H2020 – Secure societies - Protecting freedom and security of Europe and its citizens
SU-DRS02-2018-2019-2020– Technologies for first responders – Research and Innovation Action (RIA)

Search & Rescue

Emerging technologies for the Early location of Entrapped victims under Collapsed Structures & Advanced Wearables for risk assessment and First Responders Safety in SAR operations

D5.6 First responder prototype uniform and first aid for kids' device design, V2

Workpackage:	WP5 – Design and implementation of specialised equipment for first responders
Authors:	UNIFI
Status:	Final
Due Date:	28/02/2023
Version:	1.00
Submission Date:	28/02/2023
Dissemination Level:	PU

Search and Rescue Project Profile

Grant Agreement No.: 882897

Acronym:	Search and Rescue
Title:	Emerging technologies for the Early location of Entrapped victims under Collapsed Structures & Advanced Wearables for risk assessment and First Responders Safety in SAR operations
URL:	www.search-and-rescue.eu
Start Date:	01/07/2020
Duration:	36 months

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	FUNDACIÓN PARA LA INVESTIGACIÓN E INNOVACIÓN BIOSANITARIA DE ATENCIÓN PRIMARIA (FIIBAP)	Spain
	ESCUELA ESPANOLA DE SALVAMENTO Y DETECCION CON PERROS (ESDP)	Spain

Document History

Version	Date	Author (Partner)	Remarks/Changes
0.10	06/07/2022	Laura Giraldi (Unifi)	First draft ToC
0.20	31/10/2022	Giulia Sedda (UNICA)	Second draft ToC
0.30	31/12/2022	Giulia Sedda (UNICA)	UNICA contribution, first draft
0.31	02/02/2023	Laura Giraldi (UNIFI) Marta Maini (UNIFI) Francesca Morelli (UNIFI) Elisabetta Cianfanelli (UNIFI) Debora Giorgi (UNIFI)	UNIFI contribution, first draft
0.32	05/02/2023	Ioannis Symeonidis (CERTH)	CERTH contribution
0.40	14/02/2023	Giulia Sedda, Danilo Pani, Giulia Baldazzi, Andrea Spanu, Stefano Lai, Antonello Mascia (UNICA)	UNICA contribution, second draft
0.50	15/02/2023	Laura Giraldi (UNIFI)	Final draft for internal review
0.51	20/02/2023	Svenja Bertram (JOHAN)	Internal Review
0.52	20/02/2023	Birgit Schilcher (JOAFG), Tanja Brey (JOAFG)	Internal Review
0.60	22/02/2023	UNIFI TEAM	Ready for QC
0.61	24/02/2023	Christodoulos Santorinaios (NTUA)	Quality Control
1.00	28/02/2023	Christos Ntanos (NTUA)	FINAL VERSION TO BE SUBMITTED

List of abbreviations

Abbreviation	Explanation
ADC	Analog to Digital converter
AFE	Analog Front-End
API	Application Programming Interface
ASTM	American Society for Testing and Material
BLE	Bluetooth Low Energy
BP	Blood Pressure
BT	Body Temperature
CE	Conformité Européenne
DC	Direct Current
DPI	Disponsable Protective Equipment
ECG	ElectroCardioGram
EMG	ElectroMyoGram
ERM	Emergency Response health condition Monitoring device
EU	European Union
FDA	Food and Drug Administration
FR	First Responder
GPRS	General Packet Radio Service
GPS	Global Positioning System
HAZMAT	hazardous materials
HCD	Human Centred Design
I/O	Input/ Output
I2C	Inter-Integrated Circuit
IC	Integrated Circuit
ICT	Information Communication Technologies
IMU	Inertial Measurement Unit
IR LED	Infrared Light Emitting Diode
KPI	Key Performance Indicators
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MQTT	MQTT (not an abbreviation) is a lightweight, publish-subscribe network protocol
N/A	Not Applicable
N/C	Not Classifiable
NIBP	Non-Invasive Blood Pressure
NTC	Negative Temperature Coefficient
PAT	Pulse Arrival Time
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
PLA	Polylactide
PP	Polypropylene
PPE	Personal Protective Equipment
PPG	PhotoPlethysmoGram
PTT	Pulse Transit Time
REST	Representational State Transfert

RFI	Radio Frequency Interference
RR	Respiration Rate
SAR, SnR	Search and Rescue
SpO2	Peripheral Oxygen Saturation
SRAM	Static Random-Access Memory
TFT	Thin-Film Transistor
USAR	Urban Search and Rescue
UC	Use Cases
WIFI	Wireless Fidelity
WP	Work Package

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1 Technology status from D5.2

1.1 First responder uniform.

During the first year of the project, the smart uniform has been studied and designed, as described in the Deliverable D5.2. [1] The prototype is composed of two layers: the external protective and performant uniform for first responders (FR), composed of jacket and trousers, and then a smart underwear with T-shirt and leggings to be worn under the rescuer's professional uniform. The model of the uniform is designed according to the anatomy of the body to be more comfortable and protective. In order to address gender specific needs, the research project studied two different models according to the anatomy of the male and female body, even though this was not specified and requested in the DoA. The prototypes have been developed taking into account the Italian sample sizes: size L (50-52 IT) for the men's uniform, size S (38-40 IT) for the women's one.
The design of the uniform is "user centred", taking in account the human anatomy, functional and psycho-physical needs of the first responders and the characteristics of the disaster scenarios, as described in detailed in D5.2. [1] In order to highly protect the FR during the rescue activity the uniform is made of different innovative, protective and performant materials.
The fabric mainly used is the Jackal textile, produced by Textil Santanderina, chosen for its excellent mechanical and chemical properties combined with its sustainable characteristics. The Jackal textile's technical chart is attached in Annex III. Moreover, in critical points of the body (elbows, shoulders, knees), the textile is improved with an additional custom fiberglass textile layer in order to give extra protection against abrasion. Also, removable flexible 3D printed protections are implemented in these critical points to ensure an improved protection against shocks.

Polymer-based, custom-designed sensors monitoring the health status of the first responder are embedded in the smart underwear, as they require tight contact of the sensors on the skin: Electrocardiogram (ECG) electrodes in the T-shirt, Electromyogram (EMG) electrodes and strain sensors for joint angles estimation in the leggings.

Other sensors measuring environmental parameters, such as the concentration of both toxic and explosive gases (by a commercial multi-gas detector) and the X-radiation dose (by a polymeric sensor), are placed in different external pockets of the protective uniform.
The only off-the-shelf tool will be the multi-gas monitor, whereas all the other sensors were custom developed by the University of Cagliari. The sensing capabilities of the uniform are summarized in the following figure.

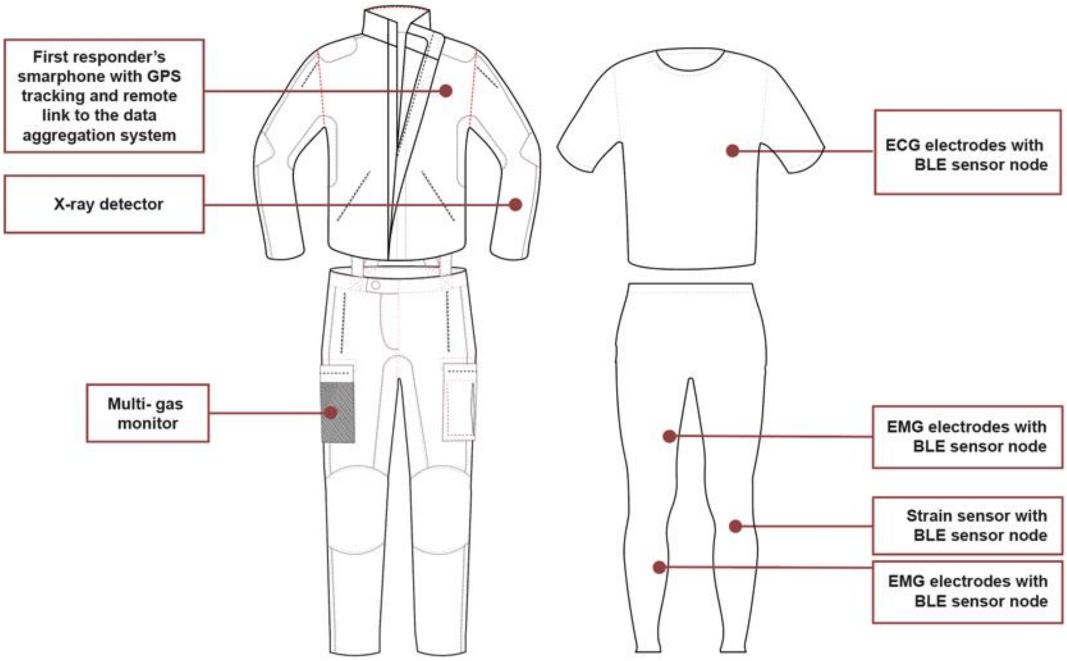


Figure 1 Sensors embedded in the smart uniform

Data from all sensors are collected by dedicated Bluetooth low energy (BLE) nodes, implementing a body sensor network: Each node is able to acquire, process in real-time and transmit electrophysiological, biomechanical and environmental data from the sensors to a custom Android app on the rescuer's smartphone, developed by the University of Cagliari. The app geolocates the data by using the information of the GPS integrated into the smartphone and sends them to the control centre for remote monitoring (as shown in Figure 2). The system features high modularity, as the rescuer can adopt a subset of sensors depending on the specific operative context without any app configuration.

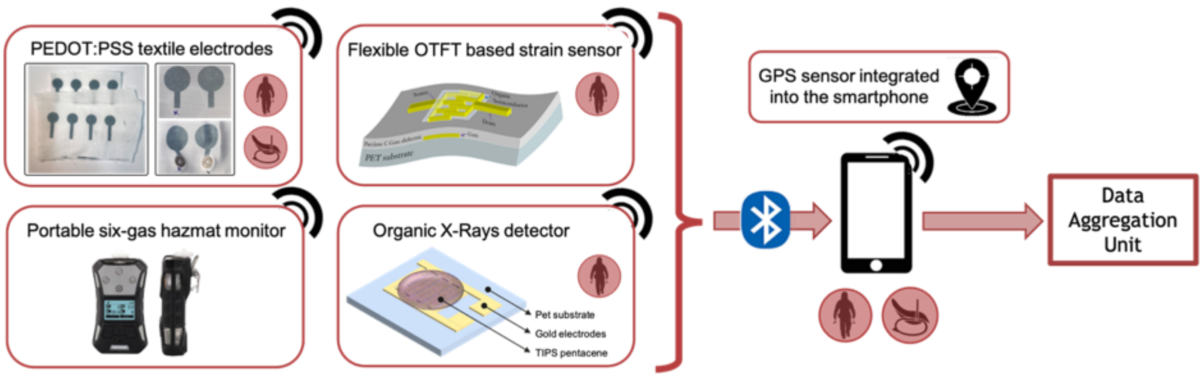


Figure 2 Software architecture

For the description and characterization of the individual sensors please see deliverable D5.2, as they were developed during the first year. The only exception concerns the custom strain sensor, which has undergone substantial modifications following technical problems encountered during the first demonstration pilot and which will therefore be described in the following paragraphs. Also, the design of the custom electronic nodes with their cases will be illustrated in this deliverable, since they have been developed and progressively modified during the second year of project activity, also exploiting the feedback received from the end-users during the demonstration pilots to reach the target TRL.

1.2 First aid device for kids.

During the first year of the project the first aid device for kids has been studied and designed as well (as described in the Deliverable D5.2. [1]) Before the tests of evaluation and during the prototyping of the device, the research team designed some modifications, implementations and improvements in comparison with the design described in D5.2. [1]
The innovative protective first aid device for kids is designed to carry the young victim safely out of the disaster scenario and to monitor the kid's health parameters if necessary. On one hand the device is children centred, designed according to the psycho-physical and emotional needs of the young victim. On the other hand, the device has been designed according to the needs of the first responders, who are the main users, helping them to easily provide first aid support to injured children.
In the final prototype the team decided to use a structure in aluminium profile for its lightness and high resistance to different mechanical shocks.
The prototype of the device is adjustable to the height and weight of the young victim and consists of a board, functioning as a paramedical spinal board, to ensure the safe positioning of the young victim and his/her transportation to the first aid point or to the hospital.
The element for enlarging the board, made of aluminium profile, is separated from the main structure in order to render the adjustment of the board length easier by first responder and to be more solid and strength resistant. Through the interlocking system, it is possible to join the extension to the main board.
The device is accessorised with different stuffed elements, adaptor and safety belts to keep the baby in comfort and in security according to the weight and height of the body.
JACKAL 8627 fabric was not used for the final prototype (as described in D5.2, chapter 7.1.3 [1]), as this fabric is not certified for contact with children's skin. A hospital hypoallergenic fabric was chosen instead of the JACKAL 8627 fabric for its excellent mechanical and chemical properties, for its ease to be cleaned, washed, and disinfected and because it's perfect for contact with the children's skin (certified ISO 8124-6:2014). The textile has been used for covering the board and the stuffed parts. The details of the lining material can be found in the Annex III.

For the final prototype a new cover was designed, which is different from the one presented in Deliverable 5.2 in order to better carry the device in the scenario.

Figure 3. First Aid device for kid prototype

Moreover, the device was also accessorized with commercial sensors embedded in wearable-socks and placed in a pocket of the device to be used if monitoring the health parameter of the kid during the transportation as described in D5.2. [1] is necessary.

1.3 Health condition monitor for victims.

The goal of the Emergency Response Health Condition Monitor (ERM for short) is to keep track of a victim's health from the time they are found until they are taken to an ambulance for expert medical care. The ERM is a small mobile, internet-connected patient monitor that can be quickly deployed in the field without hindering the wearer's mobility.

Patient monitors are used in hospitals to continuously monitor the vital signs of patients undergoing inpatient treatment. They display the patients' vital signs (Figure 4), and relay the information to a central unit. The sensors, transducers, display and communication units are the four essential parts of a patient monitor. These parts are closely integrated in the compact ERM with the target to fulfil all the functionalities of the patient monitor (Figure 5).

Figure-4. A patient monitor attached to a hospital patient (Contec 8000)

Figure 5 The ERM attached on wrist and the ear of the wearer.

2 First responders uniform test and validation

2.1 Usability and preliminary tests

The prototyping process required the execution of several laboratory tests for the functional evaluation of the textile model and of the sensors embedded in the smart underwear:

- usability tests of the textile components according to the European standard specification;
- tests on the strain sensor;
- tests on the X-ray sensor;
- circuit power consumption test;
- battery life test;
- battery recharge test;
- signal acquisition, processing and transmission tests;
- communication test between single nodes and custom Android application and packet loss check;
- comparison of signals acquired with custom electronics and a commercial system;
- washability tests of the external textile components;
- washability tests of smart underwear without the electronics.

Usability tests
The test of usability of the professional external uniform was carried out prior to the UCs pilots in March/April 2022 at the Design Campus spaces - University of Florence and, as stated in the UNI EN ISO 13688, it regards:

- the general comfort of the First Responders wearing it;
- the ease of dressing and undressing without any help;
- freedom of movement (knee bends, arms extension, sitting, walking, running, jumping, climbing stairs, etc.), also without affecting the protection and the coverage of the user;
- the ease of using the locking systems with and without DPI gloves;
- the compatibility with other DPIs;

Moreover, additional usability tests were carried out during the UCs pilots with the corresponding first responders. The test evaluations were recorded and stored in a private and protected database.

Figure 6. Model wearing the uniform during the usability test.

Figure 7. Model wearing the uniform during the usability test.

Figure 8. Model wearing the uniform during the usability test.

Washability tests
The protective uniform was tested regarding its washability properties, as stated in the UNI 13688, as well. The prototype was positively tested on different washing typology, both dry-cleaning and

homemade, using a commercial and standard washing machine. The prototype passed 5 cleaning cycles without any alteration of the model and of the mechanical and chemical properties of the textile. After 5 cycles the prototype passed the waterproofness and the usability test again.
The technical chart of the Jackal textile, with the detailed certification regarding the washability, is attached in the Annex III.
Moreover, the washability properties of the smart underwear were also successfully tested. The underwear was washed with the embedded printed sensors and without the electronics cases, using a commercial standard washing machine. The underwear has retained the pre-wash functionality of the sensors and fit.

Tests on the strain sensor
During the laboratory tests and field use cases, it was decided to replace the custom strain sensor with a commercial one due to the fragility exhibited in the field trials compared to the lab scenario. The custom strain sensor has been described in D5.2. [1]
The second version of the wearable strain sensors, that can be employed for monitoring the joints movements and also quantitatively measuring their bending angles, is based on the use of a commercial strain sensor (Sparkfun Flex Sensor 2.2"), shown in Figure 9.

When a banding radius is applied to the strain sensors the device resistance varies, with this variation

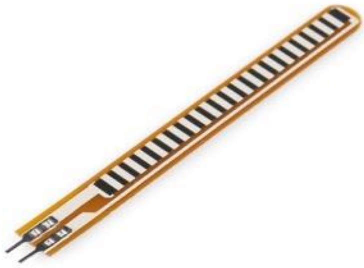
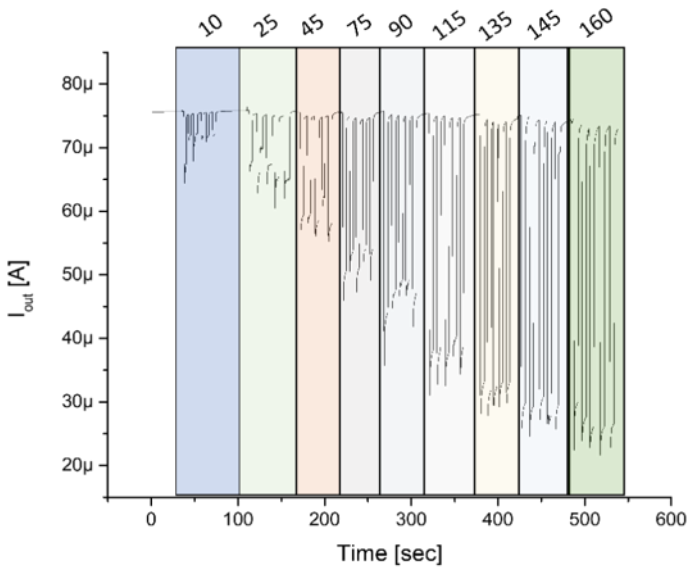


Figure 9. Commercial strain sensor.

being proportional to the applied strain. In order to measure and characterize the sensor, it has been connected to a source meter that can simultaneously bias the sensor and measures the output current. The applied voltage was about 3.3 V, which is the voltage for common wearable sensors.
In Figure 10, the electromechanical characterization is shown. It is notable that the sensor is able to detect bending radius down to 10° and up to 160°, which fits perfectly with the final application and purposes. Moreover, it is possible to notice that the baseline is almost negligible, thus allowing an easier redout of the output signal.

Figure 10. Electromechanical characterization of the commercial strain sensor.



From the electromechanical characterization, where the deformation has been applied five times for each bending radius, it has been possible to obtain the calibration curve, which is shown in Figure 11. The sensor response in the range of interest is linear and the sensitivity, calculated as the slope of the linear curve, is equal to S = 318 nA/deg.

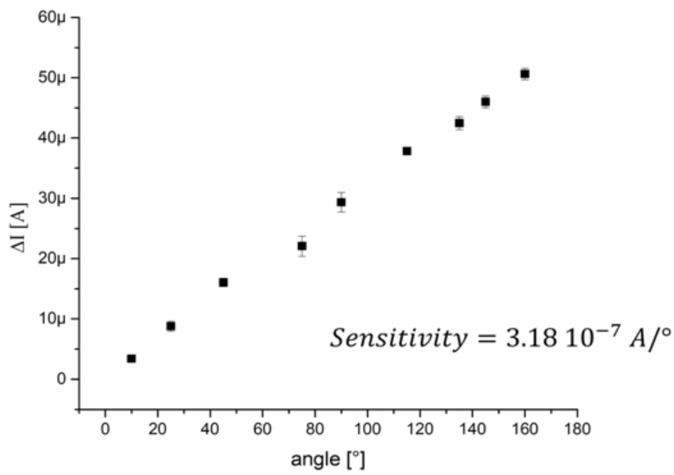


Figure 11. Calibration curve of the commercial strain sensor.

From the reported plots it can be clearly observed that each deformation for a given bending radius rise to very similar results, moreover the average current changes vary linearly with the applied deformation. Considering such results, it can be stated that this approach can be efficiently employed for monitoring the knee joint.

Tests on the X-ray sensor

Thirty flexible X-Rays sensors have been fabricated and tested, both electrically and optically, as described in D5.2. [1]

Figure 12 shows the typical electrical characteristic of fabricated devices and their extracted resistance distribution. It is possible to observe that, apart from 6 devices which are outliers, two clusters of resistance values were found: one (comprising 14 devices out of 24) with an average value of 800 kΩ, and a second one (10/24 devices) with an average value of about 1.6 MΩ.

