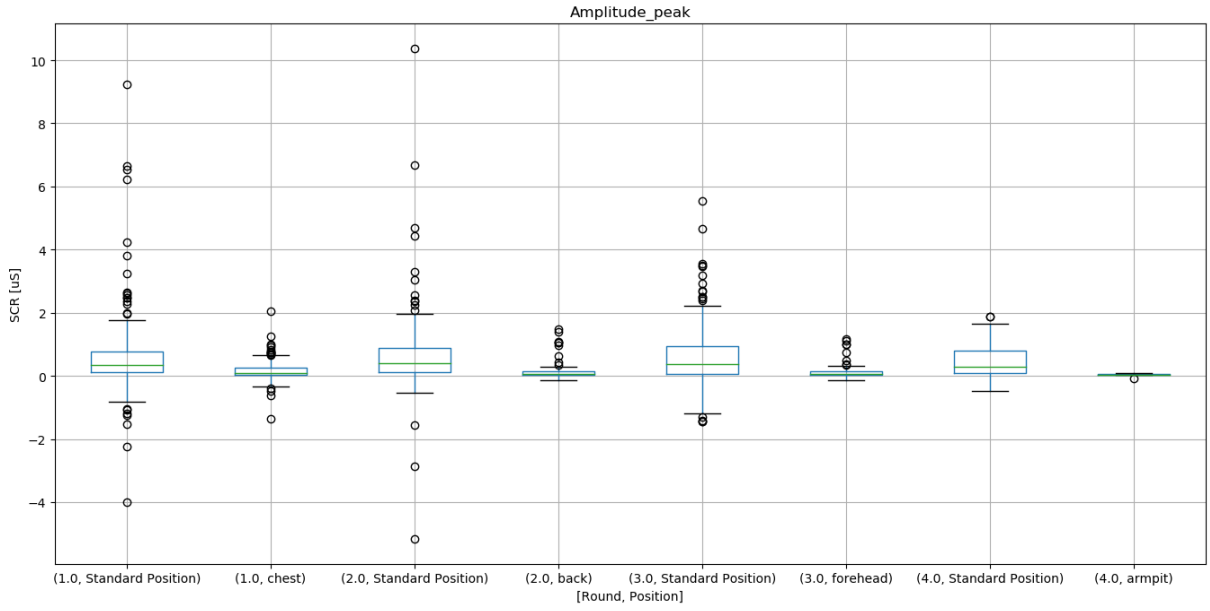

Figure 5: Boxplot with median and spread of the amplitude (Threshold of 0.02µS).

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The following plot (Figure 6) illustrates the boxplot of the sum of peaks, with median (green) and outliers (o). For the chest, 75% of the participants presented less than 8 peaks. For the back, 75% of the participants have less than 4 peaks. For the forehand, 75% of the participants present less than 3 peaks. For all these three positions, the median is around two so, on average, participants presented two peaks. For the armpit, the median is zero (no peak).

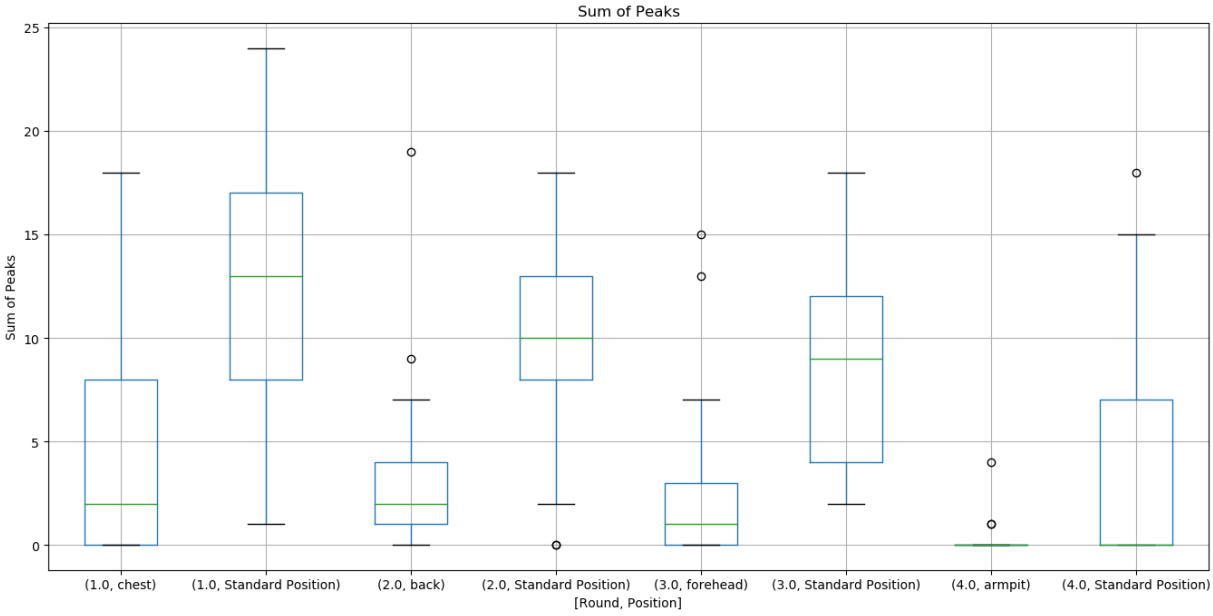

Figure 6: Boxplot of the sum of peaks (Threshold of 0.02µS).

Considering a threshold of 0.04µS, the back obtained 48% of the signals compared to the standard position. The chest and the forehead left out 60% of the SCR responses.

Table 5: Total signals with and without SCR Responses (Threshold of 0.04µS).

Round	Position	Total Signals	Total Signals with SCR Responses		Signals without SCR Responses	
1	Chest	25	10	40%	15	60%
1	SP	25	25	100%	0	0%
2	Back	25	12	48%	13	52%
2	SP	25	22	88%	3	12%
3	Forehead	25	10	40%	15	60%
3	SP	25	25	100%	0	0%
4	Armpit	7	2	29%	5	71%
4	SP	7	7	100%	0	0%

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Considering a threshold of 0.02µS, the back obtained 76% of the signals compared to the standard position. The chest also obtained an approximate value (72%) of the SCR responses. Thus, both the back and the chest appear to be good alternative locations to collect EDA signals, considering a threshold of 0.02µS.

Table 6: Total signals with and without SCR Responses (Threshold of 0.02µS).

Round	Position	Total Signals	Total Signals with SCR Responses		Signals without SCR Responses	
1	Chest	25	18	72%	7	28%
1	SP	25	25	100%	0	0%
2	Back	25	19	76%	6	24%
2	SP	25	23	92%	2	8%
3	Forehead	25	14	56%	11	44%
3	SP	25	25	100%	0	0%
4	Armpit	7	3	43%	4	57%
4	SP	7	7	100%	0	0%

Taken together, the results pointed to a solution where the EDA can be collected on the back or chest. Considering that the ECG will need to be placed in the chest, we have chosen the back as a viable option for the collection of EDA signals. Like this, the strap/belt that already has the ECG sensors can also integrate the EDA sensors and it will be a unique wearable device (which takes into account the end users' perspective regarding the wearable device solution).

2.2.2 ECG wearable

The ECG wearable was developed having in mind the end users' requirements and allows free movement. It is a strap/belt where the cardioBAN can be placed (in the front).

2.2.2.1 Description of cardioBAN

The cardioBAN is a wearable developed for continuous monitoring of vital signs in ambulatory settings. After the device is turned on, it streams physiological data in real time, including ECG, HR and movements. This device has a single lead ECG, an accelerometer (ACC) and a magnetometer (MAG). It streams data through Bluetooth (BT) for up to 4 consecutive hours. The cardioBAN can be used in two different modes. Either it can be attached to the chest area using two pre-gelled electrodes or it can be attached using a chest strap with dry electrodes which is recommended in case of doing exercise. After each use, the device is recharged with a mini-USB cable.

2.2.2.2 Specification of cardioBAN

The table below (Table 7) describes the specifications of the cardioBAN.

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Table 7: Specifications of the wearable cardioBAN.

Device Part	Specification	
Analog Ports	None (integrated sensors only)	
On-board Sensors	Electromyography	(EMG)
	Accelerometer	(ACC)
	Magnetometer	(MAG)
Processed Data	Breathing rate	(BR)
	Heart rate variability	(HRV)
Sampling rate	Up to 1000Hz	
Communication	Bluetooth Class II & Bluetooth Low Energy (BLE)	
Size	31 x 71 x 11mm	
Color	White	
Auxiliary ports	None	
Sampling Resolution	16-bit	(ECG)
	14-bit	(ACC)
	16-bit	(MAG)
Range	Up to ~10m (extendable)	
Weight	25g	
Micro-USB charging	Isolated via operation mode	
Battery	155mA 3.7 LiPo rechargeable (4h in continuous operation)	

2.2.2.3 Transfer Function of the sensors

ECG Transfer Function

The ECG input voltage range = [-1.14mV, 1.14mV]

$$V_{ECG}[V] = \frac{V_{REF}(ADC - 2^{n-1})}{2^n \, x \, Gain}$$

$$V_{ECG}[mV] = V_{ECG}[V] \; * \; 1000$$

Where:

VREF - ADC voltage reference, 2.5[V]

Gain - Analogue voltage gain, 1100

VECG[V] – Raw EMG value in Volt [V]

VECG[mV] – Raw EMG value in millivolt [mV]

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ADC – Value sampled from the channel

n - Number of bits of the channel[2]

Accelerometer Transfer Function

The ACC input range = [-4G, 4G]

$$ACC(g) = \left(ADC - \frac{2^n}{2}\right).\left(\frac{8}{2^n}\right)$$

Where:

$Acc(g)$– Accelerometer value in g (acceleration of gravity)

ADC– Value sampled from the channel

n – Number of bits of the channel[3]

Magnetometer Transfer Function

The MAG input range = [-1200µT, 1200µT]

$$Mag(\mu T) = \left(ADC - \frac{2^n}{2}\right).0{,}1$$

Where:

$Mag(\mu T)$– Magnetometer value in microTesla (µT)

ADC – Value sampled from the channel

n – Number of bits of the channel[4]

2.2.2.4 Wearable Positioning

The standard measurement technique for ECG is the application of 12 leads to cover all information of the heart in three directions. However, basic heart monitoring can be performed using a single lead (bipolar) ECG sensor setup in which the signal is measured between two measuring electrodes and the third electrode is the reference.