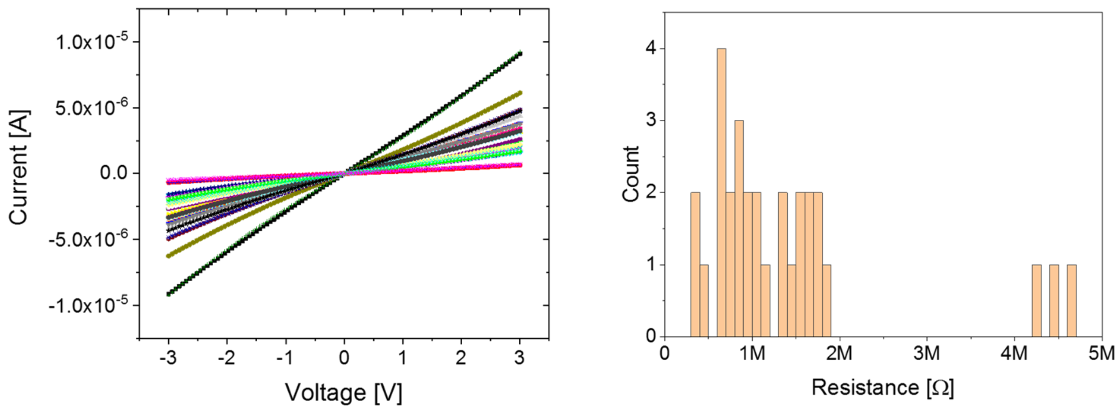


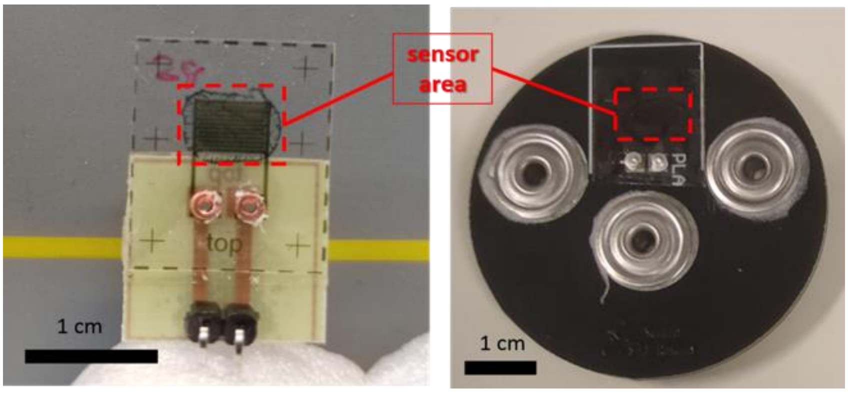
Figure 12. Electrical characteristics of fabricated X-ray sensors and distribution of values of resistance.

Figure 13 displays the final system configuration. For preliminary testing a custom Printed Circuit Board (PCB) with a pin-strip connector has been set up in order to allow an easy connection to breadboards. In its final configuration, the PCB board hosting the X-ray sensor provides the connection to the electronic module for readout and data transfer through snap connectors. The entire system is conceived to be easily embedded in a pocket on the rescuer's uniform; in this way, any possible non-specific response related to the photosensitivity of the organic semiconductor is prevented.

The correct functionality of the plastic sensor has already been assessed in previous tests, in which the current flowing in the sensor during X-rays exposure has been monitored by means of a standard source meter. In particular, the sensor response has been tested using a X-rays collimated tube with Molibdenum target at fixed voltage (35 kV) and variable dose rate, from 10 mGy/s to 60 mGy/s.

In this novel configuration, the sensor will be integrated with the PCB using a resistor divider approach. The sensor is connected in series with a commercial resistor with a similar resistance value, in order to have a steady state signal centred in the dynamic range of the Analog to Digital converter (ADC). When the impinging radiation is applied, the sensor reduces its resistance, raising the voltage in the inner node of the series (Vsens). Figure 14 shows the sensor configuration and preliminary test result on fabricated devices using a light source. The organic semiconductor employed as X-Rays sensitive layer is also photosensitive, thus presenting a response similar in shape (even if slower in

Figure 13. X-Rays platform and its connection to the electronic module.



dynamic and larger in amplitude) to the one expected when X-rays are applied. It is possible to observe the variation of Vsens, and then the progressive recovery of the original current level in time. The proposed technology has been fully assessed at laboratory scale. The sensor showed significant sensitivity and linear response in a quite wide range of dose rate, compatible with possible critical conditions for rescuers in real application scenarios.

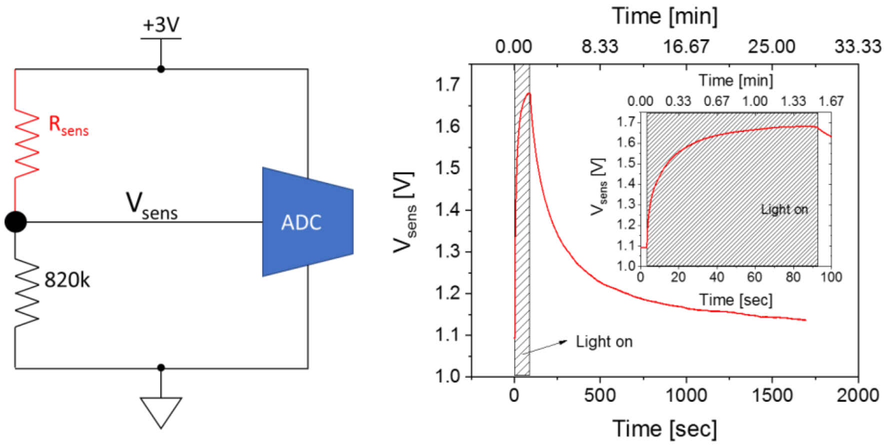


Figure 14. Configuration of the sensor in the sensing circuit and preliminary test as photodetector.

Circuit power consumption test
This test is used to check how much electrical power is consumed by the circuit of our custom electronics nodes. It is considered that power is the product of the voltage to which the circuit is connected and the intensity of the current flowing through it. Since the voltage of the battery to which the circuit is connected is known with equal to 3.7 V, the current through an amperemeter placed in series with the power supply circuit was measured. The maximum current measured in steady state is approximately 4 mA, which generates a maximum consumed power of approximately 15 mW.

Battery life test
Based on the power consumption of the circuit the battery capacity was adapted so that it can last for at least 24 hours. For this reason, a 190mAh battery was finally chosen. The battery life test was intended to verify that the power supply capacity is equal to the expected one. This was tested by running the node at full capacity until the battery runs out. The verification was made by exploiting the date and time of sending the first and last packet of data recorded by the node, saving them locally on the smartphone.

Battery recharge test
This test was carried out prior to the UC5 pilot, when the electronic node was equipped with an on-off switch and a connector that allows the system to be recharged when the device is off, through a suitably customized commercial (external) recharge circuit. This recharging circuit is provided with a LED which stays on during the recharging phase and which goes off as soon as the battery has completed recharging. To verify the correct functioning of the node recharge and its duration, the battery of one of the nodes was completely discharged and then it was recharged, by checking the voltage at its terminals. The time required for a full charge is approximately 5 minutes. The procedure was repeated several times, using different batteries of equal capacity, and testing all the nodes.

Signal acquisition, processing and transmission tests
For each of the custom nodes developed, correct data acquisition was verified using test signals with different sampling frequencies. The correct functioning of the internal signal processing stages was verified by outputting the signal processed by each stage to the system and comparing it with computer simulations developed in the Matlab. Finally, the transmission of the test signals was verified through commercial applications (e.g. BLE Scanner), saving the data locally on the smartphone and comparing them with the sent test signals. To allow the tracing of the packets containing the data, they have been tagged with a progressive number, with which the correct chronological reception of the data and the absence of packet loss has been verified.

Communication test between single nodes and custom Android application and packet loss check

The data transmission tests were repeated to verify the correct function of the custom Android application, developed for the project. Also, in this case test signals were used, sampled at different frequencies and sent to the application at different frequencies. Again, the packets were tracked to ensure they were not lost.

Comparison of signals acquired with custom electronics and a commercial system

Commercial strain sensor

In order to prove the possibility to employ such a system for monitoring the knee joint, the signals acquired by the adopted strain sensor connected to the custom electronics node and an electro-goniometer (Biometrics SG110) connected to a commercial acquisition system (Porti – TMSi) were compared. In Figure 15 the measurement setup is displayed, showing the two measurement systems worn together. The strain sensor is worn as in the smart underwear: the electronics node is located on the lower back of the upper leg, connected to the strain sensor which is placed on the back of the knee. The commercial electro-goniometer is attached on the lateral side of the knee and connected to the acquisition system (Porti – TMSi), which is held by the participant. In this way, the signal coming from the strain sensor and the commercial electro-goniometer were simultaneously recorded and a direct comparison between the two measurements was made. The following protocol has been employed: the participant was asked to perform three knee flexion movements, maintaining flexion and extension for a few seconds, followed by ten steps.

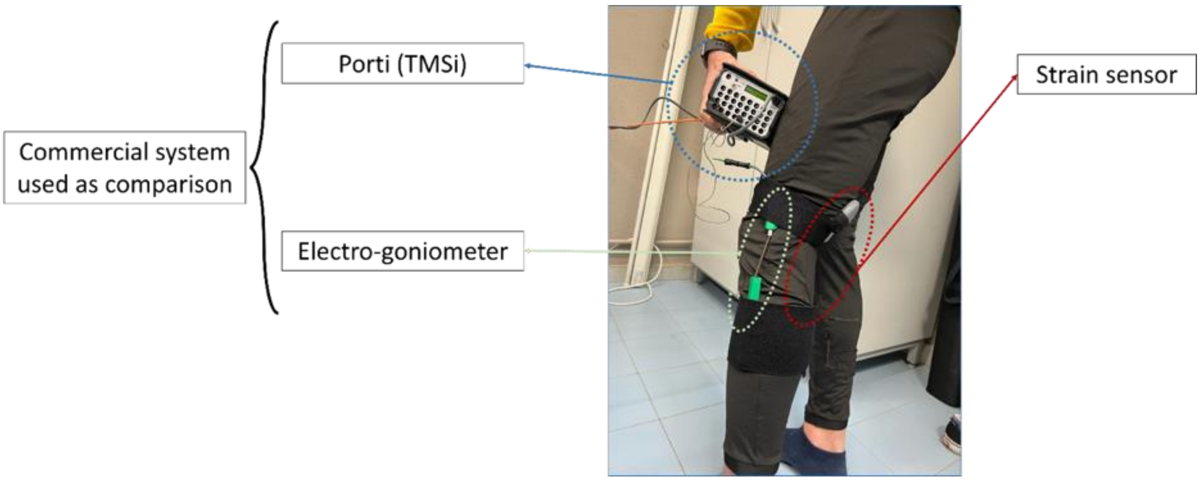


Figure 15. Measurement setup used for the comparison between our Strain Sensor node and the commercial system.

In Figure 16 the recorded signals from the commercial system and the used strain sensor node are reported. It is possible to observe that the signal coming from the commercial system used as reference and the strain sensor node output signal are comparable. In addition, it is possible to notice that the signal of the leg flexion shows an angle of about 70 degrees, while the steps have a higher angle value on average.

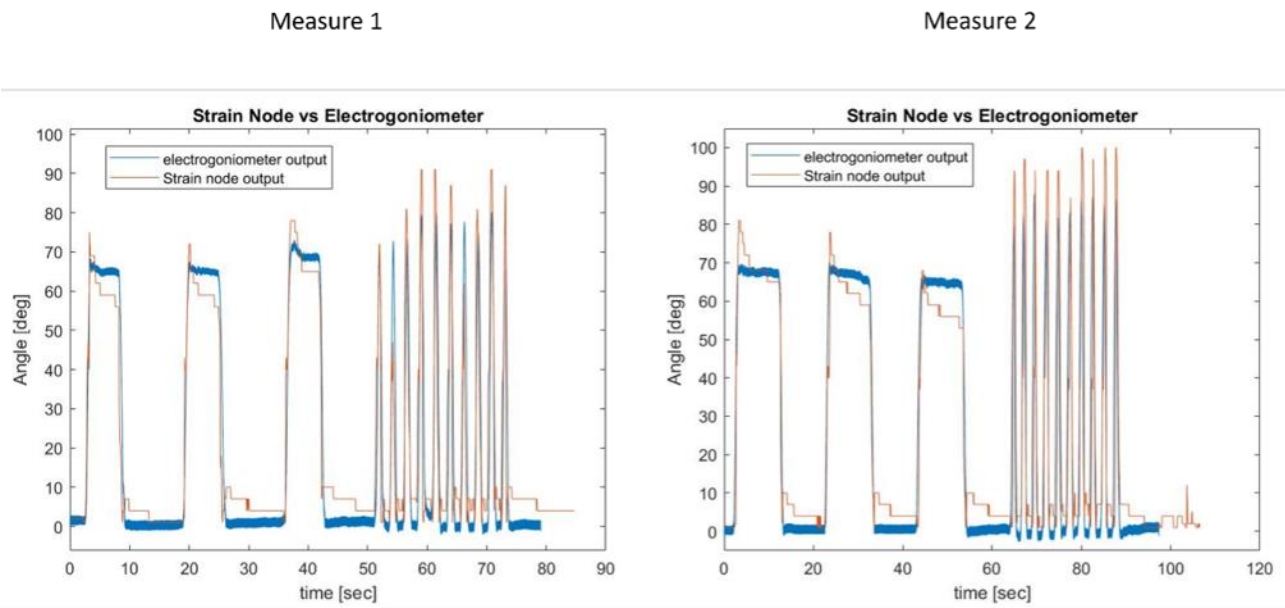


Figure 16. Two different measurements from a commercial system connected to an electro-goniometer and the strain sensor node are compared.

<u>ECG and EMG sensors</u>
In order to analyse the performance of the developed electronics and the adopted textile sensors, several tests were performed. In order to carry out a quantitative analysis, the ECG signal was chosen specifically for more deterministic nature.

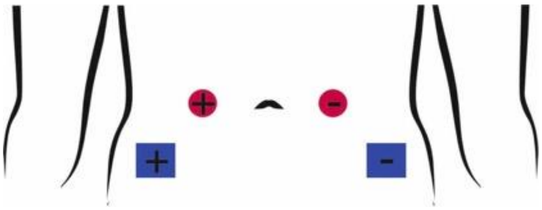


Figure 17. Electrode positioning for synchronous ECG acquisition adopted in the first acquisition. Textile electrodes are represented by blue circles, while Ag/AgCl electrodes by red circles.

Specifically, in the first validation test, ECG signals were recorded by using both the developed system (i.e., the smart underwear and the S&R node) and off-the-shelf Ag/AgCl adhesive electrodes (Spes Medica, Genova, Italy) connected to the Porti7 electrophysiological recording system (TMSI, The Netherlands). The developed system sampled the electrophysiological signal at about 250 Hz with 24 bits of resolution, without embedding any high-pass filtering stage. However, for data managing and transmission, the number of bits was then reduced to 16. Conversely, the Porti7 system acquisitions were performed at 2048 Hz with an effective bandwidth of 553 Hz, and 22 bits of resolution on the

bipolar channels. As such, an initial resampling stage was required in the offline processing, for comparative purposes, which however might cause some slight disagreement in the ECG morphology. Single-lead ECG signals acquisition was performed synchronously, by exploiting the two textile electrodes on the torso, and two Ag/AgCl electrodes close to the others, providing for a slightly smaller cardiac dipole projection (see Figure 17).
As it can be seen in Figure 18, the raw ECG signal acquired by the developed system suffers from higher baseline wandering (RMS = 1.57 mV) than Ag/AgCl-based one (RMS = 0.12 mV). However, looking at Figure 19, it is evident that, after removing the baseline wander by a high-pass filtering stage (cut-off frequency: 0.67 Hz, according to standard applications), the ECG waveforms recorded in both conditions were quite consistent (Pearson's correlation coefficient > 0.84), leading to equivalent RR interval estimates (831 ± 13 ms for both the smart underwear and the commercial device).

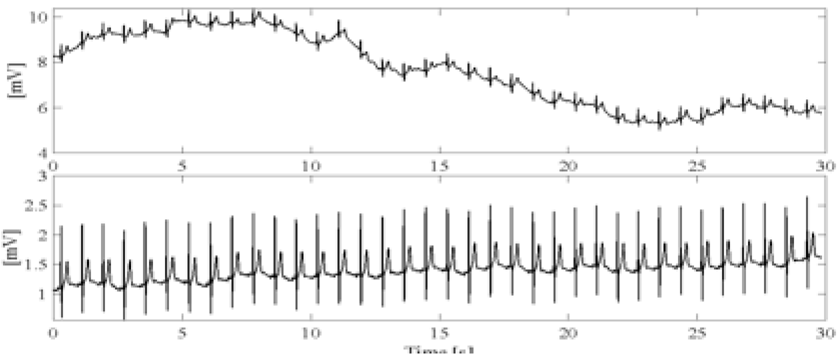


Figure 18. Electrode positioning for synchronous ECG acquisition adopted in the first acquisition. Textile electrodes are represented by blue circles, while Ag/AgCl electrodes by red circles.

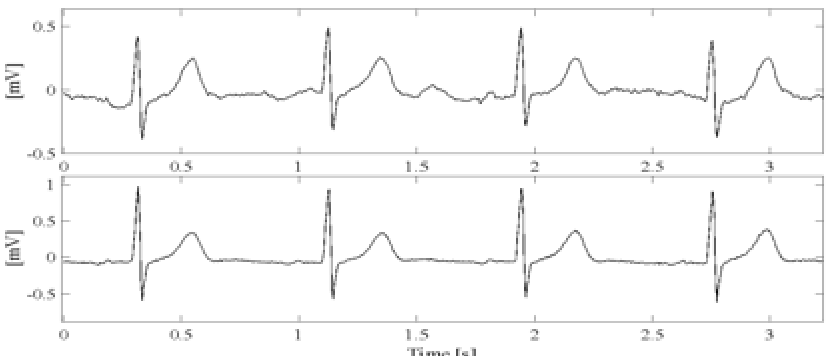


Figure 19. High-pass filtered ECG signals acquired by the smart underwear (top) and by commercial devices (bottom) during the first validation test.

In order to assess the role of the different electrode type and of the custom electronics in the slight discrepancies of ECG morphologies two other tests were carried out.
Specifically, in the second validation test, an ECG acquisition was performed by both textile and Ag/AgCl electrodes, which were connected to the Porti7 system. As it can be seen by looking at the ECG signals recorded in this setup (Figure 19 and Figure 20), similar conclusions can be drawn for baseline wander artifacts (RMS = 1.98 mV for textile electrodes, RMS = 0.29 mV for Ag/AgCl ones).

Moreover, the ECG morphologies obtained after high-pass filtering by textile electrodes closely resemble those obtained by commercial adhesive electrodes (Pearson's correlation coefficient >0.94), with same RR interval estimates (822 ± 20 ms), thus allowing for a proper use of this technology for biopotential recordings.

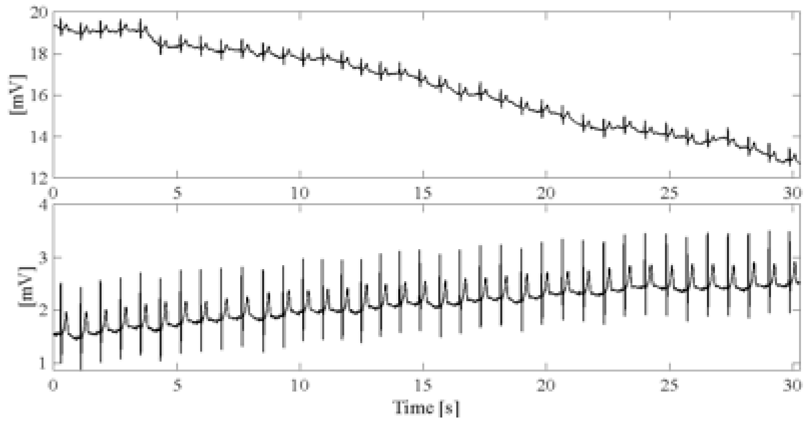


Figure 20. Raw ECG signals acquired by textile electrodes (top) and by Ag/AgCl ones (bottom) using the Porti7 system during the second validation test.

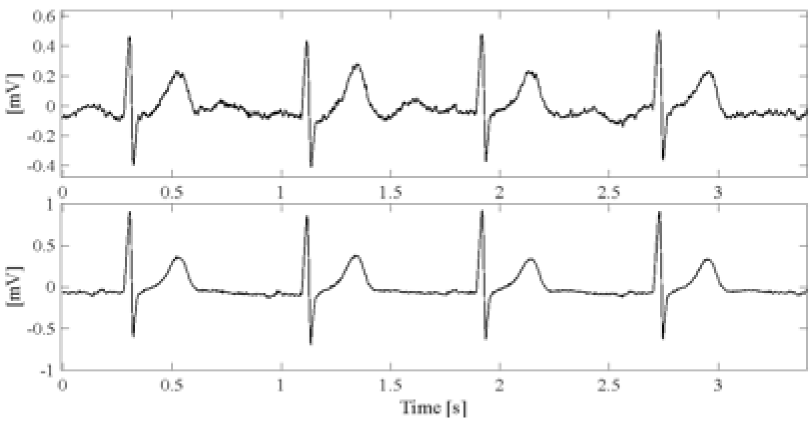


Figure 21. High-pass filtered ECG signals acquired by textile electrodes (top) and by Ag/AgCl ones (bottom) using the Porti7 system during the second validation test.