2 The number of bits for each channel depends on the resolution of the Analog-to-Digital Converter (ADC). In cardioBAN the default is 16-bit resolution (n=16)

3 The number of bits for each channel depends on the resolution of the Analog-to-Digital Converter (ADC). In cardioBAN the default is 14-bit resolution (n=14)

4 The number of bits for each channel depends on the resolution of the Analog-to-Digital Converter (ADC). In cardioBAN the default is 16-bit resolution (n=16)

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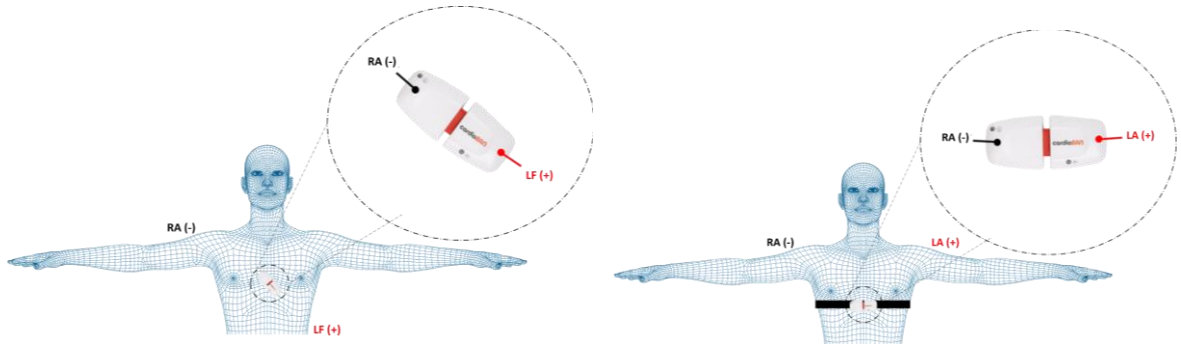
The ECG sensor of the cardioBAN is a single lead ECG sensor which can measure the cardiac cycle from Einthoven Lead I (right arm RA to left arm LA) and Lead II (right arm RA to left foot LF) with a specific position to place on the body. Figure 7 (A) represents the position to follow for Lead II with pre-gelled electrodes. Figure 7 (B) represents the position to follow for Lead I when using either pre-gelled electrodes or the chest strap.



A B

Figure 7: Wearable position on the body: pre-gelled electrodes (A) Lead II, chest strap (B) Lead I.

The ECG signal can be used to extract relevant features such as the HRV to indicate the overall cardiac health. In this analysis method, a series of inter-beat-intervals are examined, see Figure 8.

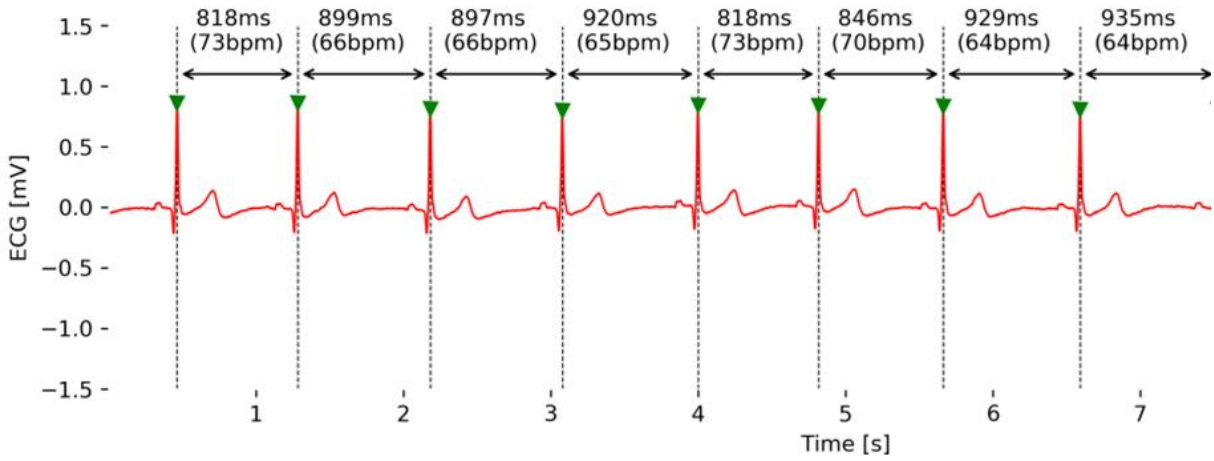


Figure 8: ECG Signal Sample in [mV] with R-Peak detection (green) and HRV values in (bpm) for each inter-beat-interval.

Because the movement of the thorax during breathing changes the distance between the electrodes and the heart (e.g., when breathing in the distance increases), it is also possible to derive the respiration rate based on the R-peak amplitude using the ECG sensor (see Figure 9).