Furthermore, in the third validation test textile electrodes were replaced by a pair of Ag/AgCl electrodes, which were connected to the custom electronics, in order to assess any influence of the node. In this situation, ECG signals were acquired synchronously by Ag/AgCl electrodes connected to the S&R node, and by Ag/AgCl electrodes connected to the Porti7 system. Raw and high-pass filtered ECG signals are reported in Figure 22 and Figure 23. As expected, in this condition no substantial difference can be observed when evaluating the entity of baseline wander (RMS = 0.42 mV when using the Porti7 device, RMS = 0.12 mV for S&R node), thus ascribing this interference mainly to the textile electrode technology. The S&R node allows to properly acquire ECG waveforms with Pearson's correlation coefficient >0.94 and same RR interval estimates with respect to the Porti7 system (795 ± 38 ms in both cases).

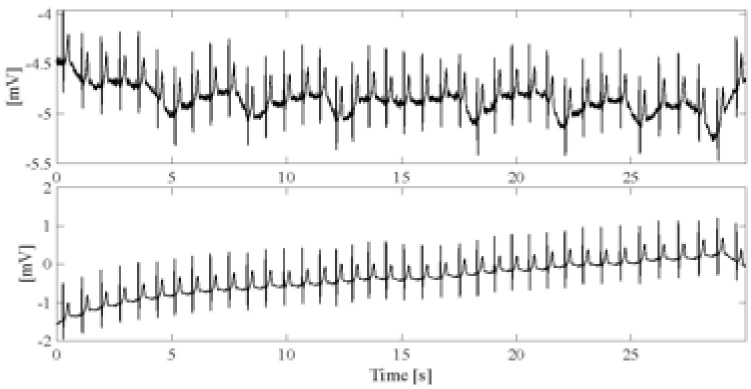


Figure 22. Raw ECG signals acquired by S&R node (top) and by Porti7 system (bottom) exploiting Ag/AgCl electrodes during the third validation test.

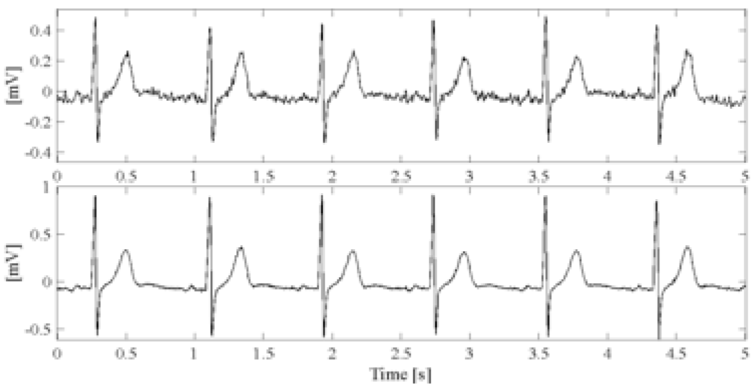


Figure 23. High-pass filtered ECG signals acquired by S&R node (top) and by Porti7 system (bottom) exploiting Ag/AgCl electrodes during the third validation test.

Remarkably, some slight difference in the ECG amplitude can be attributed also to the different cardiac dipole projection sensed by the two electrode pairs, as can be also appreciated in Figure 24, where ECG signals were acquired as in the third validation test but exploiting the Porti7 system for both recordings.

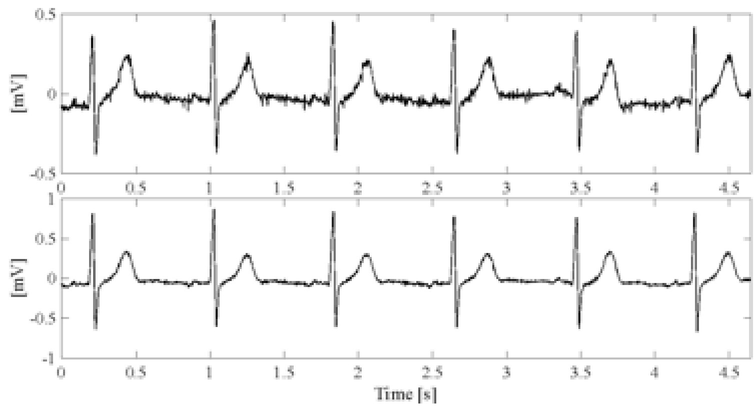


Figure 24. High-pass filtered ECG signals acquired by Ag/AgCl electrodes and the Porti7 system exploiting the textile (top) and the Ag/AgCl (bottom) electrode positioning, according to Figure 17.

Finally, additional tests were executed in order to validate the textile electrodes in an EMG signal acquisition. However, as the electronic node developed for the project is able to send the envelope only, and because of the highly stochastic nature of the EMG signals, the Porti7 system was exploited to make the comparative assessment on synchronous signals with the different kinds of electrode. As such, EMG recordings were performed at 2048 Hz on the gastrocnemius muscle by a pair of textile electrodes, and by a pair of Ag/AgCl electrodes that were placed nearby, in order to sense the same muscular activation. In this condition, the participant was asked to perform 5 contractions lasting about 5 s each, and a final shorter one. As shown in Figure 25, both EMG signals were acquired properly by both electrode types, despite the textile ones introduced higher baseline drift. Indeed, after a resampling of about 250 Hz in order to mimic the S&R node acquisition, in this representation a high-pass filtering stage was introduced for proper visualisation (cut-off frequency of 20 Hz). As such, it is clear that the proposed textile electrodes allow for a proper acquisition also of this kind of biopotential.

Finally, an example of the EMG activity caught by both electrode types when connected to the S&R node is depicted in Figure 26. Remarkably, the EMG activity is reported as envelope, acquired by the S&R node in two different recording sessions.

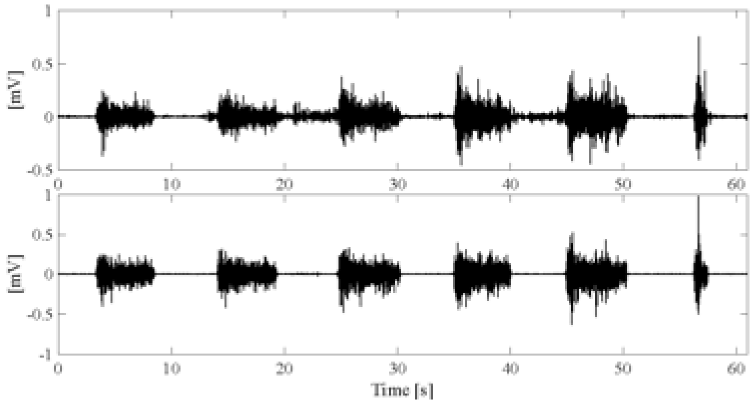


Figure 26. High-pass filtered EMG signals acquired by the Porti7 system exploiting textile (top) and Ag/AgCl (bottom) electrodes.

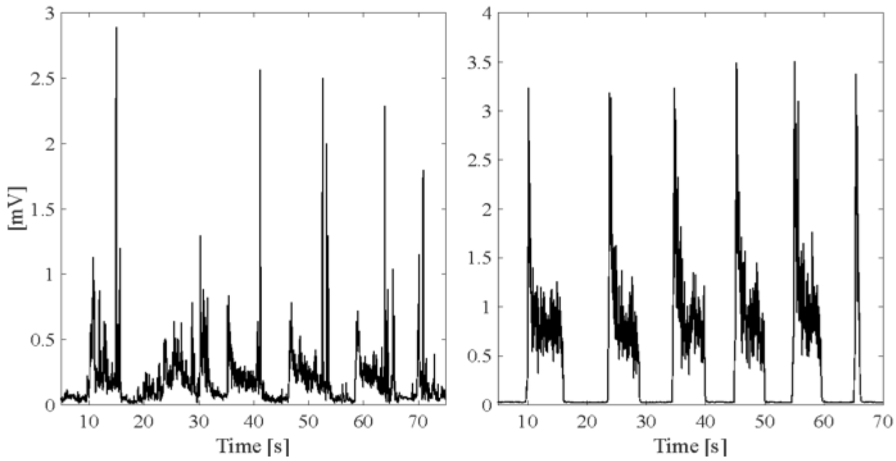


Figure 25. EMG envelopes acquired by the S&R node when exploiting textile (on the left) and Ag/AgCl (on the right) electrodes in two different recording sessions.

2.2 UC tests and results

The validation tests of the smart uniform was performed both in laboratory and in relevant field scenarios during the following Use Cases pilots of the project:

- UC1 - Victims trapped under rubble (Poggioreale - Italy)
- UC5 - Victims trapped under rubbles (La Souterraine - France)
- UC6 - Resilience Support for Critical Infrastructures (Tuzla - Romania)
- UC7 - Chemical substances spill (Madrid - Spain)

The gas monitor attached to a robot was also tested during the Use Case pilot UC3 - Heavy storms and derailed train, conducted at the Lower Austrian Fire and Safety Centre in Tulln an der Donau. Due the storm an uprooted tree falls on the tracks, derailing a train approaching Kufstein railway station (Cross-border pilot, Austria-Germany).

The X-rays sensor was tested only during the Use Case pilot UC4 - Forest fire expanded and threatened the industrial zone (Attica Region, Greece).

Compared to what was foreseen in D5.2 [1], the smart protective uniform was tested in the further case study UC7 in order to test also the additional smart protective uniform for woman.
The prototype was evaluated through interviews and questionnaires taken after the activity, and also through direct observation. The questionnaire results are stored on the Alfresco platform accessible only to the S&R consortium.
The evaluation of the external uniform took into account the following points, some of them were already tested during the preliminary usability test in the lab:

- the general comfort of the First Responders wearing it (long term comfort, comfort while working on the knees, comfort while working on and under the rubbles);
- the ease of dressing and undressing, without any help;
- freedom of movement without compromise the protection and the coverage of the user;
- the ease of using the locking systems with and without DPI gloves;
- the compatibility with other DPIs;
- the visibility/recognizability of the first responder in the scenario;
- the mechanical protection of the suit according to the scenario tasks;
- the abrasion protection of the suit according to the scenario tasks;
- the thermal protection of the suit according to the scenario tasks;

Moreover, the evaluation took into account the general and technical KPI indicated by the project.

2.2.1 UC1

The UC1 "Victims trapped under the Rubbles" took place in April 2022 in Poggioreale (Italy). Detailed specifications of the pilot can be found in the deliverable D8.2 "S&R Use Case 1: Victims trapped under rubble (Italy) - Pilot plan" [2]. The pilot represented the first test on a relevant environment for the validation of the prototype. The uniform has been tested by a professional member of the USAR Catania Fire Brigade team. The FR wore the uniform for 2 hours.
The fitting of the uniform was good, although the garment was slightly too large for the size of the model. The rescuer managed to move easily and completed all the tasks required by the usability test as stated in the standard UNI EN ISO.
During the pilot, the prototype highlighted some critical issues especially in the activity under the rubbles. It needs to be noted that the uniform was not designed to be used specifically under the rubbles. The most critical point highlighted by that was regarding the two-piece model of the garment and the cargo pockets in the trousers. In case of activity under the rubbles, it is in fact necessary, to have a one-piece garment without cargo mesh pockets in order to avoid any danger of entrapment for the rescuer. Although the cargo pockets were evaluated as unnecessary and dangerous for the FR, the rescuer used them continuously during the action.
The colour chosen for the garment was different from the one currently used by the rescue team (black) and the rescuer didn't feel totally at ease with it. However, the direct observation and the interviews with other end-users highlighted positively that, compared with the others already used, it makes the rescuer instantly recognizable and identifiable in the scenario.
Moreover, the uniform was tested positively regarding the compatibility with other DPIs and additional equipment. The FR has easily managed to open and close all the closure zipped systems also with the DPI Kevlar gloves.
The uniform accomplished all the KPI requested by the project.
In this pilot the functionalities of five wearable sensors were evaluated with the smart uniform: the ECG node, two EMG nodes applied to two muscles of the right leg (vastus lateralis and gastrocnemius

lateralis), the strain node applied to the left knee, and the GPS module integrated in the rescuer's smartphone.
Regarding data communication, both the EMG nodes and the strain sensor had technical problems, whereas the other wearables (ECG and GPS tracker) communicated their data correctly to the server center.
Moreover, according to the after-pilot interviews, the rescuer has found the sensors' placement in the leg uncomfortable.

Figure 27. FR wearing the smart protective uniform during the exercise

Figure 28. FR wearing the Smart underwear before the exercise.

The summarised results of the post pilot questionnaire and interviews are described in the following charts. The results show the level of satisfaction of the user (from not sufficient to excellent) regarding the evaluated points.

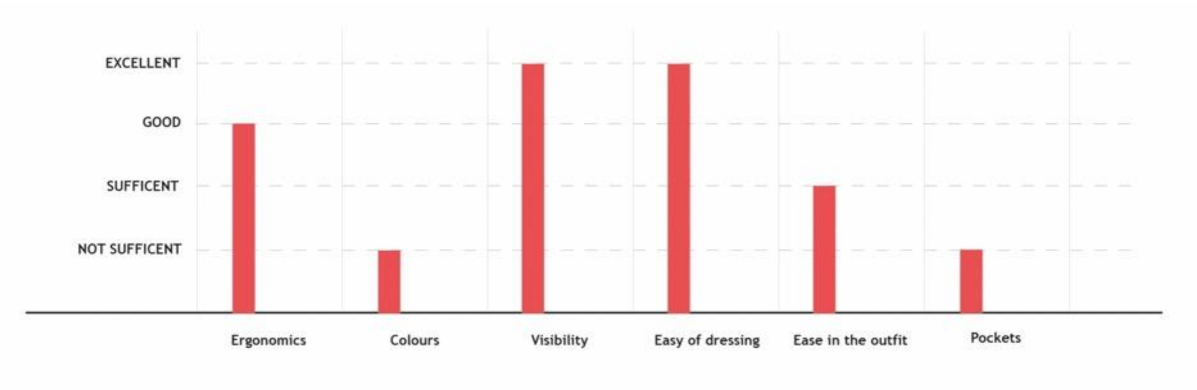


Figure 29. UC1: Summarized results of the after pilot questionnaires and interviews

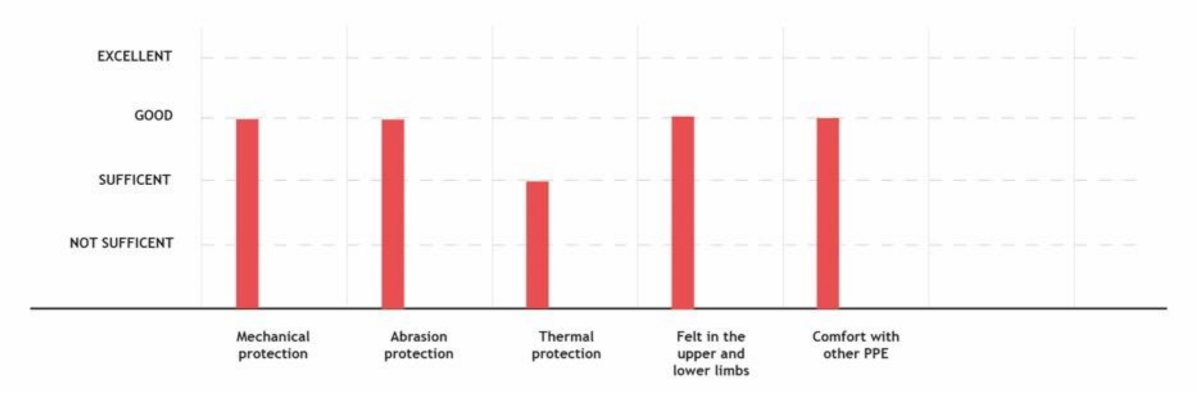


Figure 30. UC1: Summarized results of the after pilot questionnaires and interviews

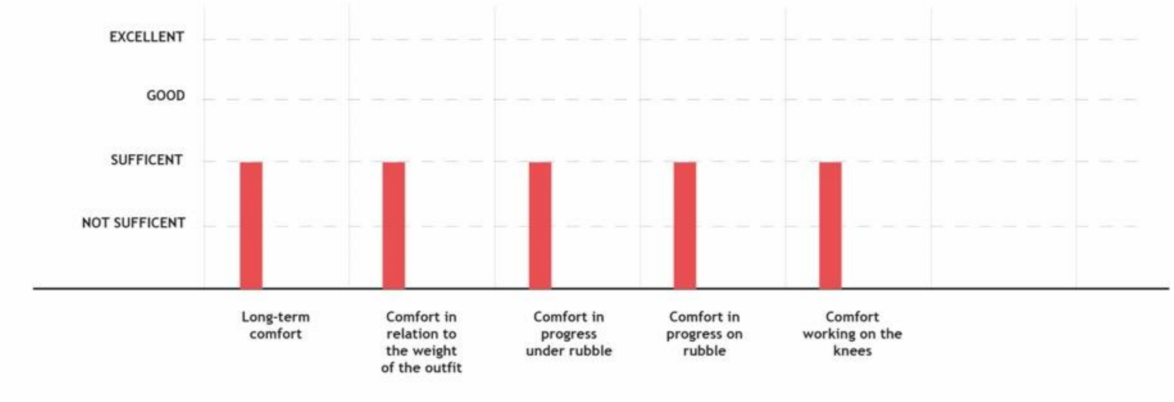


Figure 31. UC1: Summarized results of the after pilot questionnaires and interviews

2.2.2 UC5

The UC5 "Victims trapped under the Rubbles" took place in June 2022 in Limoges - La Souterrain (France). Detailed specifications of the pilot can be found in the deliverable D8.6 "S&R Use Case 5: Victims trapped under rubble (France) - Pilot plan" [3].
The uniform has been tested by a trained professional volunteer of PUI France. The FR wore the uniform for 2 hours. The exercise took place under extreme weather conditions, caused by the heat wave that hit France in June 2022. During peak hours the temperature reached 44 ºC/45 ºC.
The pilot proposed a similar scenario to the UC1 one.
Despite the extreme and very problematic conditions of the exercise, the uniform was judged very positively. The fitting of the uniform was evaluated very positive, the model had a size suitable for the tested prototype. The rescuer was able to move easily even under the rubble and completed all the tasks required by the usability test indicated in the international regulations and exercise.
As in the UC1, the activity highlighted some critical points, in particular regarding the cargo pockets in the trousers. For this reason, the FR suggested removing the cargo pockets. Although they were evaluated dangerous for the FR also during this UC, the rescuer used them continuously during the action.
The colour chosen for the uniform, similar to the current ones used by the rescue team, was positively evaluated, the FR was instantly recognizable and identifiable in the scenario.
Moreover, the uniform was tested positively regarding the compatibility with other DPIs and additional equipment. The FR has easily managed to open and close all the closure zipped systems also with the DPI Kevlar gloves.
The uniform accomplished all the KPI requested by the project.
In this pilot the functionalities of five sensors were evaluated with the smart uniform: the ECG node, two EMG nodes applied to two muscles of the right leg (vastus lateralis and gastrocnemius lateralis), the portable multi-gas monitor, and the GPS module integrated in the rescuer's smartphone.
About data communication, all sensors correctly communicated their data to the central server. The placement and the cases of the electronic boards needed for the sensors were also evaluated partially positive. The one under the neck was judged partially uncomfortable while working under the rubbles.
The trousers of the suit were damaged after an unscheduled test during the activity. The test was about cutting a thick iron sheet. The uniform's fabric isn't certified for the protection against the melted metals (EN11611 Class 2), for this reason it was damaged. The certification against melted metals isn't requested for the purposes of the project. However, the test confirmed the fire proofness of the textile and the rescuer was unharmed.

Figure 32. FR wearing the Smart uniform during the exercise under the rubbles.

Figure 33. FR wearing the Smart protective uniform during the metal sheet cutting task and the damages in the pants.

The summarised results of the post pilot questionnaire and interviews are described in the following charts. The results show the level of satisfaction of the user (from not sufficient to excellent) regarding the evaluated points.

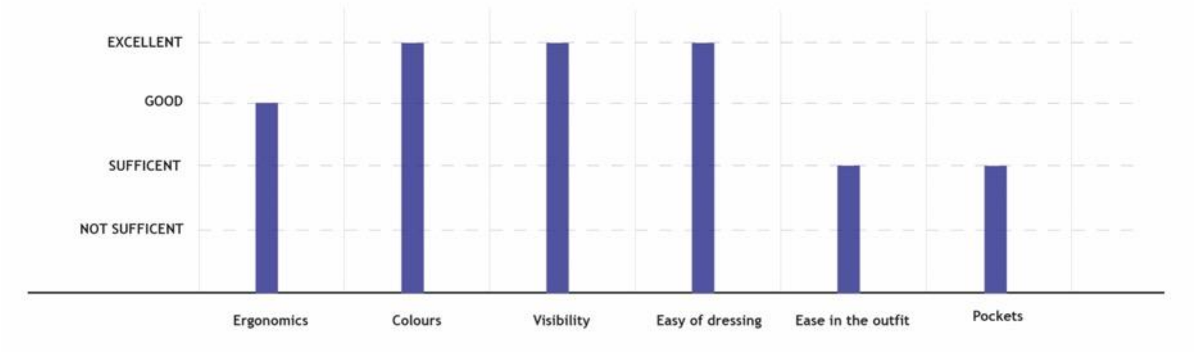


Figure 34. UC5: Summarized results of the after pilot questionnaires and interviews.