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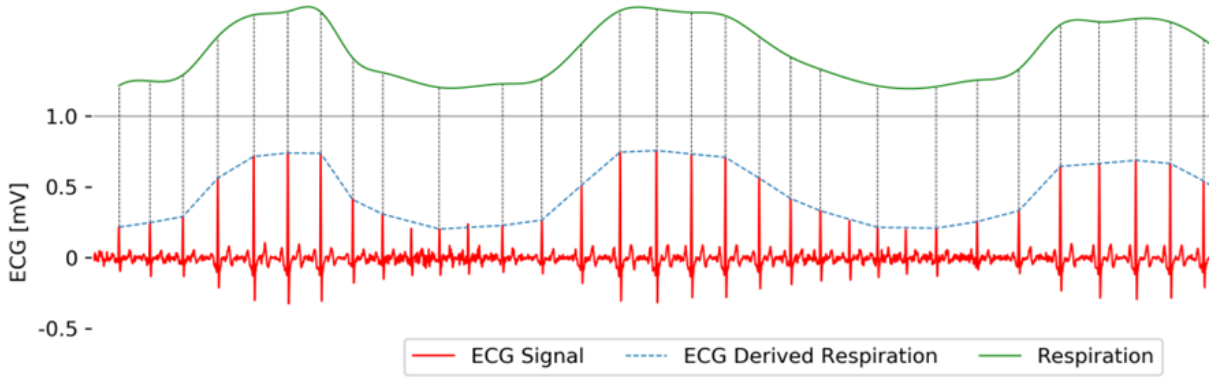

Figure 9: ECG Signal Sample in [mV] with ECG derived respiration curve (blue) and respiration (green).

Device

The cardioBAN device has different ways to operate, depending on each situation. Table 8 describes the led color code of the device for the three modes standby, real-time streaming and charging.

Table 8: LED color code in different situations.

State	Bat LED state	System LED state	Device state	Battery	Charging	Switch	On-body
Standby	OFF	OFF	OFF	-	No	OFF	-
	OFF	OFF	OFF	Discharged	No	ON	-
	OFF	Green blink	Standby	Good	No	ON	-
	OFF	Red blink	Standby	Low	No	ON	-
Real-Time Streaming	OFF	Green (fast blink)	Streaming	Good	No	ON	Yes
	OFF	Red (fast blink)	Streaming	Low	No	ON	Yes
	OFF	Orange (steady)	Streaming	-	No	ON	No
Charging	Green and Red (steady)	OFF	OFF	Charging	Yes	OFF/ ON	-

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State	Bat LED state	System LED state	Device state	Battery	Charging	Switch	On-body
	Green (steady)	OFF	OFF	Fully charged	Yes	OFF/ ON	-

The charging is done by mini-USB cable using a 5V USB universal voltage source. The protection between the power supply and the electrodes, which are in contact with the skin, is guaranteed by the physical switch on the device. Only when the switch is OFF, it is possible to charge the device.

2.2.2.5 Accessories of cardioBAN

Chest strap

The cardioBAN device can be attached on an adjustable and comfortable chest strap for unobtrusive ECG acquisitions.

Figure 10: Chest strap (A) with dry electrodes (B) and snaps (C) to connect to cardioBAN (D).

The chest strap should be tightened enough for the ECG electrodes (<1mm) to be in contact with the skin surface without limiting the user's movements or comfortability. The chest strap has an adjustment system that allows everyone to use it and, contrary to the gelled disposable electrodes, it's not necessary to use the gel.

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Electrodes

Another alternative to the chest strap is the use of pre-gelled self-adhesive Ag/AgCl electrodes - Ambu BlueSensor VL ECG Electrodes, Figure 11.

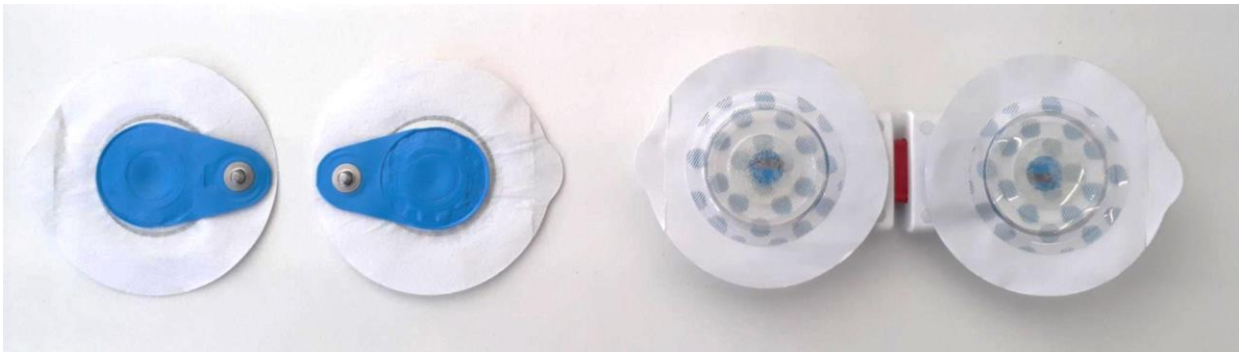

Figure 11: Pre-gelled electrodes (left) connected to the cardioBAN (right).

These electrodes are Biocompatible acc. to DIN ISO 10993 and have CE Mark according to MDD 93/42/EEC CE. The material is breathable and comfortable over longer time periods. The electrodes are the preferable way in the field trials of this project to avoid the possibility of slipping of the chest belt and ensure a good signal quality to collect enough useful data.

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3 Hardware and Software Framework

The PLUX Hardware and Software Framework is composed by a) the cardioBAN and edaBAN wearable devices (Hardware Component) and by b) the Python Server and Unity Client APPs (Software Component). The cardioBAN and edaBAN wearables were carefully developed to ensure an accurate acquisition of ECG and EDA signals, respectively.

Regarding the two aforementioned APPs, the Python Server is the kernel of the Data Processing module while the Unity Client is a simple sample aimed to demonstrate how the processed data, streamed by the Python Server, can be received in a Unity client/application.

The Hardware and Software components of the framework will be explored with more detail in the next sections.

3.1 Hardware Component

In D2.4 - High-Level System Architecture - the integration of the modules into the MR training system is described: The VR training system, manikin ADAM-X, PLUX wearable sensors, and the dashboard application. Regarding the Wearable PLUX Biosignals Sensor system it is modular, interoperable, and efficient, and it supports the full process from the data recording to the feature transmission to the server.

3.1.1 Biosignals sensor hardware architecture

The PLUX Vital Sensor Hardware system will be composed of two different hardware components: the wearable device and the gateway, as illustrated in Figure 16. The wearable device is developed specifically for this purpose, and it is composed of the following items:

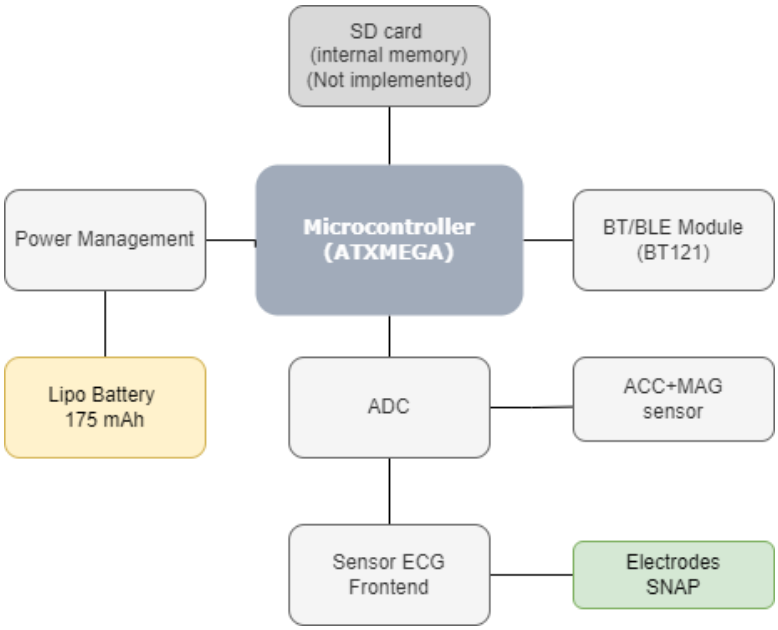

Figure 12: High level block diagram of the cardioBAN.

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The ATXMEGA microcontroller is responsible for managing all actions related to the cardioBAN functionality, it interfaces with:

- Power management module for charging the battery and distributing of the required voltage levels.
- Bluetooth module for the communication with the software API, handling all commands via the developed protocol.
- ADC (Analogue to Digital Converter) to digitalize with a 12-bit resolution the signals from the sensors.
    - The ADC interfaces with both ECG frontend and the ACC+MAG (accelerometer and magnetometer) sensors.

BOM list (main components)

The following table describes the critical components for the cardioBAN.

Table 9: Critical components.

Item	Part Number
Microcontroller	ATXMEGA256A3BU
Bluetooth module	BT121/2
ECG frontend	AD8232ACPZ-R7

Hardware view:

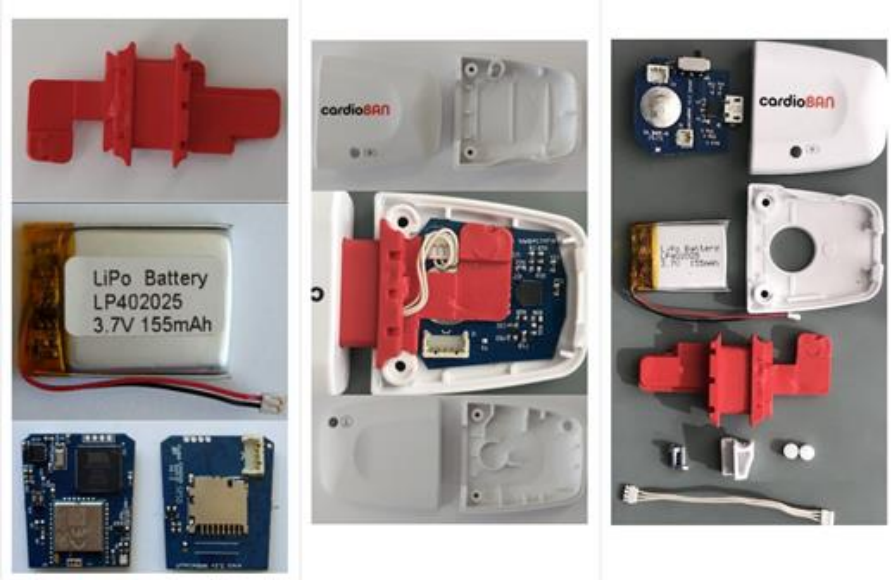

Figure 13: Disassembled parts of the cardioBAN.