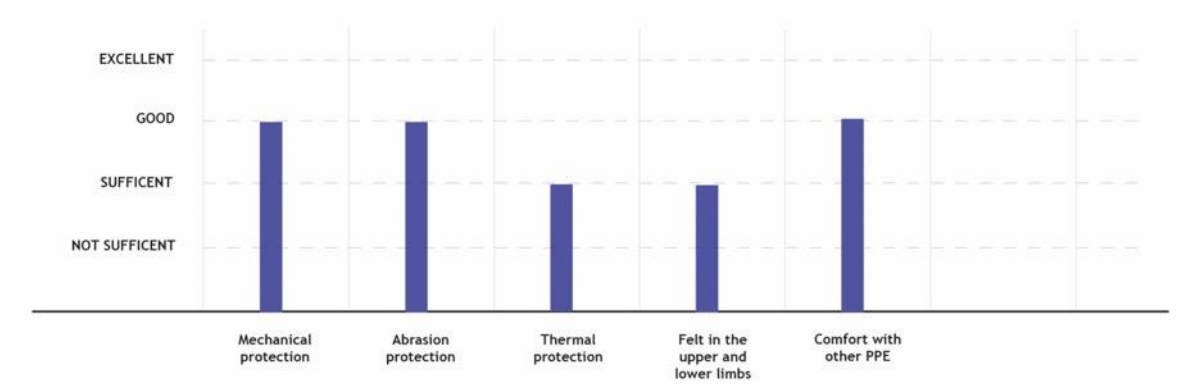


Figure 35. UC5: Summarized results of the after pilot questionnaires and interviews.

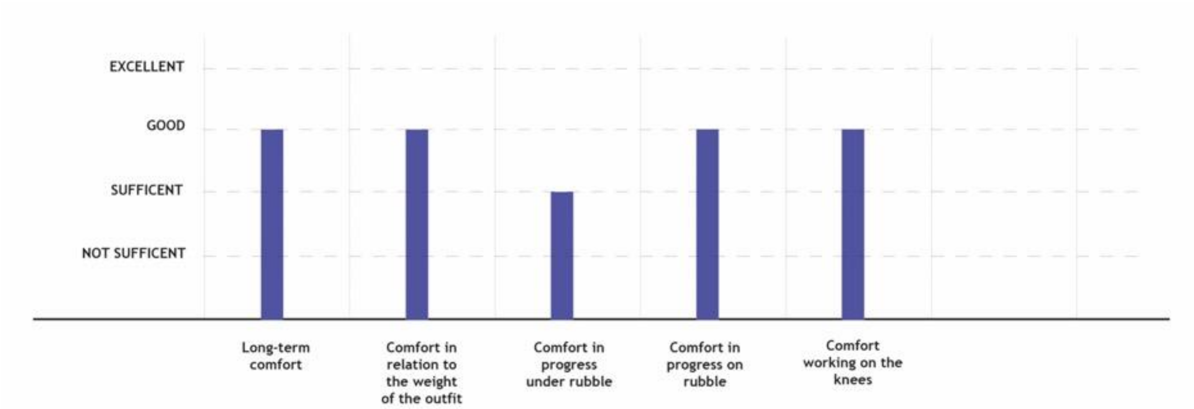


Figure 36. UC5: Summarized results of the after pilot questionnaires and interviews.

2.2.3 UC6

The UC6 "Resilience support for critical infrastructures through Standardized Training on CBRN" took place in September 2022 in the airport of Tuzla (Romania). Detailed specifications of the pilot can be found in the deliverable D8.7 "S&R Use Case 6: Resilience support for critical infrastructure through Standardized Training on CBRN (Romania) - Pilot plan". [4]
For this exercise, the suit has been modified according to the results of the previous UCs. In particular, the two cargo pockets have been removed from the pants and they have been replaced

with invisible pockets. The changes are detailed described in the next chapter of the present document.
The uniform has been tested by a professional member of the Tuzla Airport Fire Brigade team. The FR wore the uniform for 2 hours. Since the uniform wasn't already certified for CBRN risk, during the exercise it was worn under the certified suit.
The fitting of the uniform was judged very positively. The model had a size suitable for the prototype. The rescuer was able to move easily despite the double suit and completed all the tasks required by the usability test indicated in the international regulations and in the exercise plan.
The colour chosen for the new uniform was positively evaluated, the FR was instantly recognizable and identifiable in the scenario. The FR judged positively the new pockets in the pants.
Moreover, the uniform was tested positively regarding the compatibility with other DPIs and additional protective equipment. The FR has easily managed to open and close all the closure zipped systems also with the DPI Kevlar gloves.
The uniform accomplished all the KPI requested by the project.
In this pilot the functionalities of six sensors were evaluated with the smart uniform: the ECG node, two EMG nodes applied to two muscles of the right leg (vastus lateralis and gastrocnemius lateralis), the strain node applied to the left knee, the portable multi-gas monitor, and the GPS module integrated in the rescuer's smartphone.
Regarding data communication, all sensors correctly communicated their data to the central server. The cases of the electronic boards' design were improved from the one used during the UC5, as described in detail in the next chapter. Also, the new positioning of the cases of the electronic boards needed for the sensors were positively assessed. The new integration of the components is described in the paragraph 3.2.1 of the present document.

Figure 37. FR wearing the Smart underwear during the exercise under the CBRN certified suit.

The summarised results of the post pilot questionnaire and interviews are described in the following charts. The results show the level of satisfaction of the user (from not sufficient to excellent) regarding the evaluated points.

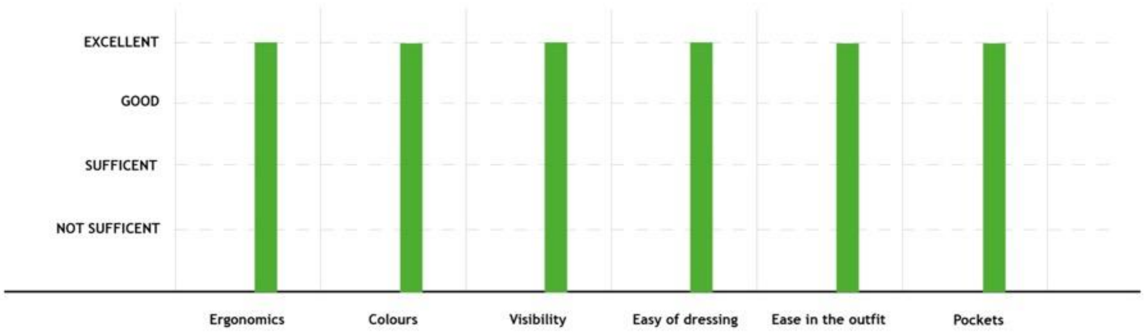


Figure 38. UC6: Summarized results of the after pilot questionnaires and interviews.

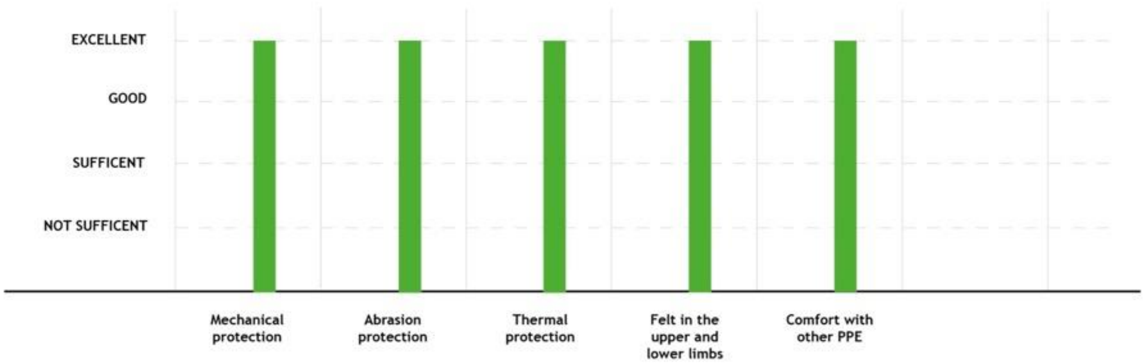


Figure 39. UC6: Summarized results of the after pilot questionnaires and interviews.

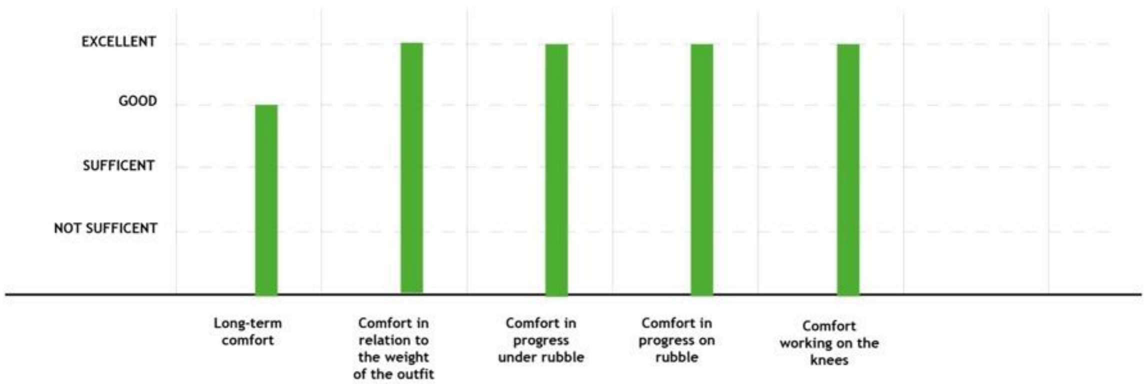


Figure 40. UC6: Summarized results of the after pilot questionnaires and interviews.

2.2.4 UC3

The UC3 "Heavy storms and derailed train)" took place in October 2022 in Tulln an der Donau (Austria). Detailed specifications of the pilot can be found in the deliverable D8.4 "S&R Use Case 3: Earthquake/ heavy storms between Vienna Rail Station & Kufstein railway station heavy damages in the rail station (Cross-border pilot, Austria-Germany) - Pilot plan". [5]
In this use case, the functionalities of the COncORDE platform (including SOT-DSS), the rescue robot (SeekurJr) with Obstacle Detection System and HLX3000 gas detector, the wearable GPS tracker (integrated in the rescuers' smartphones) and the smart watches were evaluated.

The commercial sensor was attached to a robot for exploration of toxic environments before human intervention by chemical, biological, radiological and nuclear units (CBRN).
About data communication, both the gas sensor and the GPS module correctly communicated their data to the central server, without packet losses or significant delays.
All technologies were evaluated through questionnaires (filled-in by the users) and observations. The questionnaire results are stored in the Alfresco platform accessible only to the S&R consortium.

2.2.5 UC4

The UC4 "Forest fire expanded and threat to industrial zone" took place in November 2022 in Korinthos (Greece). Detailed specifications of the pilot can be found in the deliverable D8.5 "S&R Use Case 4: Forest fire expanded and threat to industrial zone - Pilot plan". [6]
In this pilot, the functionality of the X-ray node was evaluated. The X-ray node was evaluated through questionnaires taken after the activity. The questionnaire results are stored in Alfresco. The node was housed in an external pocket of the rescuer's professional suit. In fact, this node, unlike the other custom sensors embedded in the smart underwear, does not need to be fixed on it and can be positioned as desired on an external pocket of the suit, provided that the sensor is exposed to the outside (even if contained inside a pocket).
Regarding data communication, the X-ray sensor correctly communicated all data to the central server, with no packet loss or significant delay.

2.2.6 UC7

The UC7 "Chemical substances spill" took place in December 2022 in Madrid (Spain). Detailed specifications of the pilot can be found in the deliverable D8.8 "S&R Use Case 8: Chemical substances spill (Spain) - Pilot plan". [7] The exercise was the last scheduled evaluation test on the relevant environment of the project.
The female uniform was tested only during this exercise, together with the male one. The female model has been tested by a professional nurse of SUMMA112, while the male model has been tested by a professional trained volunteer of ESDP. The FRs wore the uniforms for 4 hours. The exercise took place under extreme weather conditions, caused by a rainstorm. The site was extremely muddy, and it was rainy for the whole time of the pilot. The prototype passed the waterproofness test.
The prototypes had a quite good fitting. The fitting of the female uniform was evaluated very positively. The rescuers were able to move easily and to complete all the tasks required by the usability test indicated in the international regulations and in the exercise plan. Moreover, the uniforms were tested positively regarding the compatibility with other DPIs and additional equipment (such as climbing harness or CB protective disposable suit), but the uniforms' caps were too small to be worn on the helmet. The FRs have easily managed to open and close all the closure zipped systems also with the DPI Kevlar gloves.
The colour chosen for the new uniform was positively evaluated, the FR was instantly recognizable and identifiable in the scenario.
The uniform accomplished all the KPI requested by the project.
In this pilot the functionalities of six sensors were evaluated with the smart uniform: the ECG node, two EMG nodes applied to two muscles of the right leg (vastus lateralis and gastrocnemius lateralis), the strain node applied to the left knee, the portable multi-gas monitor, and the GPS module integrated in the rescuer's smartphone. The female uniform hadn't the smart underwear with the embedded sensors, but only the GPS module integrated in the rescuer's smartphone.
Regarding data communication, all sensors correctly communicated their data to the central server. The new positioning and the cases of the electronic boards needed for the sensors were also positively evaluated.

Figure 41. FR wearing the Smart protective uniform (female version) during the exercise tasks.

Figure 42. Open male jacket with a detail of the smart underwear (male version).

The summarised results of the post pilot questionnaire and interviews are described in the following charts. The results show the level of satisfaction of the user (from not sufficient to excellent) regarding the evaluated points.

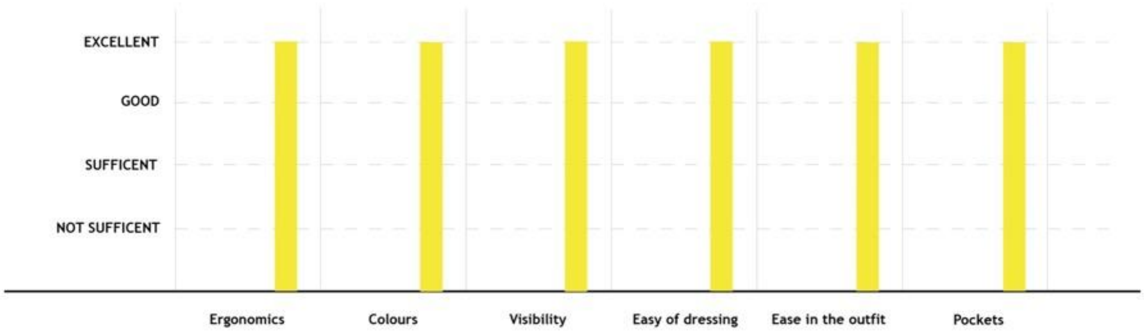


Figure 43. UC7: Summarized results of the after pilot questionnaires and interviews.

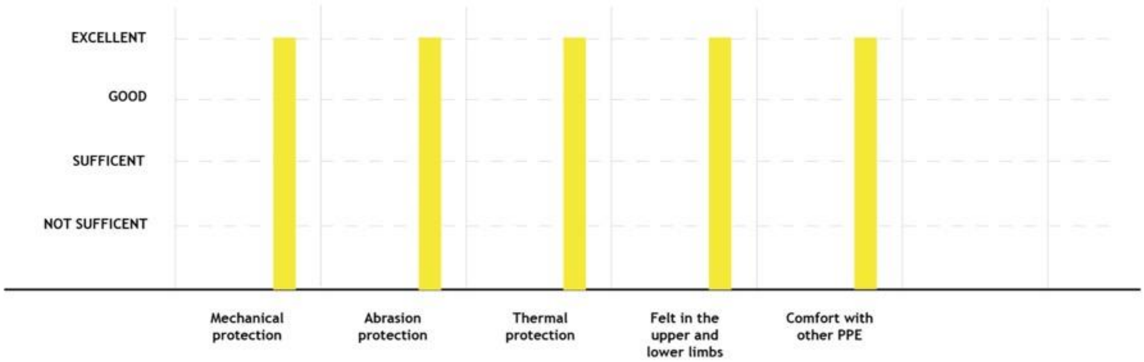


Figure 44. UC7: Summarized results of the after pilot questionnaires and interviews.

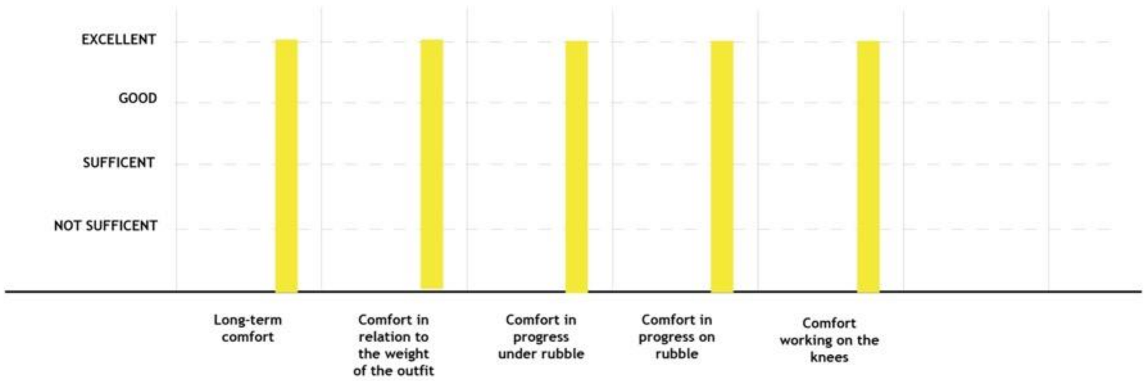


Figure 45. UC7: Summarized results of the after pilot questionnaires and interviews.

2.3 Final results and considerations

As already explained in paragraph 1.1, the uniform tested during the Use Cases was composed of a jacket, trousers and smart underwear (t-shirt and leggings). The after pilots' questionnaires and interviews, as already shown in each UCs' section, highlighted the level of satisfaction of the user (from not sufficient to excellent) regarding the evaluated points. The results are summarized and compared below. The charts are referred to the external uniform only.

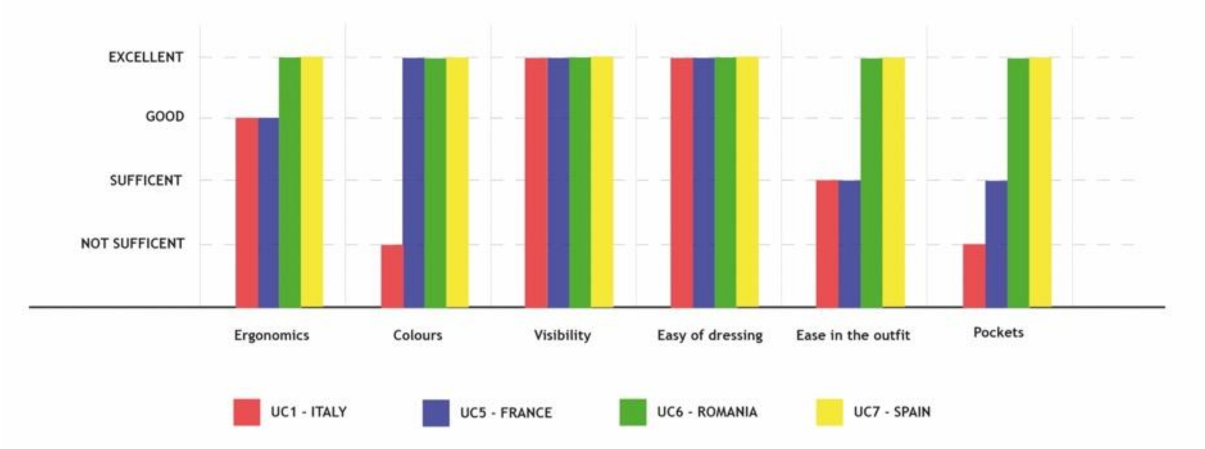


Figure 46. Comparative questionnaires' results.

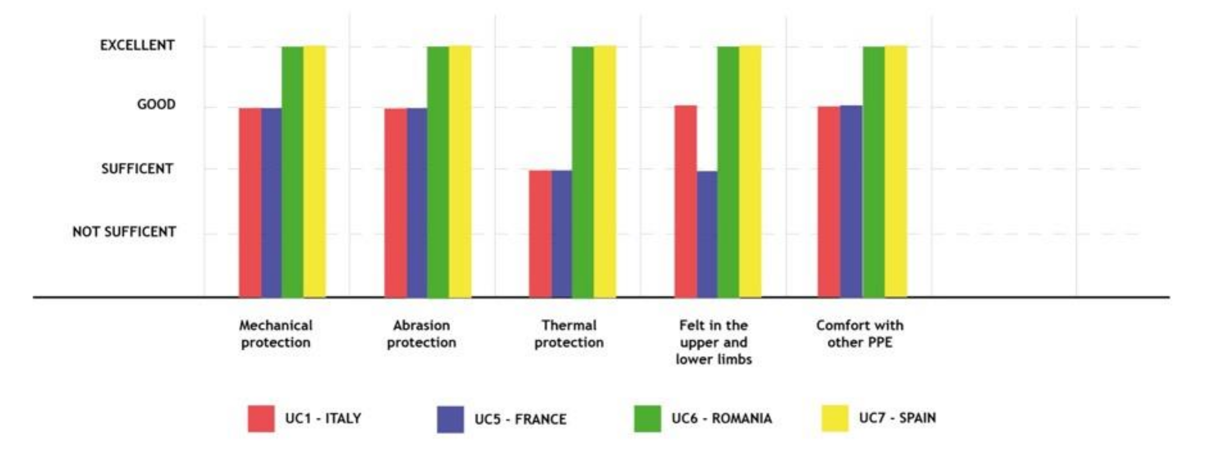


Figure 47. Comparative questionnaires' results.

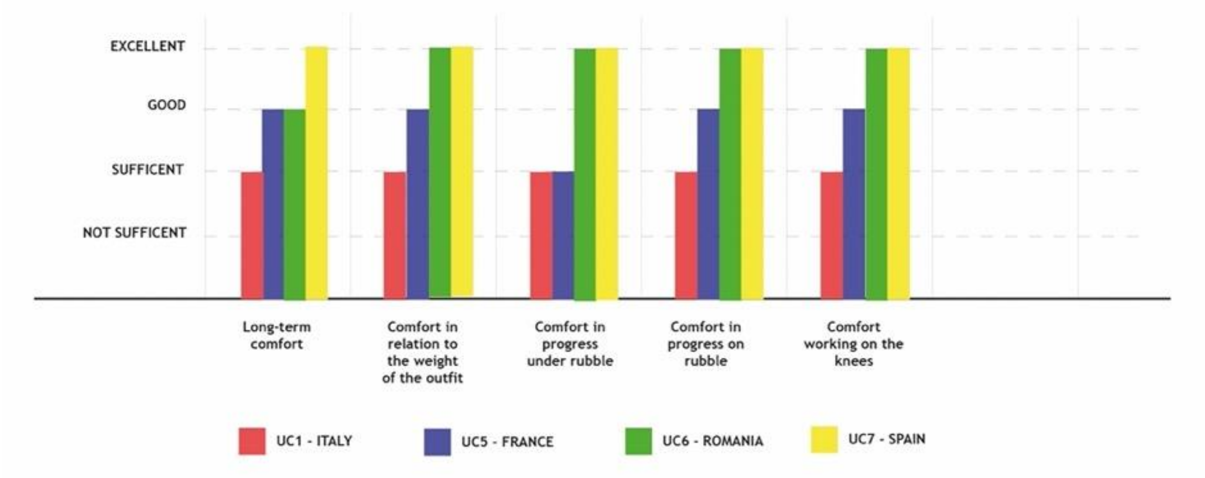


Figure 48. Comparative questionnaires' results.

The charts show a visible progressive improvement of the users' satisfaction, especially after the modification of the trousers' pockets. Moreover, the questionnaires highlighted the excellent satisfaction regarding the visibility of the first responders in the activity scenario and, as a consequence, about the colour choice.
Overall, the charts show a relevant satisfaction regarding the general comfort, also under the rubbles. Regarding the critical points highlighted by the FRs during the UCs related to the two pieces model, it would be interesting in the future to study, design and develop an additional one-piece suit for the under rubbles rescuer. The present prototype was designed in order to be used in different scenarios, not only under rubble, and the two pieces model, as shown in the previous deliverable, was the most suitable choice for this purpose. Furthermore, the prototype could also be improved regarding the visibility, adding for example retroreflective textile or embedding led-based lightning textile elements.
The smart underwear and the rescuer's Android app, developed by the team of the University of Cagliari, have undergone many improvements and evolutions during the second year of project activity, thanks to the feedback received during the pilots from both end-users and partners of the Consortium.
For this reason, as will be shown in the next paragraphs, the smart underwear was modified during the tests phase according to the after UCs questionnaire results.
These improvements have led to obtaining a final prototype that has been positively evaluated and validated in a relevant environment for search and rescue operations, regarding the fit, comfort, protection, data communication, effectiveness, and usability.
The prototype is capable of acquiring different types of signals, both from the rescuer (ECG, EMG, knee angle) to assess their physical and health conditions, and from the external environment (concentration of X-rays and toxic and/or explosive gases) to monitor the safety of the rescuer's operating conditions.
In this way the prototype can also improve the general response activity. If the first responder feels at ease and secure about himself and his tools, the vulnerability of the whole team is reduced, facilitating the rescue operations.

Further developments may be evaluated in the future. For example, the prototype can easily integrate other sensors, such as temperature or photoplethysmography; in addition, the nodes could communicate directly with the central server, to avoid the passage through the smartphone, but with larger size and weight of the nodes. Moreover, the underwear could be made by compressive and self-adjustable textile in order to improve the fit and the comfort for the First Responder. Finally, a female underwear model could also be created for women's uniform, which necessarily requires new features and studies related to female anatomy.

3 First responders uniform prototype

3.1 Uniform implementation

As a consequence of the results of the tests carried out in the UCs described above, the team decided to make some modifications and improvements to the smart uniform. The modifications were implemented after the UC5, in order to test the new model during the UC6.
Moreover, the smart underwear underwent important changes and improvements during the second year of project activity, according to the feedback received from the end-users who tested and evaluated it in the field. The underwear was modified after the UC1, and again after the UC5.

The following sections describe the details and specifications of the improvements implemented in the external uniform and in the smart underwear.

3.1.1 Details and specifications.

According to the UC1 and UC5's results the team decided to improve the model of the external protective trousers, removing the two cargo lateral pockets, and replacing them with invisible lateral pockets as shown in the pictures below.

Figure 49. Cargo lateral pockets.

Figure 50. UC6: New trousers with invisible lateral pockets.

Figure 51. UC7: New trousers with invisible lateral pockets.

The FRs tested the new pants model during the UC6 and the UC7 and they evaluated them positively.

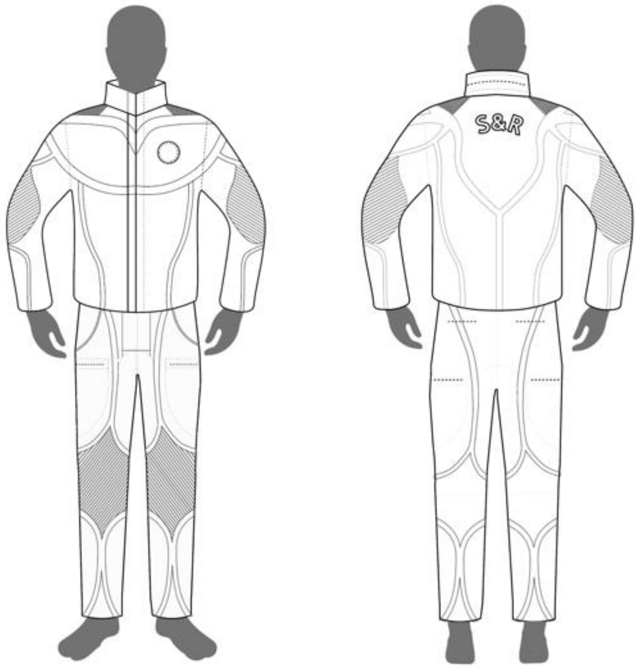


Figure 52. UC7: Improved uniform with the invisible lateral pockets in the trousers.

3.2 Materials and sensors

The materials and the sensors used in the first prototype of the smart protective uniform for first responders were positively tested during the different UCs. The detailed description of the materials used in the different components of the garments can be found in the previous version of the present deliverable D5.2 "First responder prototype uniform design and first aid device for kids" paragraph 3.5.1 "System architecture components". [1] The detailed description of the sensors integrated in the smart underwear can be also found in the previous version of the present deliverable D5.2 "First responder prototype uniform design and first aid device for kids" paragraph 4.2 "Smart materials and sensors". [1]

3.2.1 Integration of the components.

The smart protective uniform for first responders developed in the Search and Rescue project is composed, as already stated, of an external protective uniform and a smart underwear. The protective uniform is a two-piece garment with jacket and trousers. The details of the protective garment can be found in the previous version of the present deliverable D5.2 "First responder prototype uniform design and first aid device for kids" paragraph 4.1.1. [1] The integration between the different components has not changed after the UCs' tests, from the one described in the D5.2. As previously mentioned, instead, the smart underwear and the integration between the sensors and the textile had important improvements resulting from the different UCs' results.
The developed smart underwear has been designed to be worn under the rescuer's uniform, allowing monitoring the ECG, EMG, and knee joint angle of the first responder during the search and rescue operations. It is composed of a T-shirt and leggings made of a highly breathable, stretchable, resistant, and comfortable polyester fabric. Moreover, a custom organic X-ray sensor and a portable commercial multi-gas monitor were integrated in external pockets of the protective uniform.

<u>The electronics node</u>

The first version of the electronics of each node, used only in the UC1 pilot, consisted of two complementary boards, called "mother" and "daughter", as shown in Figure 53. The motherboard is the same for all the nodes and basically contains the microcontroller with the integrated BLE module, some voltage regulators, the connection to the power supply battery and two LEDs (see Figure 53 A,B). The daughter board is instead of two types (see Figure 53D,E): one is characterized by the ADS1292 module, consisting of a 24-bit 2-channel ADC with an integrated front-end for electrophysiological signals (ECG, EMG), combined with the required voltage regulators, while the second type is characterized by a dense network of operational amplifiers, capacitors and voltage regulators for conditioning the output signal from the ADC integrated in the microcontroller on the mother board, serving the custom strain sensor for measuring the knee angle; in this second type of the daughter board, a resistor was also integrated, to modulate a second output of the ADC reserved for the detector of the X radiation dose.

For each node, a pair of mother-daughter boards is available, which are joined in a sandwich structure via two complementary male-female micro-connectors, each placed in the center of one of

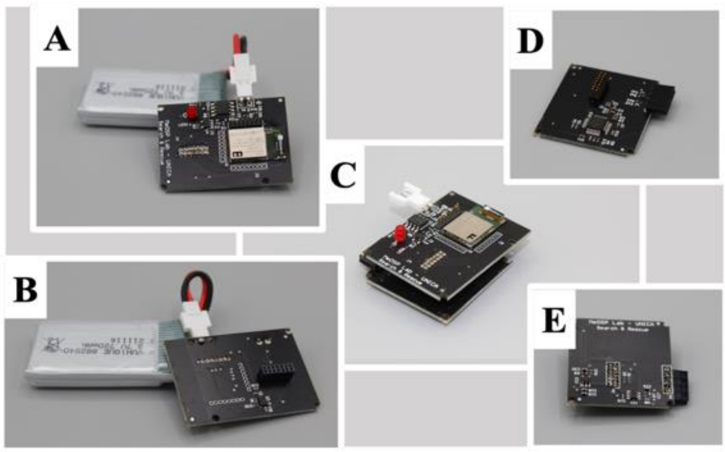
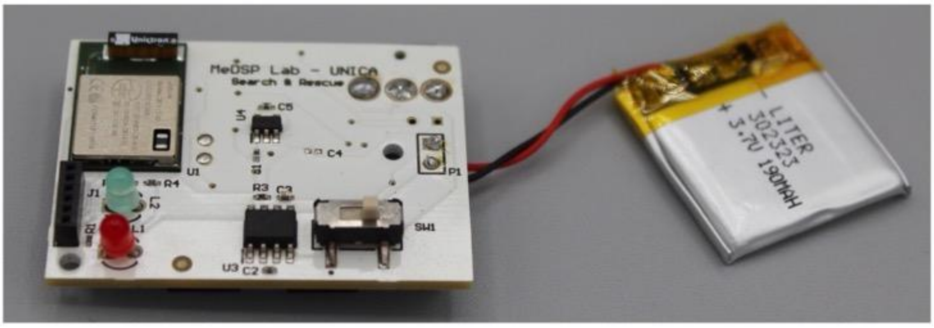


Figure 53. First version of the electronics node. A: Top view of the mother board with battery. B: Bottom view of the mother board. C: Mother-daughter "sandwich" structure. D: Top view of the daughter board. E: Bottom view of the daughter board.

the two boards (see Figure 53C). This structure, while allowing to minimize the overall volume of the node, has made it fragile due to the micro-twisting astride the central connector, with consequent lower strength in the connections as well as in the mechanical structure.
In the first demonstration pilot an oversized battery with capacities between 750-1200 mAh was used to allow continuous use of the node, which in this phase did not have an on-off switch for power supply. Therefore, to disconnect the node it was necessary to manually disconnect the battery from the relative connector, a condition that was not convenient during field trials.

The electronics of each node has been further miniaturized and reduced to a single board (UC5, UC6, UC3, UC4, UC7), as shown in Figure 54, no longer having the fragile sandwich structure. The mother and daughter board components were distributed on the two layers of the board, constituting two types of boards, similar to the first prototype: one type dedicated to the ECG and EMG nodes, one dedicated to the strain and X-ray nodes. The node is equipped with an on-off switch and a connector that allows the system to be recharged when the device is off, through a suitably customized commercial external recharge circuit. The power supply has been designed for a continuous duration of about 24h, choosing a 190mAh battery.

Figure 54. Final version of the board with the battery. On the left, the BLE module.



The case

During UC1, the boards have been housed in neoprene sleeves covered with plush, a soft and consistent synthetic material, and were attached to the underwear via velcro strips, as shown in Figure 55. Neoprene was chosen to give greater comfort to the rescuer during movements while

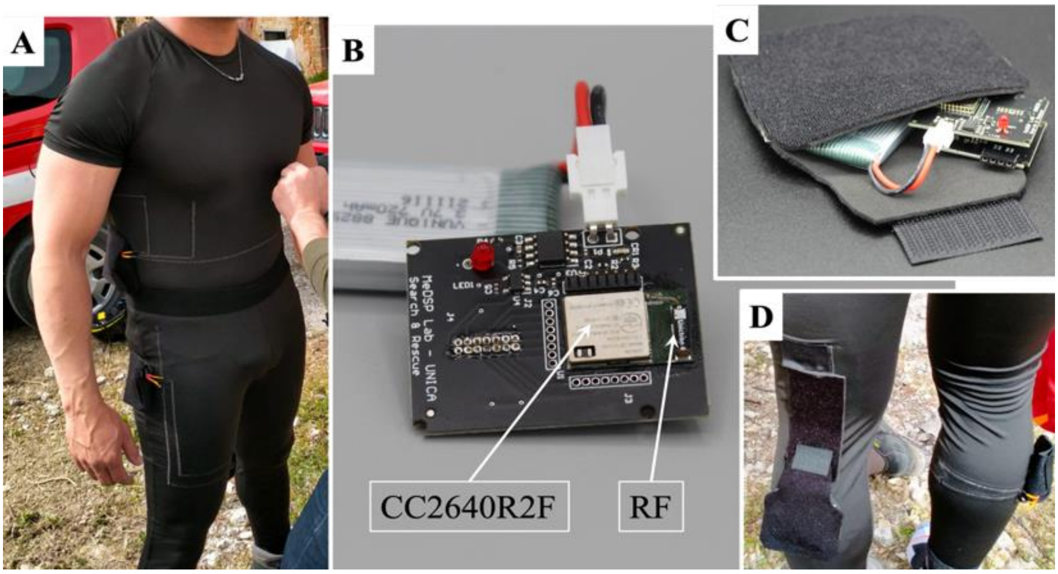


Figure 55. A: Front view of the smart underwear, with ECG and EMG electrodes for vastus medialis muscle; B: Custom developed wireless node; C: Neoprene pocket housing the electronic node. Velcro stripes allow the pocket to be easily attached to the garment. D: Back view of the smart underwear, with detail on both the strain sensor on the left, and EMG electrodes for gastrocnemius medialis on the right.

wearing the sensorized underwear. However, if on the one hand the comfort was confirmed by the same rescuers who tested the prototype, the soft shell did not guarantee strength and protection for the boards, which risked being crushed and compromised during the exercises. Furthermore, using velcro to secure the cases did not prove to be effective, as one of the four cases detached from the underwear during the field test and the rescuers found the male velcro on the underwear uncomfortable. Finally, in this configuration the connecting threads between the node and the underwear were partly exposed to twisting and crushing during the rescuer's movements.

Therefore, the neoprene cases have been replaced by small PLA cases (UC5), custom modelled and produced with a 3D printer, in the shape of a regular parallelepiped, with dimensions of approximately 4.5 x 3.5 x 1.2 cm^3, as shown in Figure 56.

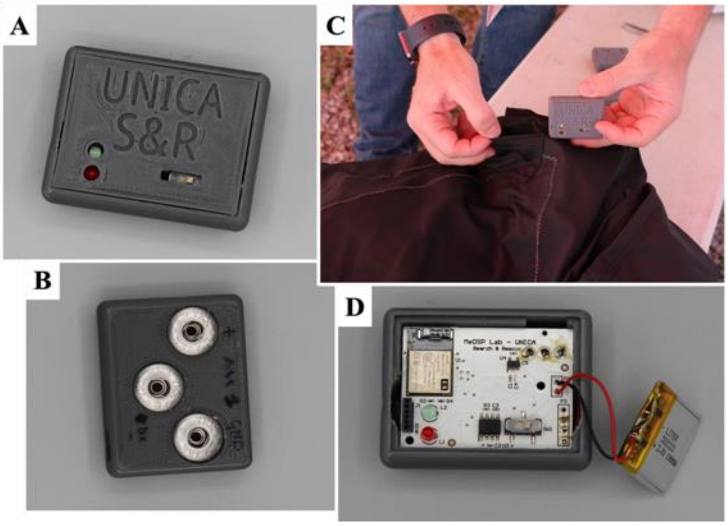


Figure 56. A: Top view of the PLA case. B: Bottom view of the case. C: The case is connected to the smart underwear through press studs and is wrapped in a small external pocket.

The connection between the conductive wires built into the smart underwear and the nodes has been modified with snap fasteners, whose male-female components have been crimped onto the fabric and the nodes in a complementary way. This made it possible to mechanically fix the nodes to the underwear, also thanks to small external pockets for housing each node, and to improve the connection between the sensors and the nodes. This solution proved to be more robust and efficient than the previous one in both laboratory and field tests, even if the overall profile of the node was evaluated as not low enough during the test phase in the field.
For these reasons, a final version of the cases was designed and developed, in engineered resin and in the shape of a low profile semi-ellipsoid, with dimensions equal to 5.5 x 5.5 x 0.8 cm^3 (see Figure

57). The absence of corners and the lower height of this solution were optimally evaluated during the field test.

The position of both sensors and nodes on the smart underwear

The garments were functionalized in the targeted areas using a biocompatible conductive ink based

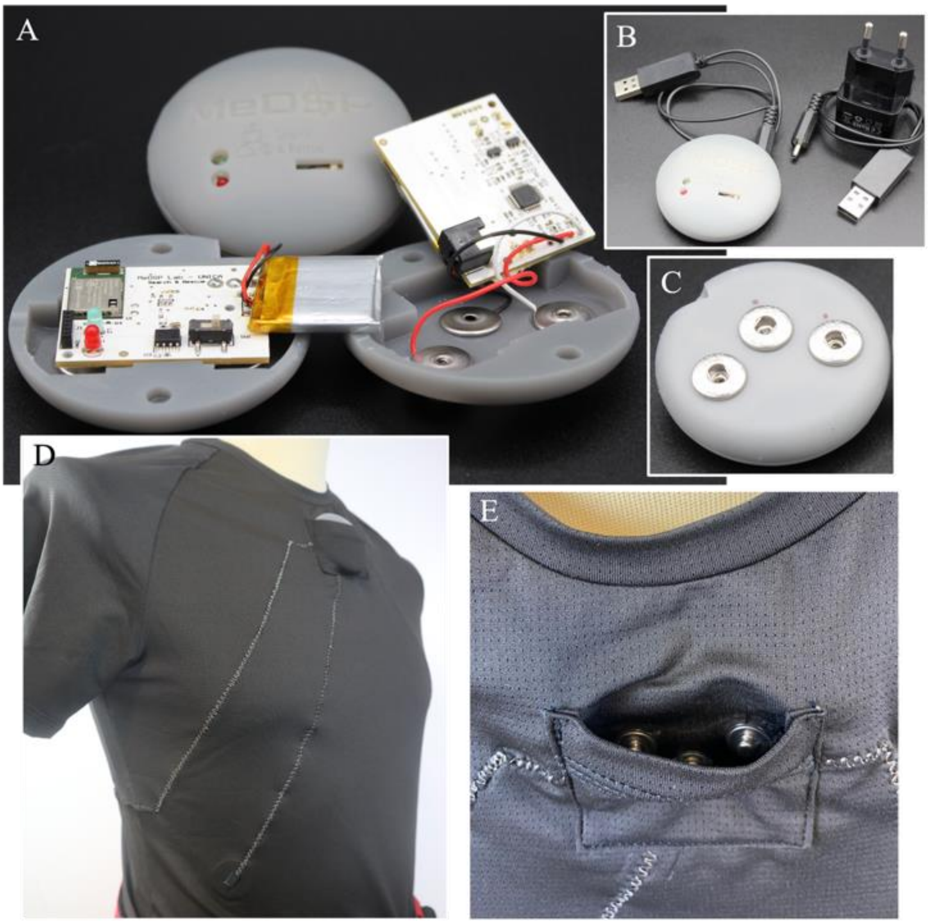


Figure 57. . A: Final version of the electronics board with the resin case. B: External charging system. C: Female press studs on the bottom of the node. D: ECG node on the smart underwear t-shirt. E: Male snap buttons on the underwear, to connect with the nodes.

on poly (3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), to form electrodes able to detect cardiac and muscle biopotentials.