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Figure 14: Final assembled unit cardioBAN.

3.1.2 EDA sensor hardware architecture

The PLUX EDA sensor wearable will follow the exact **same architecture** of the cardioBAN, with a customization on the sensor EDA frontend.

Figure 15: Expected final assembled unit edaBAN.

Gateway

The gateway will be the component responsible for connecting and managing the communication with the wearable device, processing the recorded data, and packing the extracted features to be uploaded to the system's server. This mission will be done using a standard computer running a Windows

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Operating System and which will be running a new software that will guarantee a full integration in the solution.

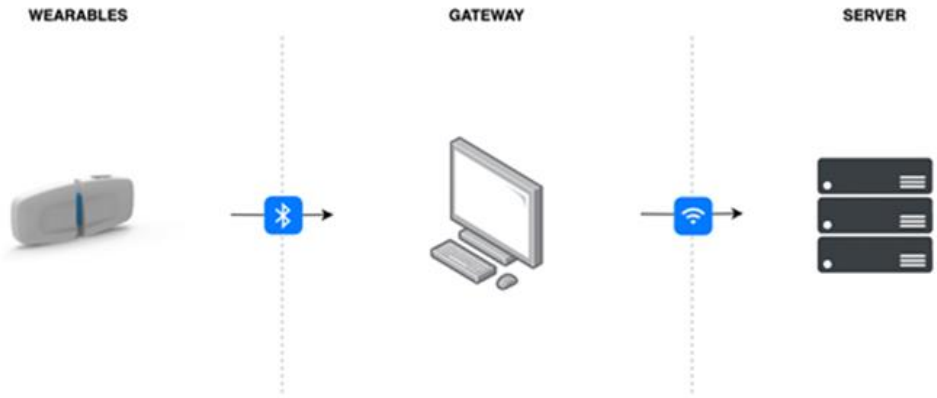

Figure 16: MED1stMR PLUX Hardware Diagram.

3.2 Software Component

The PLUX Vital sensor software architecture is modular, interoperable, and efficient, to support the full process from the data recording to the feature transmission to the server.

The PLUX Vital sensor software architecture diagram is illustrated in Figure 17. The system is composed of six components: four main components (gateway application, device manager, gateway local database and syncing service), one capturing component (PLUX API) and one processing component (main processing service).

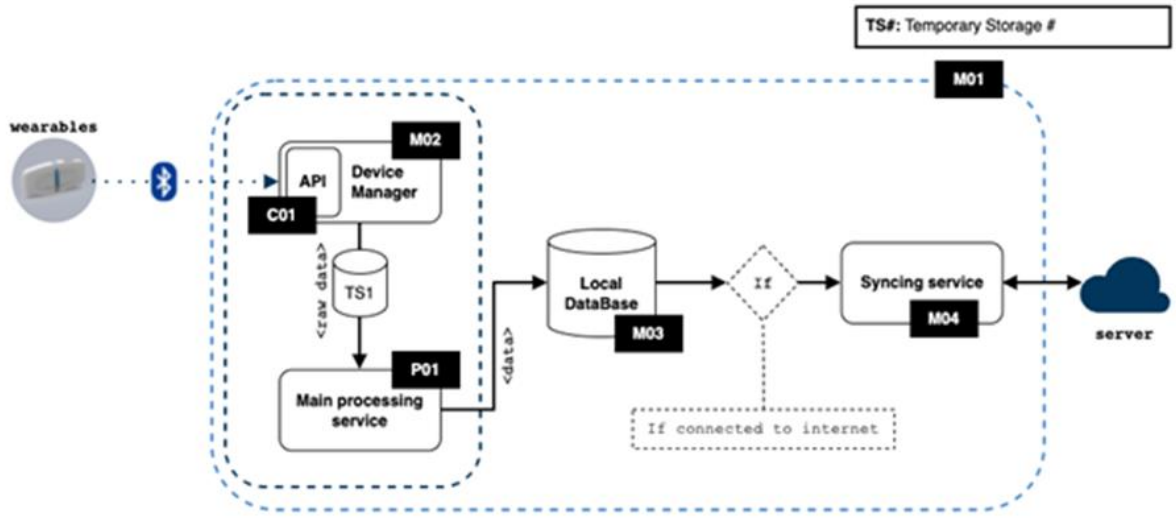

Figure 17: PLUX Sensor Software Architecture diagram.

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The gateway application (M01) combines all the components that are part of the system. The Device Manager (M02) is the component responsible for all the operations linked with the wearable device, this component implements the communication layer for the API (C01).

When the system receives the raw data, which is fetched by C01, it sends it to the main processing service (P01) for data processing and feature extraction. The extracted features will be stored in a local database (M03) and uploaded to the system's server using the syncing service (M04), when an internet connection is available.

The kernel of the **Software Component** consists in the **Python Server APP**, which is focused on providing to the end-user an interactive and intuitive platform that allows him to: **1)** interact with the **PLUX** devices, described in the **Hardware Component** subsection, controlling the **Start** and **Stop** of the real-time biosignals data acquisition (**User Commands → System Action)**; **2)** access specific device related states (battery level, connection status,...) and the streamed data samples.