During UC1, as shown in Figure 26, two ECG electrodes were positioned on the chest, symmetrically with respect to the sagittal line, to detect the ECG according to the lead I direction. A further electrode on the back, approximately at the same height, provides the signal ground for this recording (Figure 58 - light blue circles - and Figure 55A). A couple of EMG electrodes was placed on the upper leg, to detect the activity of the vastus medialis, with a ground electrode over the knee (Figure 58 - red circles – and Figure 55A,D). A second couple of EMG electrodes was positioned on the gastrocnemius medialis, with the ground electrode over the shinbone. All the electrodes were patterned directly on the finished garment using a customized screen-printing technique. The employed technique allowed to obtain perfectly functional electrodes even upon a sustained stretch of the garment.

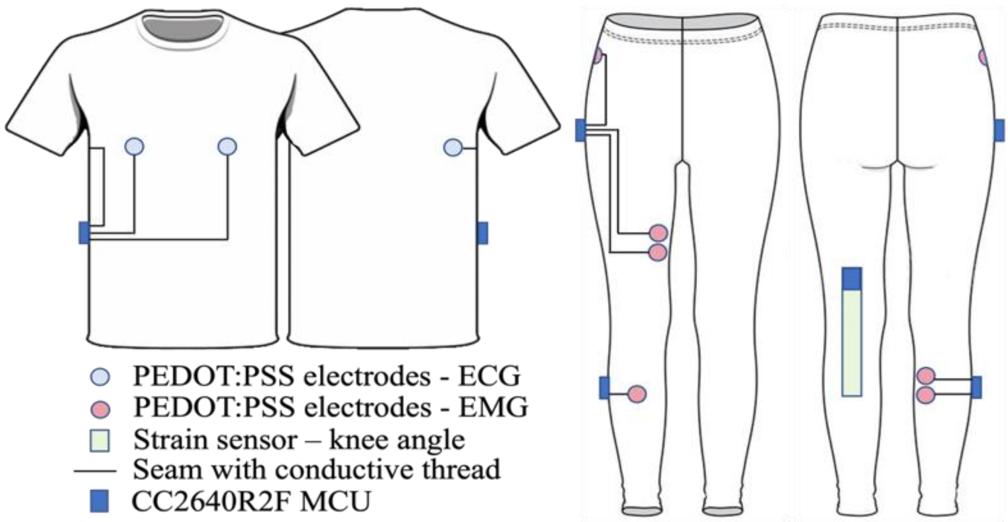


Figure 58. Overview of the first version of the smart underwear.

Biopotentials from the electrodes were read by the custom-developed BLE nodes and the connection between the wireless node and the electrodes is made up of conductive steel threads sewn directly on the underwear (see both Figure 58 and Figure 55A,D). As the performance of the electrodes depends on their coupling with the skin, which must be stable and characterized by low impedance, the electrodes were firmly attached on the skin by using soft neoprene bands able to guarantee a uniform and constant pressure over the skin (Figure 55D).
The organic semiconductor-based strain sensor was placed over the popliteal fossa (Figure 58, the green vertical strip), that is able to dynamically change its resistance according to the angular extension of the joint. It was a three-terminal device, namely thin-film transistors (TFT), whose sensitivity can be tuned and amplified by means of the gate field, and that can be incorporated into cotton garments for measuring joint movements. In this case, the wireless node was directly attached to the sensors without any conductive yarn.
The position of the ECG and EMG nodes on the underwear was judged uncomfortable by the rescuers: the ECG node was on the rescuer's right side, while the EMG nodes were placed laterally on the leg. These positions, in the event of the rescuer crawling on the ground, are subject to shocks and traction that can cause the case to release and/or crush the electronics housed inside.

For these reasons, the position of both sensors and nodes on the smart underwear was changed (UC5, UC6, UC7). As shown in Figure 59, two ECG electrodes were positioned laterally under the chest, symmetrically with respect to the sagittal line, and one on the back (i.e. the ground electrode), approximately at the same height (they are indicated by blue circles in Figure 59). A couple of EMG electrodes were placed on the upper leg, in order to detect the activity of the vastus medialis, with a ground electrode on the knee (they are reported in Figure 58 as red circles). A second couple of EMG electrodes was positioned on the gastrocnemius medialis, with the ground electrode on the shinbone. The position of the ECG and EMG nodes on the underwear has been modified: the ECG node has

been placed in correspondence with the sternum, while the EMG nodes have been placed posteriorly on the leg, one at mid-thigh, the other on the calf.
The position of the ECG and EMG cases on the underwear was considered optimal by the rescuers, because in the event of the rescuer crawling on the ground, are less subject to shocks and traction that can cause the case to release and/or crush the electronics housed inside.

3.3 Integration with the SnR Platform

Software architecture
The software architecture is based on the presence of a smartphone acting as a collector for the signals coming from the sensor nodes and the remote data lake, as described in D5.2 [1] and summarized in Figure 60.

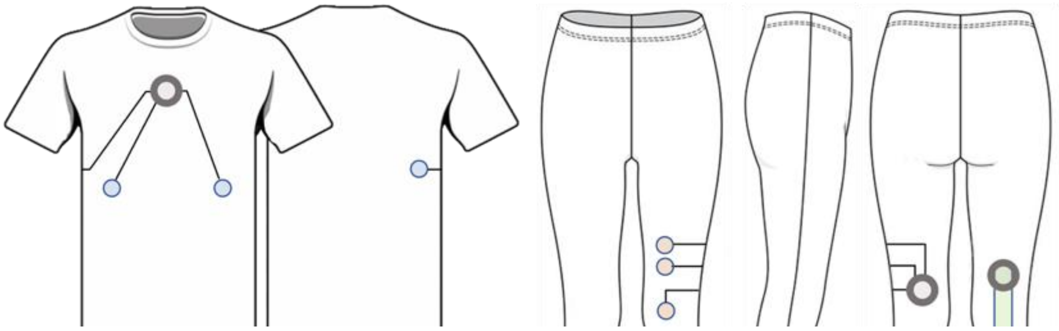


Figure 59. Overview of the second version of the smart underwear.

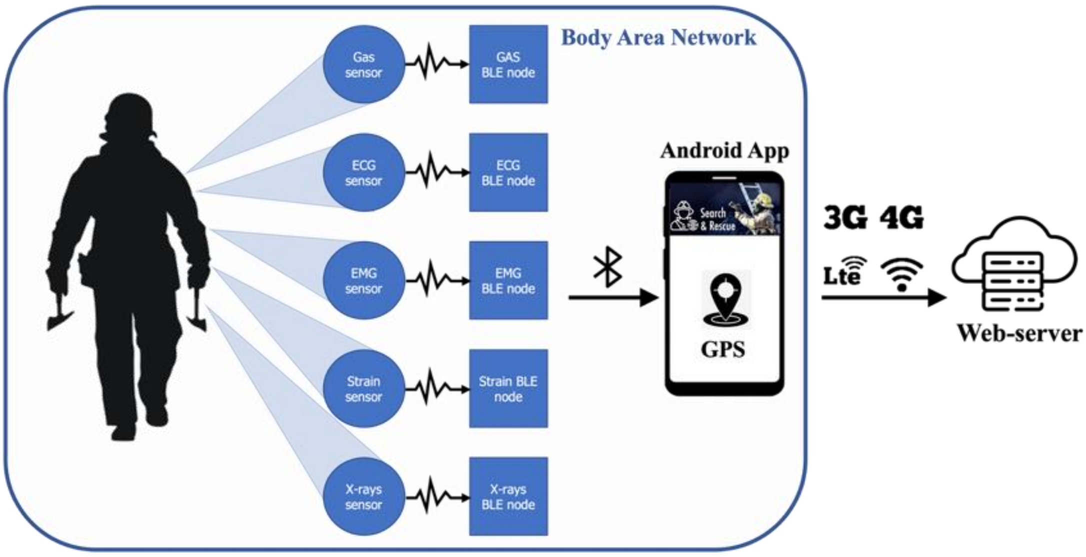


Figure 60. Overview of the system architecture.

Each wireless node is able to detect a single-channel signal, which is edge-pre-processed to extract the heart rate from the ECG signal, the maximum voluntary contraction of the EMG signal, and the angular extension of the knee joint. Raw data and key features (such as the heart rate) are sent to the rescuer's smartphone in real-time, by using custom-defined GATT characteristics. The data rate is signal-dependent: as such, the ECG signal is sampled and sent at 250 Hz; the EMG signal is sampled at 250 Hz, whereas its envelope is edge-computed and sent at 50 Hz; joint angles are sampled at 10 Hz and their average value is sent at 1 Hz. A custom Android app was designed to collect the data from the different wireless nodes (see Figure 60). On the smartphone, by using the information of the integrated GPS module, data are geolocated and sent to the remote web server every five seconds in independent chunks, through Wi-Fi or cellular network. The smartphone can support simultaneous streaming from up to 7 BLE nodes.

The app is able to interact with Apache Kafka by a "middleweare", i.e. the app communicates with an API, a REST API implemented by KT is fed with data and publishes it to Kafka topics, a broker for streaming processing based on a distributed data storage, which receives the data in JSON format in real-time every 5 s. Depending on the sensor type, the data file comprises different fields; the size of the field that contains the signal depends on the sampling frequency of the data.

The application has a very simple interface (Figure 61), which provides information on the sensors connected to the application, and therefore in use. In addition, the app allows real-time display of some characteristics of the Global Navigation Satellite Systems (GNSS) location, including latitude, longitude and altitude coordinates, detected through the GPS sensor embedded in the smartphone. Finally, it shows the status of communication with the server (SERVER RESPONSE: OK/NO NETWORK), and the total number of packets sent and queued (therefore not yet consumed by the server) for each of the connected nodes.

Figure 61. The Search & Rescue Android App sends the data.

The integration of the Digitron Gas Monitor

In order to enable a direct communication of the data between the Digitron Gas Monitor and the Android, the Bluetooth Low-Energy (BLE) communication module was used. However, despite the advertising and quotation by the company, no API was provided with the device, rather the explanation of the protocol only.

The shared protocol was specially designed for the communication of Shenzhen Yuante Technology Co., Ltd. multi-gas handheld series of detectors. The communication protocol follows the MODBUS-RTU standard protocol and adopts a question-and-answer communication method. The Android smartphone (master) sends commands to the detector, which acts as slave in the communication. If the address code matches and the check code is ok, the command is executed, and the result sent to the master. Otherwise, an error is issued. The data format follows the MODBUS-RTU standard format, and each frame of data is divided into address code, function code, data area and check code:

Start	Address code	function code	Data area	Check code	End
4 byte cycles	1 byte	1 byte	N bytes	2 bytes	4 byte cycles

According to the MODBUS-RTU standard format, there is no specially established start and end bytes, but duration of 4 byte cycles is rather used. As it is recommended to send the frame interval in more than 5 milliseconds, and the byte interval in the same frame within 2 milliseconds, this limits the information rate for the communication, but does not represent a constraint for the application based on the project specifications. The check code is a CRC code, whose algorithm was provided by Digitr on and implemented in the Android App. This allows a first-level integrity check on the data packet. It complies with the MODBUS-RTU standard, according to a 16-bit redundant cyclic code (CRC-16).

The most important part is the Address/Function/Data:

- Address is used by the master (the app) to specify the device (in presence of multiple ones) that should receive the command

- Function code is used by the master (the app) to specify what the slave needs to do (e.g., read 0x03, write 0x06-0x10, etc.). The slave (device) responds with the same code, if the communication was successfully performed, or 0xFF in case of problems
- Data area is used in different ways by master and slave, according to the type of request.

The code implemented the whole protocol in Java for Android. The data was collected for five gases:

- CO
- CO_2
- O_2
- H_2S
- EX (explosives)

The device provides the concentration, unit of measurement, alarm status, and other information when a query for a given sensor is issued by the Android App. In presence of an alarm, the app reports the value in red, otherwise in green (see Figure 60). Data transmission to the App does not alter the normal function of the device, so that the alarm starts a loud buzzer on the device, which also starts flashing red until the concentration goes again below the threshold value. Multiple alarms can be contemporarily issued.
According to the project specification, the information collected by the Android App is sent to Kafka every 5 s similarly to all the other sensors.

4 First aid device for children tests and validation

4.1 Usability and preliminary tests.

The prototyping process required the execution of several laboratory tests for the functional evaluation of the first aid device for children and the sensors, embedded in a sock placed in a fabric pocket of the device. The tests regarded:

- usability tests of the device and its components also according to the KPI request by the project;
- washability tests of the external textile components;
- tests on the prototypical sensors;

Usability test
The test of usability of the prototype of the first aid device for kids was carried out prior to the UCs pilots in March/April 2022 at the Design Campus building - University of Florence.
During the test a dummy baby of approximately six months, has been used.
The evaluation tests regarded:

- the lightness of the device to be carried;
- the ease to pull out the device from the cover;
- the ease to prepare the device for putting the dummy baby inside: open or take away stuffed adaptors, unlock security belts;
- the ease of putting the dummy baby on the board of the device;
- the ease to adjust the length of the board to the height of the body of different kids;
- the ease to adjust and lock the security belts when a dummy kid on board;
- the ease to adjust the device's side holder elements to the weight and height of the body of the dummy-kid.

All the above tests of evaluation in laboratory were conducted with and without DPI gloves.

Figure 62. Usability test: Model with First aid device, Design Campus Florence

Moreover, additional usability tests were carried out during the UCs pilots with the corresponding first responders. The test evaluations were recorded and stored in a private and protected database.

Washability test
The device for kids was tested regarding its cleanability and washability properties as well, in accordance with the KPI of the project.
The prototype was positively tested by cleaning and washing it by hand, using different commercial terry clothes, water and soaps, and disinfectant cleaners.
The prototype passed 5 cleaning cycles without any alteration of the model and of the mechanical and chemical properties of the textile. After 5 cycles of cleaning the prototype passed the waterproofness and the usability test again.
The textile components are easily removable in order to easily wash and decontaminate them.

Tests on the prototypical sensors
During the development of the project the UNIFI and UNICA teams decided to use commercial health sensors for equipping the rescue device for kids. This decision was due to the difficulty of involving children during the tests according to the 'ethics requirements' that the project must comply, as described in D11.2 : H - Requirement No. 2 [8]
Consequently, the use of commercial sensors guarantees their functionality, without the need to test them during the case studies.
The mandatory sensing elements were developed according to the original schedule. In particular, the following sensors were considered:

- ECG
- Respiration
- Temperature

As the electrocardiogram node was also developed for the first responders, the same device was adopted for this device (which is described in the associated section). In this case, however, the ECG electrodes are commercial (any kind, we used the AMBU Blue Sensors N, which are paediatric sensors) for their size and the decentred snap connector. A shielded cable with a spring-like snap head by Spes Medica was selected for its light weight and effectiveness. A receptacle able to connect up to 5 shields of the cables from Spes Medica was also used, as shown in the following pictures.

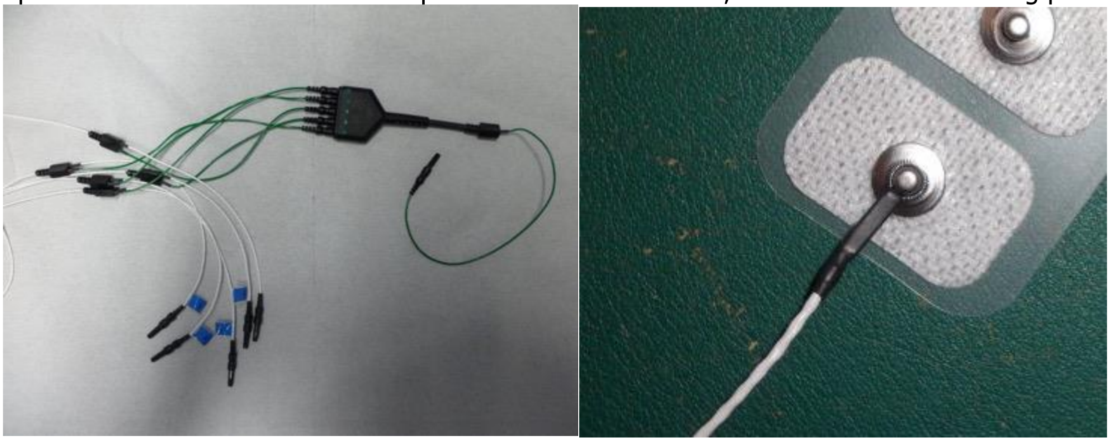


Figure 63. Shielded cables for the ECG recording.

Moreover, custom adaptors were created to accept the safe lead connectors of the cables to the textile snaps of the uniform, as shown in the following figure.

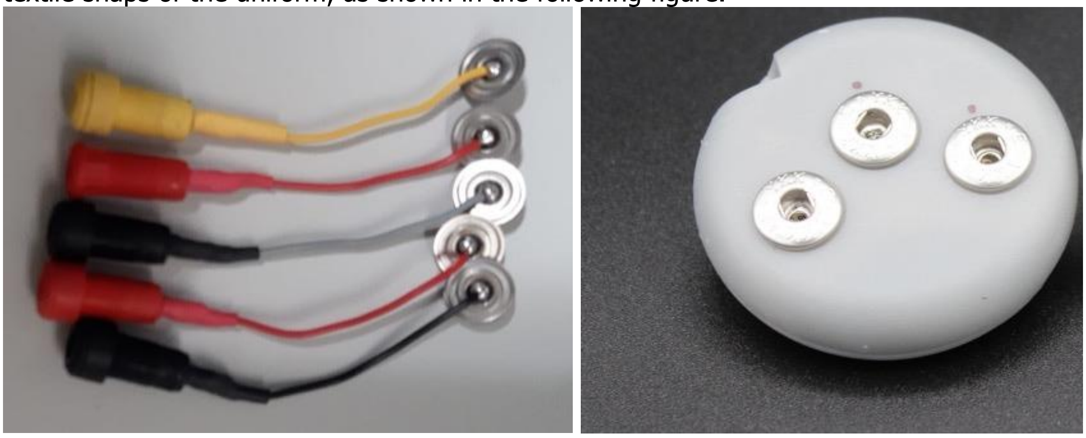


Figure 64. Custom connectors for ECG cables for the electronic nodes.

According to D5.2 [1], the possibility of recording the respiration rate was also considered. To this aim, the ADS1292R analogue front-end (AFE) for ECG and respiration was adopted.
The chip features two low-noise PGAs and two high-resolution ADCs; one of the two channels can be configured to record biopotential (a second differential lead) or a signal correlated to the respiration rate. This latter signal is recorded according to an impedance measurement approach, only on the first channel of the AFE, so in this case the second channel must be used for the ECG. Remarkably, the same two electrodes for the acquisition of a differential lead can be used for both measurements, even though this requires the two are applied on the torso so that the respiration can change the body impedance, which is recorded by the AFE. The modality with internal clock was used, to limit the number of external components. The conventional respiration circuitry provided by Texas Instruments was successfully adopted. Unfortunately, the design requirements are quite tight. In particular, a low-noise recording from the two arms is required. This is difficult as the arms are subject to movements and muscular contractions introducing electromyographic interferences. This was partially solved by placing the electrodes on the torso according to placement defined on the first responder. An example of the signal recorded in static and dynamic conditions (walking) is presented in the following pictures. As can be seen, muscular activation hampers the detection of a clean signal, though some filtering can still be able of providing enough information to estimate the respiration rate.

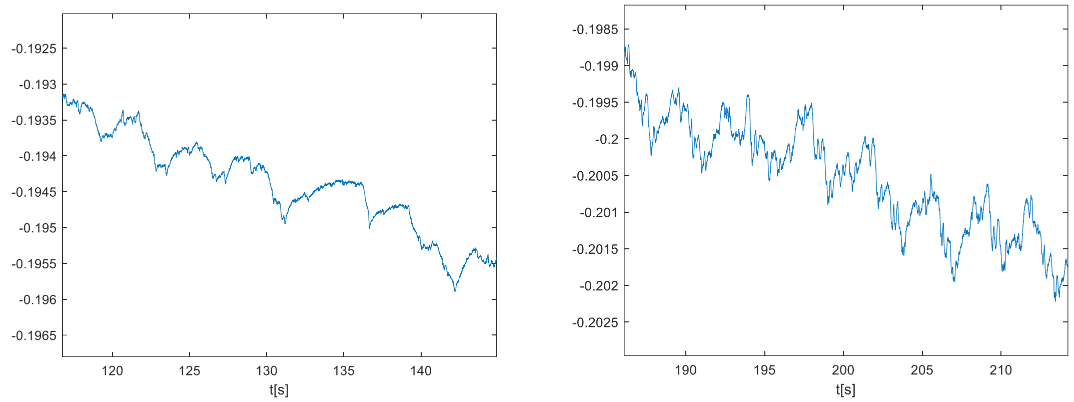


Figure 65. Respiration rate signal on a same adult subject at different exercise levels.

Unfortunately, other requirements are: respiration impedance values ranging from 2 kΩ to 15 kΩ, and noise levels of less than 10 μV. These requirements are more difficult to meet; in particular, the AFE requires to change some demodulation parameters used to extract the phase-shift signal based on the square-wave injected in the human body, to achieve a subject-specific configuration able to properly work in a given condition. In particular, the phase of the respiration demodulation control signal must be set in a range of 16 values, 32 if we consider the different stimulation frequency (32 kHz or 64 kHz). Based on some tests performed in laboratory, this changes dramatically according to the body characteristics, including BMI and size, so in some subjects it was impossible to extract a usable respiration signal. No tests on children could be performed, according to the ethical protocol of the project. As the ECG signal is negatively influenced by the presence of the additional respiration channel, and the electronics could not be tested on the expected subjects (children), the respiration rate measurement was removed from the implemented node, making it identical to the one used for the first responder. A further test was made on adults by using a piezoresistive respiration belt, with a simple voltage divider configuration on the second channel of the ADS1292. Although this version is able to produce more stable waveforms for the respiration rate, no tests on children could be performed, for the aforementioned issues. In this case, the problem is related to the measurement approach: the respiration belt measures the dilation and contraction of the chest during inspiration and expiration, so that the piezoresistive element changes its length (and, accordingly, its resistance) following the chest rhythm. A proper calibration of the system necessarily requires a calibration based on the level of deformation applied to the sensor by the chest movement, which cannot overlook the size of the chest and the amount of volume change. Also in this case, as for the ECG signal, only commercial devices were used. In particular, the respiration belt by TMSi was used for the reported tests.
A commercial probe was considered for the body temperature. The NTC technology was selected, for its cheap cost and ease of use. In particular, the YSI skin temperature probe (409B), model T0175AU, By King-Med, was adopted. The probe is able to measure the contact temperature when applied on the skin by a change in the resistance (negative coefficient, the higher the temperature the lower the resistance). A very simple conditioning circuit was adopted, properly dimensioned according to the human temperature range from 20 °C to 45 °C.

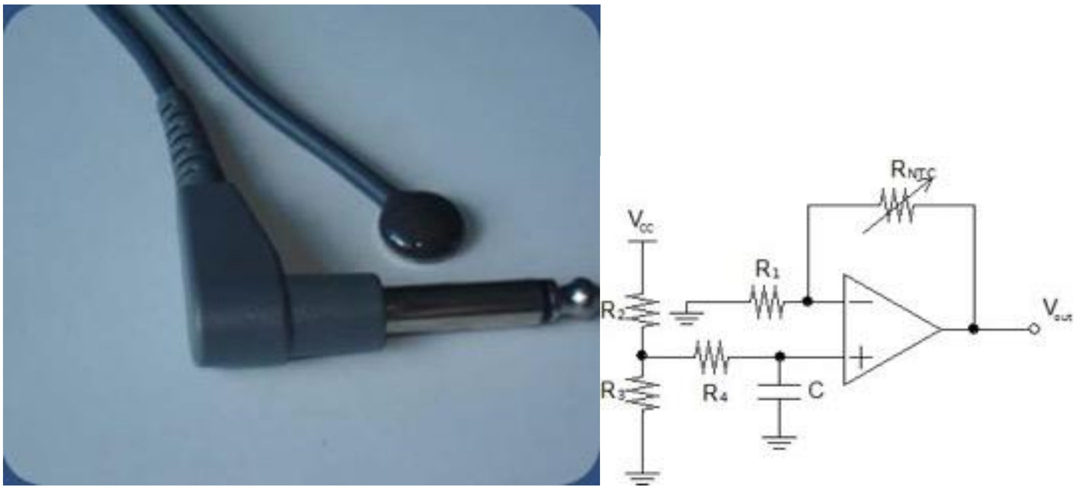


Figure 66. YSI skin temperature probe (409B) and the adopted conditioning circuit.

The Steinhart-Hart equation was used to compute the temperature based on the parameters A, B, C. To obtain the values of the constants A, B and C, the resistance values were used at temperatures (later converted into Kelvin) of 20°C, 25°C and 40°C, according to the table provided by the manufacturer and reported hereafter.

Temperature		Resistance	Temperature		Resistance	Temperature		Resistance
°F	°C	(Ω)	°F	°C	(Ω)	°F	°C	(Ω)
-112.0	-80	1,660,000.00	37.4	3	6,319.00	186.8	86	233.400
-110.2	-79	1,518,000.00	39.2	4	6,011.00	188.6	87	226.200
-108.4	-78	1,390,000.00	41.0	5	5,719.00	190.4	88	219.300
-106.6	-77	1,273,000.00	42.8	6	5,444.00	192.2	89	212.600
-104.8	-76	1,167,000.00	44.6	7	5,183.00	194.0	90	206.100
-103.0	-75	1,071,000.00	46.4	8	4,937.00	195.8	91	199.900
-101.2	-74	982,800.00	48.2	9	4,703.00	197.6	92	193.900
-99.4	-73	902,700.00	50.0	10	4,482.00	199.4	93	188.100
-97.6	-72	829,700.00	51.8	11	4,273.00	201.2	94	182.500
-95.8	-71	763,100.00	53.6	12	4,074.00	203.0	95	177.100
-94.0	-70	702,300.00	55.4	13	3,886.00	204.8	96	171.900
-92.2	-69	646,700.00	57.2	14	3,708.00	206.6	97	166.900
-90.4	-68	595,900.00	59.0	15	3,539.00	208.4	98	162.000
-88.6	-67	549,400.00	60.8	16	3,378.00	210.2	99	157.300
-86.8	-66	506,900.00	62.6	17	3,226.00	212.0	100	152.800
-85.0	-65	467,900.00	64.4	18	3,081.00	213.8	101	148.400
-83.2	-64	432,200.00	66.2	19	2,944.00	215.6	102	144.200
-81.4	-63	399,500.00	68.0	20	2,814.00	217.4	103	140.100
-79.6	-62	369,400.00	69.8	21	2,690.00	219.2	104	136.100
-77.8	-61	341,800.00	71.6	22	2,572.00	221.0	105	132.300
-76.0	-60	316,500.00	73.4	23	2,460.00	222.8	106	128.600
-74.2	-59	293,200.00	75.2	24	2,354.00	224.6	107	125.000
-72.4	-58	271,700.00	77.0	25	2,252.00	226.4	108	121.600
-70.6	-57	252,000.00	78.8	26	2,156.00	228.2	109	118.200
-68.8	-56	233,800.00	80.6	27	2,064.00	230.0	110	115.000
-67.0	-55	217,100.00	82.4	28	1,977.00	231.8	111	111.800
-65.2	-54	201,700.00	84.2	29	1,894.00	233.6	112	108.800
-63.4	-53	187,400.00	86.0	30	1,815.00	235.4	113	105.800

-61.6	**-52**	174,300.00	**87.8**	**31**	1,739.00	**237.2**	**114**	103.000
-59.8	**-51**	162,200.00	**89.6**	**32**	1,667.00	**239.0**	**115**	100.200
-58.0	**-50**	151,000.00	**91.4**	**33**	1,599.00	**240.8**	**116**	97.600
-56.2	**-49**	140,600.00	**93.2**	**34**	1,533.00	**242.6**	**117**	95.000
-54.4	**-48**	131,000.00	**95.0**	**35**	1,471.00	**244.4**	**118**	92.500
-52.6	**-47**	122,100.00	**96.8**	**36**	1,412.00	**246.2**	**119**	90.000
-50.8	**-46**	113,900.00	**98.6**	**37**	1,355.00	**248.0**	**120**	87.700
-49.0	**-45**	106,300.00	**100.4**	**38**	1,301.00	**249.8**	**121**	85.400
-47.2	**-44**	99,260.00	**102.2**	**39**	1,249.00	**251.6**	**122**	83.200
-45.4	**-43**	92,720.00	**104.0**	**40**	1,200.00	**253.4**	**123**	81.100
-43.6	**-42**	86,650.00	**105.8**	**41**	1,152.00	**255.2**	**124**	79.000
-41.8	**-41**	81,020.00	**107.6**	**42**	1,107.00	**257.0**	**125**	77.000
-40.0	**-40**	75,790.00	**109.4**	**43**	1,064.00	**258.8**	**126**	75.000
-38.2	**-39**	70,930.00	**111.2**	**44**	1,023.00	**260.6**	**127**	73.100
-36.4	**-38**	66,410.00	**113.0**	**45**	983.800	**262.4**	**128**	71.300
-34.6	**-37**	62,210.00	**114.8**	**46**	946.200	**264.2**	**129**	69.500
-32.8	**-36**	58,300.00	**116.6**	**47**	910.200	**266.0**	**130**	67.800
-31.0	**-35**	54,660.00	**118.4**	**48**	875.800	**267.8**	**131**	66.100
-29.2	**-34**	51,270.00	**120.2**	**49**	842.800	**269.6**	**132**	64.400
-27.4	**-33**	48,110.00	**122.0**	**50**	811.300	**271.4**	**133**	62.900
-25.6	**-32**	45,170.00	**123.8**	**51**	781.100	**273.2**	**134**	61.300
-23.8	**-31**	42,420.00	**125.6**	**52**	752.200	**275.0**	**135**	59.800
-22.0	**-30**	39,860.00	**127.4**	**53**	724.500	**276.8**	**136**	58.400
-20.2	**-29**	37,470.00	**129.2**	**54**	697.900	**278.6**	**137**	57.000
-18.4	**-28**	35,240.00	**131.0**	**55**	672.500	**280.4**	**138**	55.600
-16.6	**-27**	33,150.00	**132.8**	**56**	648.100	**282.2**	**139**	54.300
-14.8	**-26**	31,200.00	**134.6**	**57**	624.800	**284.0**	**140**	53.000
-13.0	**-25**	29,380.00	**136.4**	**58**	602.400	**285.8**	**141**	51.700
-11.2	**-24**	27,670.00	**138.2**	**59**	580.900	**287.6**	**142**	50.500
-9.4	**-23**	26,070.00	**140.0**	**60**	560.300	**289.4**	**143**	49.300
-7.6	**-22**	24,580.00	**141.8**	**61**	540.500	**291.2**	**144**	48.200
-5.8	**-21**	23,180.00	**143.6**	**62**	521.500	**293.0**	**145**	47.000
-4.0	**-20**	21,870.00	**145.4**	**63**	503.300	**294.8**	**146**	45.900
-2.2	**-19**	20,640.00	**147.2**	**64**	485.800	**296.6**	**147**	44.900
-0.4	**-18**	19,480.00	**149.0**	**65**	469.000	**298.4**	**148**	43.800
1.4	**-17**	18,400.00	**150.8**	**66**	452.900	**300.2**	**149**	42.800
3.2	**-16**	17,390.00	**152.6**	**67**	437.400	**302.0**	**150**	41.800
5.0	**-15**	16,430.00	**154.4**	**68**	422.500	**303.8**	**151**	40.900
6.8	**-14**	15,540.00	**156.2**	**69**	408.200	**305.6**	**152**	40.000
8.6	**-13**	14,700.00	**158.0**	**70**	394.500	**307.4**	**153**	39.100
10.4	**-12**	13,910.00	**159.8**	**71**	381.200	**309.2**	**154**	38.200
12.2	**-11**	13,160.00	**161.6**	**72**	368.500	**311.0**	**155**	37.300
14.0	**-10**	12,460.00	**163.4**	**73**	356.200	**312.8**	**156**	36.500
15.8	**-9**	11,810.00	**165.2**	**74**	344.500	**314.6**	**157**	35.700
17.6	**-8**	11,190.00	**167.0**	**75**	333.100	**316.4**	**158**	34.900
19.4	**-7**	10,600.00	**168.8**	**76**	322.300	**318.2**	**159**	34.100
21.2	**-6**	10,050.00	**170.6**	**77**	311.800	**320.0**	**160**	33.400
23.0	**-5**	9,534.00	**172.4**	**78**	301.700	**321.8**	**161**	32.700
24.8	**-4**	9,046.00	**174.2**	**79**	292.000	**323.6**	**162**	32.000
26.6	**-3**	8,586.00	**176.0**	**80**	282.700	**325.4**	**163**	31.300

28.4	**-2**	8,151.00	**177.8**	**81**	273.700	**327.2**	**164**	30.600
30.2	**-1**	7,741.00	**179.6**	**82**	265.000	**329.0**	**165**	29.900
32.0	**0**	7,355.00	**181.4**	**83**	256.700	**330.8**	**166**	29.300
33.8	**1**	6,989.00	**183.2**	**84**	248.600	**332.6**	**167**	28.700
35.6	**2**	6,644.00	**185.0**	**85**	240.900	**334.4**	**168**	28.100

Table 1. Table provided by the manufacturer.

The architecture of the node included an MSP430FG4618 microcontroller and an external BLE module, identical to those used for the first responders, connected via serial port. As the node could not be tested in the UC, it was not optimized for size and performance.
Lab tests for data integrity (packet loss) and functional validation were carried out at the MeDSP Lab of the University of Cagliari, allowing to assess the quality of the proposed design. Functional performance was performed on adult volunteers but no tests with kids were possible, so the design was not optimized for final use.

4.2 UC tests and results

The validation tests of the First aid device for kids was performed both in laboratory and in relevant field scenarios during the following Use Cases pilots of the project:

- UC1 - Victims trapped under rubble (Poggioreale - Italy)
- UC6 - Resilience Support for Critical Infrastructures (Tuzla - Romania)
- UC7 - Chemical substances spill (Madrid - Spain).

Compared to what was foreseen in D5.2, the first aid device for kids has been tested in the further case study the UC7 - Chemical substances spill, to evaluate the improvement regarding the safety belts and to evaluate it by professional paramedical staff.
All the tests were carried out with and without DPI gloves.
The tests aim to evaluate as follows:

- the dimension of the device related to the rescue protocols and the other equipment;
- the lightness to be carried by a single first responder without a child;
- the lightness of the device to be carried with child;
- the lightness of the device to be carried without child;
- the ease to prepare the device for putting the dummy baby inside;
- the ease of putting a dummy baby on the device's board;
- the ease to adjust stuffed adaptors;
- the ease to lock and unlock security belts with and without a dummy baby on board;
- the ease to adjust the device's side holder elements to the weight and height of the body of the dummy baby;
- the ease of holding the handles for the device transportation and the quality of the grip;
- the compatibility with other equipment;

The prototype was evaluated through interviews and questionnaires taken after the activities on the field and also through direct observation. The questionnaire's results are stored in the Alfresco platform accessible only to the S&R consortium.

4.2.1 UC1

The UC1 "Victims under the Rubbles" took place in April 2022 in Poggioreale (Italy). Detailed specifications of the pilot can be found in the deliverable D8.2 "S&R Use Case 1: Victims trapped under rubble (Italy) - Pilot plan". [2] It represented the first test on a relevant environment for the validation of the prototype. The rescue device for kids was tested by professional first responders of the USAR Catania Fire Brigade team using a dummy baby of about 12 months on board to simulate a baby victim. In particular the device was tested in the "collapsed car park" site.
The device accomplished all the KPIs requested by the project.

The device's weight was evaluated very light to be carried. The first responders were able to move themselves easily with the device over the rubble while the dimensions were not evaluated optimal for the rescue activities under the rubbles. In this case the operation was slowed down because a larger opening in the rubbles was needed to pass the device. As a consequence, the FRs suggested to reduce a little the width of the device.
The five points belts were evaluated to be hard to unlock wearing gloves DPI. The rescuers suggested adding supplementary straps to lock the victim's head, shoulders and knees improving the security of the rescue device.

Figure 67. First aid device in with dummy baby, UC1

The level of satisfaction of First Responders (from not sufficient to excellent) regarding the First Aid Device for kids is summarised in the following charts.

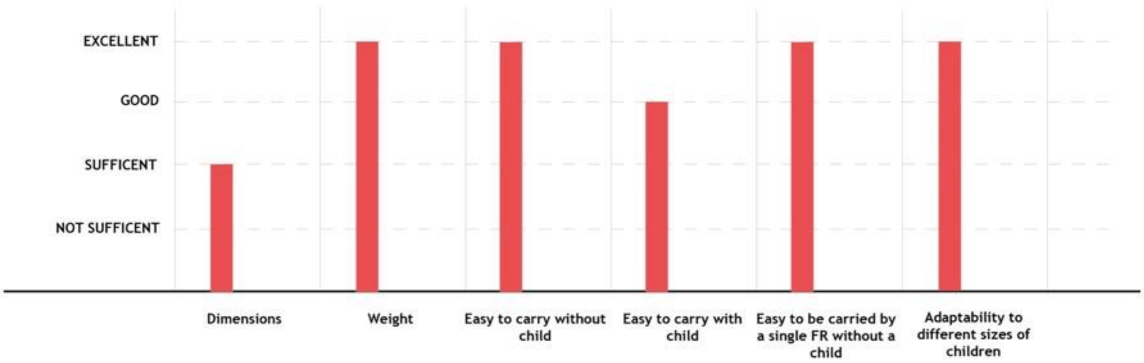


Figure 68. Summarized results of the after UC1 pilot questionnaires and interviews.

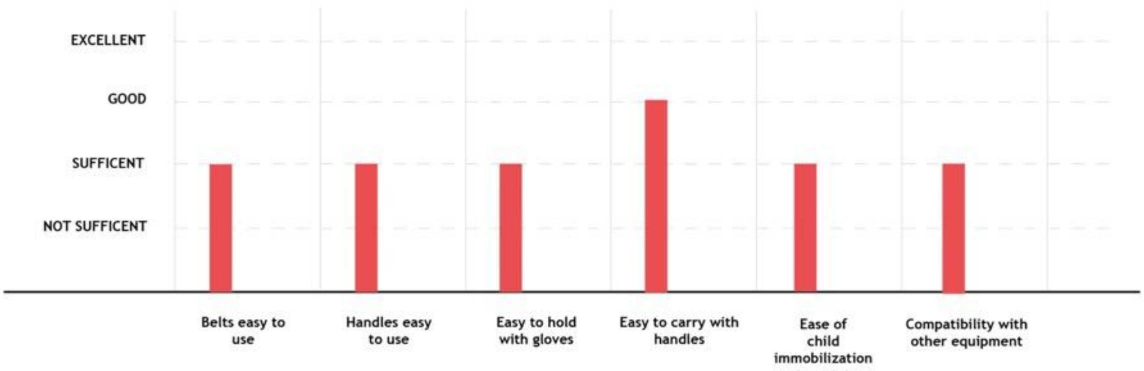


Figure 69. Summarized results of the after UC1 pilot questionnaires and interviews.

4.2.2 UC6

The UC6 "Chemical terrorist attack" took place in September 2022 in Tuzla (Romania). Detailed specifications of the pilot can be found in the deliverable D 8.7 "S&R Use Case 6: Resilience Support for Critical Infrastructures through Standardized Training on CBRN (Romania) - Pilot plan" [4]
It represented the second test on a relevant environment for the validation of the prototype. The rescue device for kids was tested by professional first responders of the Tuzla Airport Fire Brigade team using a dummy baby of about 6 months on board to simulate a baby victim. The device was tested to rescue a young victim (dummy baby) carried from the passengers' terminal to the decontamination site, after a "CBRN attack".
The critical issues that emerged in this Use Case correspond to those of the Use Case in Sicily.
The device's weight was evaluated very light to be carried and its dimensions suitable for the scenario. The first responders were able to move easily carrying the device with and without a dummy baby on board. The handles were partially uncomfortable to be easily held by the gloves used for CBRN rescue.
The five points belts were evaluated not optimal to be unlocked wearing gloves DPI. The first responders suggested to replace the five points belts with supplementary straps to lock the victim's head, shoulders and knees improving the ease of use of the rescue device.

Figure 70. First responders testing the First aid device for kids, UC6

The level of satisfaction of the First Responders (from not sufficient to excellent) regarding the First Aid Device for kids is summarised in the following charts.