In addition, the **Python Server APP** is also prepared to communicate with **Client APPs** through the **WebSocket** communication protocol, more specifically, the **Server** can be: **1)** controlled by a **Client APP** when a command message is received and **2)** a "relay" by retransmitting the data samples communicated by the **PLUX** devices to the **Clients**.

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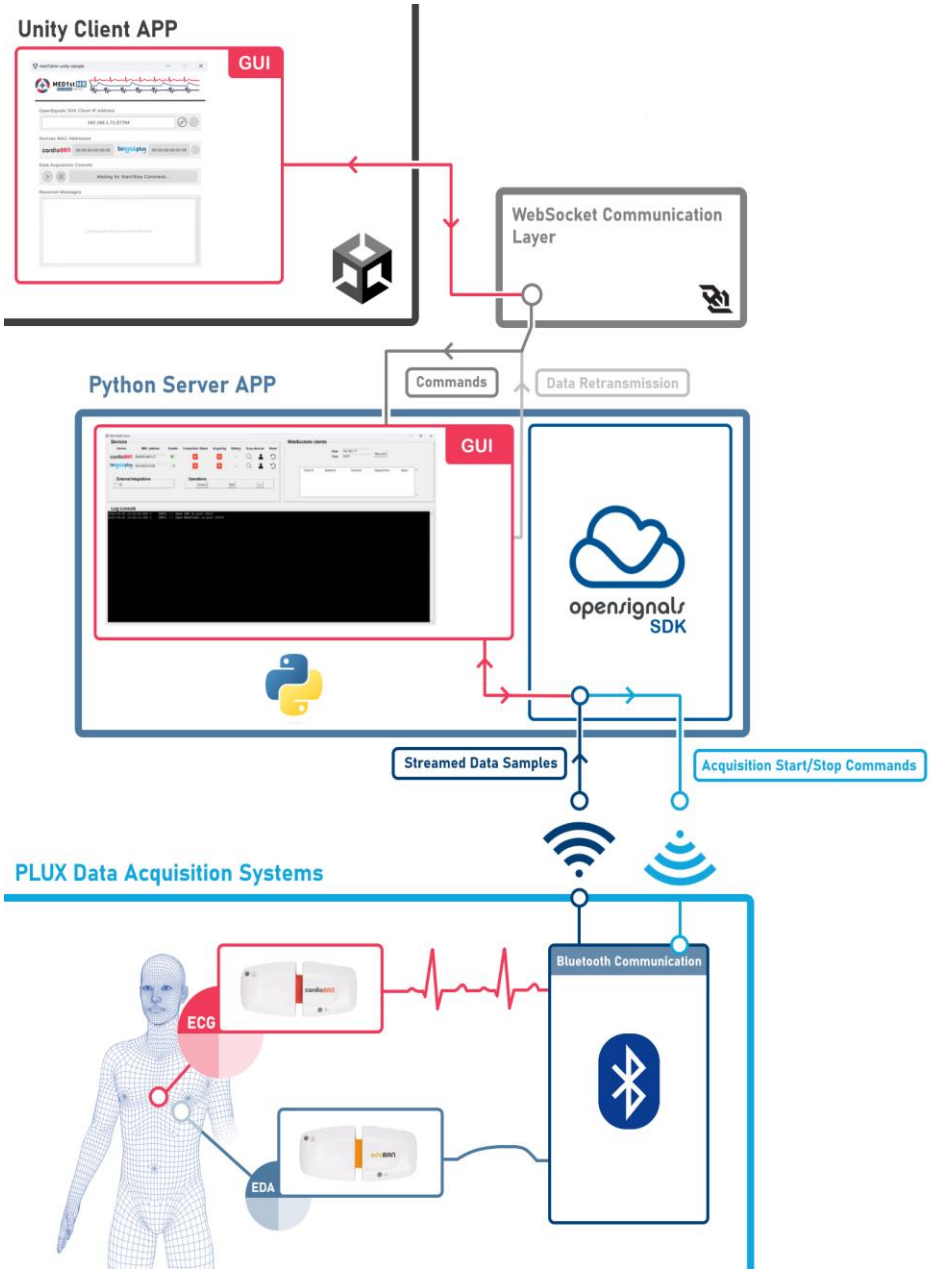

Figure 18: Software Architecture Diagram highlighting all of its major components.

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3.2.1 Python Server APP

The **Python Server APP** is composed by **1)** a **Tkinter Frontend/Graphical User Interface (GUI)** and by **2)** the **OpenSignals SDK**.

The **Frontend** allows the user to interact with the **OpenSignals SDK** data acquisition and processing features, namely: **a)** search for valid **Bluetooth** devices in the surroundings; **b)** establish a connection with the devices found; **c)** start a real-time data acquisition session and **d)** stop a real-time data acquisition session under progress.

The **OpenSignals SDK** will provide textual responses to all actions described in the previous paragraph, which are shown in the **Frontend** in a dedicated console panel.

Finally, while a real-time data acquisition session is being conducted, the data samples acquired by the **PLUX Data Acquisition Systems** and communicated through **Bluetooth** to the **OpenSignals SDK** are **i)** retransmitted to the **Clients** through a **WebSocket** connection and **ii)** processed by the **OpenSignals SDK Algorithms (Heart Rate Variability** and **Electrodermal Activity** analysis**)**.

Similarly, to the data samples flow, the processing results, when available, will be communicated by the **OpenSignals SDK** and retransmitted to the **Clients**.

3.2.2 Unity Client APP

The Unity Client APP is a very simplified example of a Python Server APP client, i.e., it provides a simple template showing **1)** how-to send commands that will control the **Python Server APP** and **2)** how-to receive the replies/messages sent by the **Python Server APP**.

This **Server/Client** mechanism is achievable through a **WebSocket Communication Layer**, that guarantees a bidirectional communication between the **Server** and **Client APPs**.

Based on this architecture, the **Unity Client APP** is prepared to send some commands, namely, the ones that will **a)** trigger the start of a real-time data acquisition in the **Python Server APP** and **b)** its respective stop/conclusion.

In addition, all messages (**Acquired Data Samples** + **Processing Results**) are received and presented in the **Unity Client APP**.

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3.2.3 Dashboard Software Architecture

IDENER will implement a data architecture solution for the Dashboard application to comply with all the expected requirements. The modules developed by IDENER are described in Figure 19 below, painted blue, in the next data flow diagram.

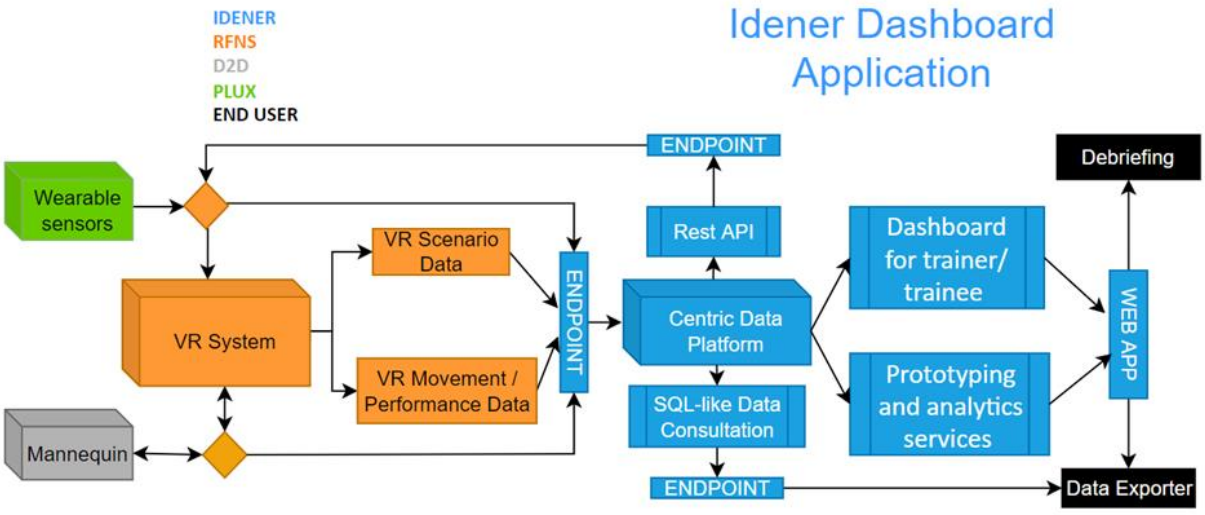

Figure 19: Dashboard Application System Overview.

- **Centric Data Platform**: This module will receive data from all sorts of sources, which will be connected to its endpoint. It will also act as a fault-tolerant database that sends raw data to the rest of the modules that compose the Dashboard application.
- **REST API**: All raw data stored in the data platform will be accessible via REST API. This provides data for smart scenario control algorithms training.
- **Dashboard toolbox**: The Dashboard toolbox module allows the user to create visualizations of the training data for trainer and trainees.
- **Prototyping and analytics services**: This module contains an internal processing engine that extracts advanced analytics and enables machine learning models training.
- **Data consultation module**: This module will enable SQL-like consultations of the data for further data processing or exporting. This opens the door to the use of external processing engines and for analysis by the scientific project partners.

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4 Summary

The wearable device for the acquisition of physiological data from trainees will integrate both ECG sensors (on the front) and EDA sensors (on the back) in a strap/belt, allowing the free movements of MFRs and ensuring that end users' requirements defined on previous deliverables are met. The wearable will be able to gather heart rate, heart rate variability and breathing rate as well as EDA parameters.

This deliverable will be the basis for the development of the wearable prototype for MFR monitoring during training (D4.5). This will provide all physiological data from the trainees, important for the D4.3 - *Activity Recording for the Exercise Debriefing* - where all physiological data will be recorded and communicated over the API and must be stored for debriefing purposes, specifically for the assessment of stress levels.

The physiological data will be relevant for the integration of trainees' physiological data, done via API, to allow a visual display of information into a real-life data dashboard for the trainings (D5.2 - *MR Trainings Environment, Trainings-Scenarios and MR Live Editor infrastructure for conducting the Evaluations*). The physiological data will also enable the assessment of stress (D5.4 - *Integrated Sensorics for Physiological Measurement of Trainees*), contributing for the overall assessment of trainees' performance during the training and this information will also be embedded in the scenario, as it will have access to the stress levels of trainees and the scenario itself will be able to introduce some changes according to the stress levels displayed (D5.5 - *Smart Scenario Control Module*).

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