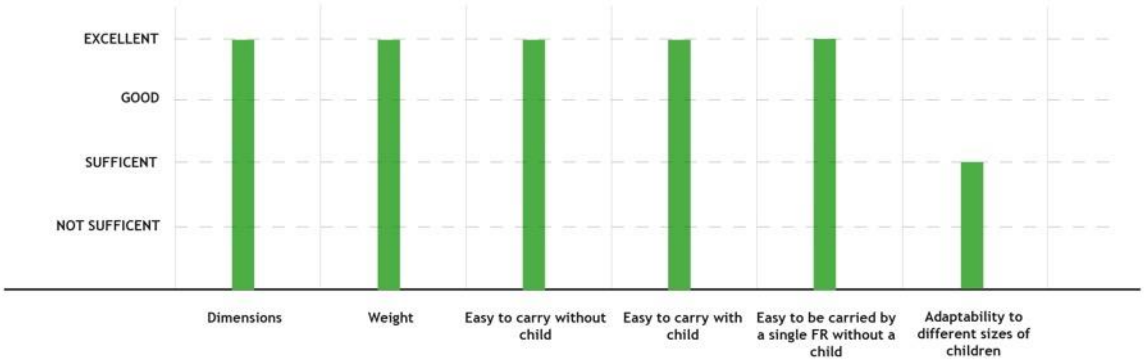


Figure 71. Summarized results of the after UC6 pilot questionnaires and interviews.

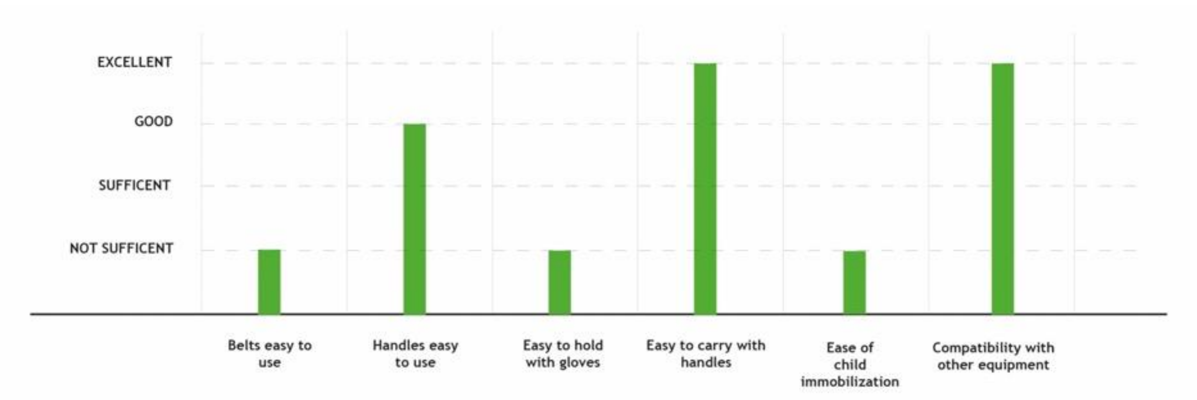


Figure 72. Summarized results of the after UC6 pilot questionnaires and interviews.

4.2.3 UC7

The UC7 "Chemical substances spill" took place in December 2022 in Madrid (Spain). Detailed specifications of the pilot can be found in the deliverable D8.8 "S&R Use Case 7: Chemical substances spill (Spain) - Pilot plan.". [7] It represented the final test on a relevant environment for the validation of the prototype. The first aid device for kids was tested by the paramedical rescue staff of SUMMA112, using a dummy baby of about 6 months on board to simulate a baby victim.
The device's weight was evaluated very light to be carried. The first responders were able to move themselves easily carrying the device with and without a dummy baby on board. The handle sizes were appropriate to be held with DPI gloves. The prototype, tested in this use case, had different security belts in comparison to the previous UC6. As suggested by first responders after the UC6, the 5-point belts system has been removed and replaced with 3 other safety straps. During UC7 this locking method was evaluated suitable for the immobilisation of the child, even if first responders suggested to repositioning the 5 points belts system to improve the security of the child during the transportation. The device's cover with shoulder straps was tested to carry the device during the operation, confirming the easy portability of the device also by one FR.

Figure 73. First responders testing the First aid device for kids, UC7

The level of satisfaction of First Responders (from not sufficient to excellent) regarding the First Aid Device for kids is summarised in the following charts.

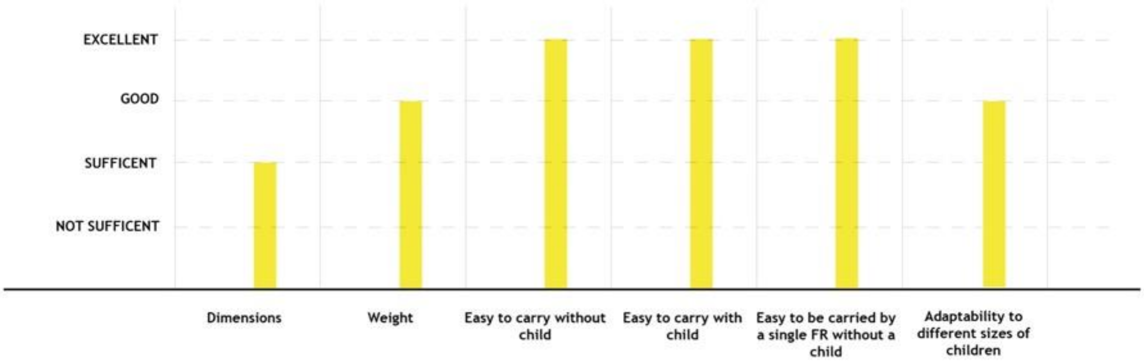


Figure 74. Summarized results of the after UC7 pilot's questionnaires and interviews.

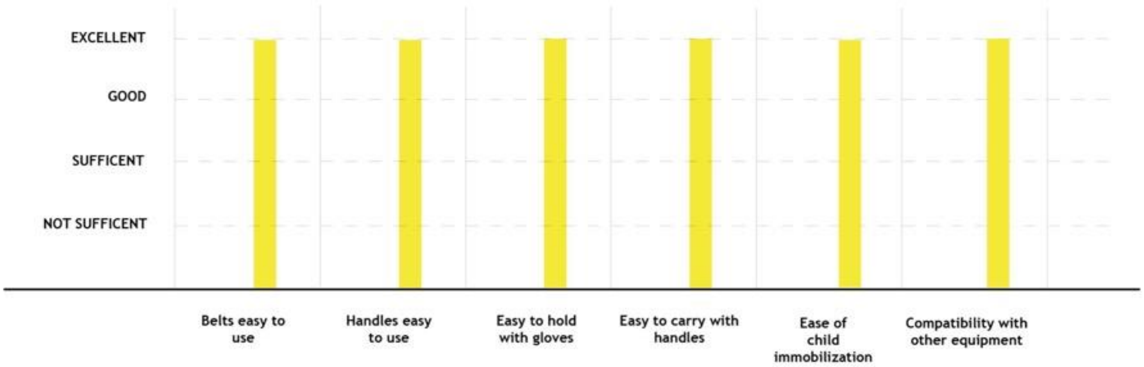


Figure 75. Summarized results of the after UC7 pilot's questionnaires and interviews.

4.3 Final results and considerations.

The final results of the UCs have highlighted that usually the FRs do not have a device designed for children's rescue, they generally used a device for adults also for the rescue of children. For this reason, the prototype was evaluated very positively by first responders.
The after-pilot questionnaire and interview, as already shown in the previous section, highlight the level of satisfaction of rescuers (from not sufficient to excellent) regarding the first aid device.
The comparative questionnaire results of the UCs are summarized in the following charts.

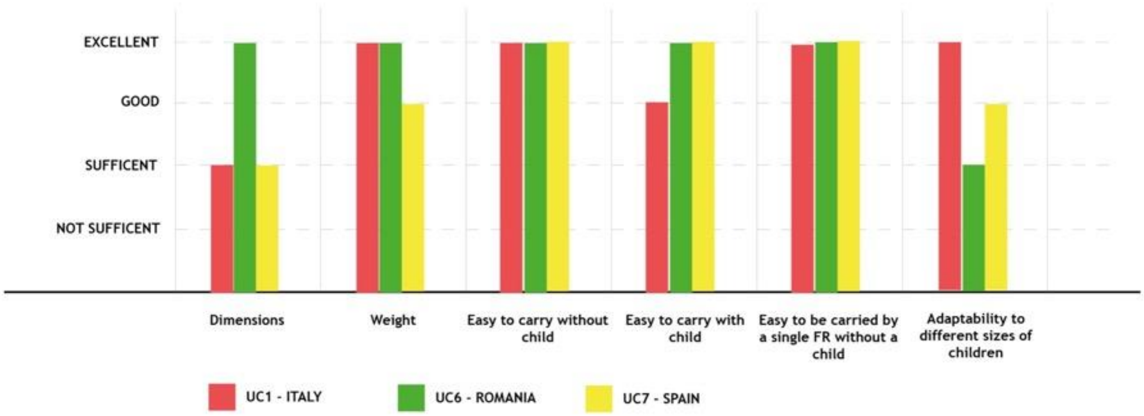


Figure 76. Comparative questionnaires' results.

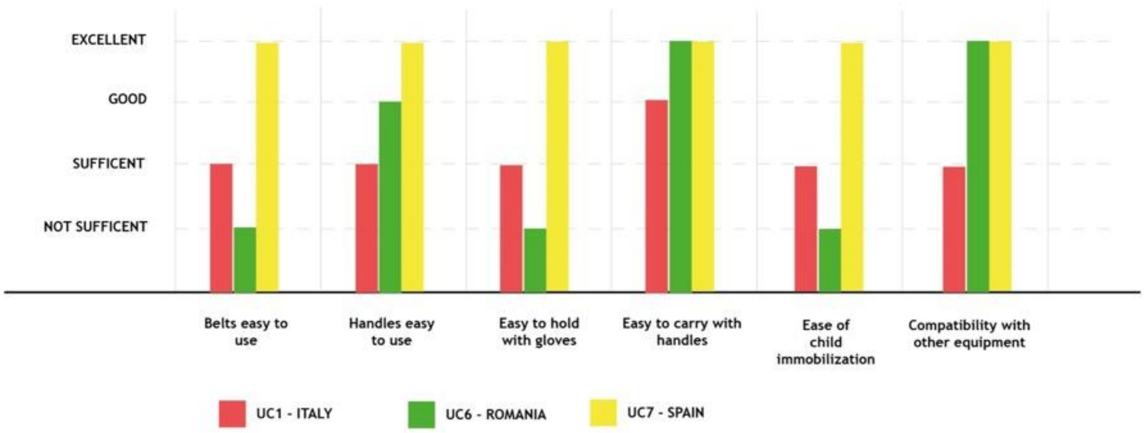


Figure 77. Comparative questionnaires' results.

The most positive characteristic of the device was the lightness, highlighted by the first responders in the after pilots' questionnaires and interviews. For this reason, the device is easy to be carried in different disaster scenarios.
During the pilot, the first responder was easily able to fast prepare the device for putting the dummy baby inside.
As described in chapter 1.2 of the present document, the first aid device can adapt to different sizes of the child. This function allowed First Responders to adapt the side holder elements and the adjustable board to the body of the dummy baby.
At the same time, the tests showed weakness regarding the dimensions. First Responders reported that the device was cumbersome, and it slowed down some of the rescue operations under the rubbles.
Other considerations, emerged from UCs tests, regarded the safety belts. Although during Use Case 6 First responders suggested to remove the 5 points belts, during Use case 7 the rescuers recommended to replace the 5 points belts to improve the safety of the child.

5 First aid device for kids Prototype.

5.1 First aid device for kids' implementation

As a consequence of the results of the tests carried out in the laboratory and in the UCs described above, the team decided to make some modifications and improvements to the first aid device for kids' design.
In the final prototype, the UNIFI team decided to replace the 5-point safety belts, in order to ensure the safety of the child, keeping the new safety straps (added for UC7). In this way the baby can have greater safety, and the first responder can work optimally.

The technical drawings of the new version of the First aid device have been described in the following chapter 5.1.1" Detail and specifications".

5.1.1 Details and specifications.

According to First responders' suggestions after the UC7, the team replaced the 5-point safety belts in the device, in order to improve the safety during the transportation of the baby.

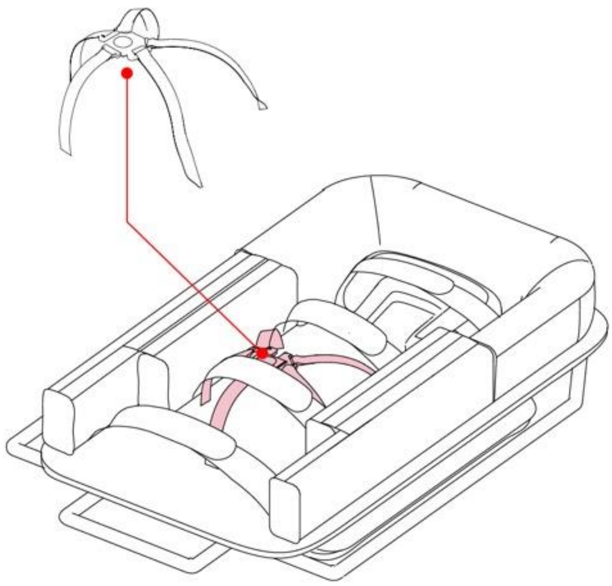


Figure 78. Positioning of 5-point safety belts on the device (Version 1 without the extension board)

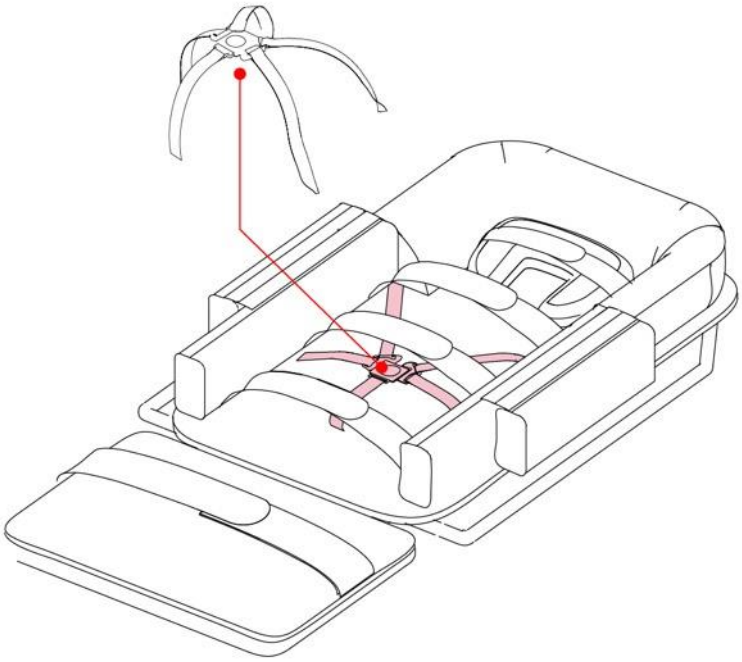


Figure 79. Positioning of 5-point safety belts on the device (Version 2, with the extension board)

5.2 Materials and sensors

The materials used for the first aid device for kids have been positively evaluated during the UCs. The materials' details are described in the paragraph 1.2 of the present document.
The details of the lining's fabric (tested for kids according to ISO 8124-6:2014) can be found in Annex III.
The health sensors were not tested during UCs as specified in paragraph "Test on the wearable sensor". The detailed description can be found in Deliverable 5.2 chapter "6.6 System architecture design", paragraph "6.6.2 Software architecture". [1]

6 Health condition monitor Device Prototype

6.1 Device implementation.

6.1.1 Details and specifications.

The Emergency Response Health Condition Monitor, ERM for short, is a wearable device for measuring the most important physiological signals. It covers the main functionality of a patient monitor in a compact and easy to wear form that does not influence the mobility of the wearer.

Figure 80. The ERM device placed on a subject.

6.2 Materials and sensors.

The ERM integrates individual sensors for each physiological signal. The concept for the integration of all the sensors to the device was based on Jordan [9]. The controller used for the integration of all the sensors and the preliminary signal processing is a Teensy 3.6 controller board. The board is additionally using a Bluetooth module for the communication of the physiological signals to the smartphone.

The physiological signals that are measured from the ERM are the following:

- Electrocardiogram (ECG)
- Photoplethysmogram (PPG)
- Blood oxygen saturation
- Body temperature
- Non-Invasive Blood Pressure (NIBP)

From the above signals the following secondary measurements are possible after processing their signals: Heart Rate from ECG, PPG and NIBP.

Additionally, the environmental temperature and relative humidity is measured.

The sensors used for each signal are the following, as already detailed described in the D5.2 paragraph 10.2 "Sensors". [1]

6.2.1 NIBP

Figure 81. NIBP Shenzhen ChangKun Technology Co., Ltd. CK-101s

Measurement method	Pulse scanning
Range	20-280mmHg
Accuracy	± 3mmHg
Type	Wrist cuff
Cuff Circumference	135-195mm
Battery Type	2 AAA batteries
Functions	Systolic & diastolic blood pressure measurement
	Heart rate extraction
	Independent channels for blood pressure & heart rate
	Automatic pressurization, decompression & air discharge

Table 2. NIBP sensor specifications

6.2.2 ECG

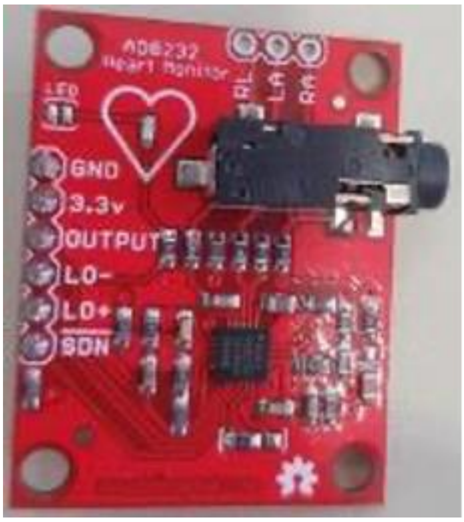


Figure 82. ECG sensor

Fully integrated single-lead ECG		
Range	20-280mmHg	
Accuracy	± 3mmHg	
Type	Wrist cuff	
Cuff Circumference	135-195mm	
Power supply voltage	2.0 V to 3.5 V	
Functions	Fully integrated single-lead ECG	
	Two or three electrode configurations	
	Internal RFI filter	
Dimensions	Weight	4 g
	Width	28 mm
	Length	35 mm

Table 3. ECG sensor specifications

6.2.3 PPG

Figure 83. PPG sensor

Sensor	MAX30102	
Purpose	Pulse rate and oximeter	
Function	Sensor and signal processor	
LED	IR LED	880 nm
	Red LED	660 nm
Photodetector	Resolution	14 bit
Communication	I2C	
Power	Circuit operating voltage	1.8- 3.3V
Dimensions	Weight	4 g
	Width	15 mm
	Length	20 mm

Table 4. PPG sensor specifications

6.2.4 Body temperature

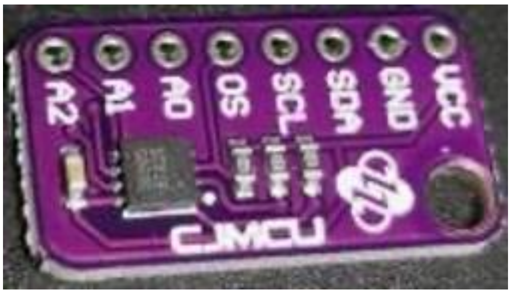


Figure 84. Body temperature sensor

Sensor	MAX30205	
Purpose	Body temperature sensor	
Function	Sensor and signal processor	
Resolution	16 bit	
Accuracy	0.1°C	
Communication	I2C	
Power	Circuit operating voltage	2.7- 3.3V
Certification	ASTM E1112	
Dimensions	Weight	4 g
	Width	14 mm
	Length	18 mm

Table 5. Body temperature sensors specifications

6.3 Integration of the components.

The above components are integrated in a compact and ergonomic shell that is attached on the wrist of the wearer. Below are two photographs of the shell of the device.

Figure 85. ERM device shell

An ear clip with a PPG sensor and an electrode is used on the left earlobe (Figure 86)

Figure 86. Ear clip with a PPG sensor.

A smartphone is placed on the ERM device with a smartphone holder. The smartphone is used for three purposes:

- As a display for the device
- As the internet communication module
- As GNSS sensor

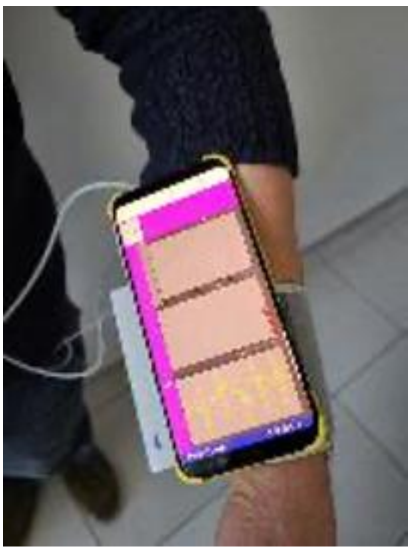


Figure 87. Smartphone attached on the ERM

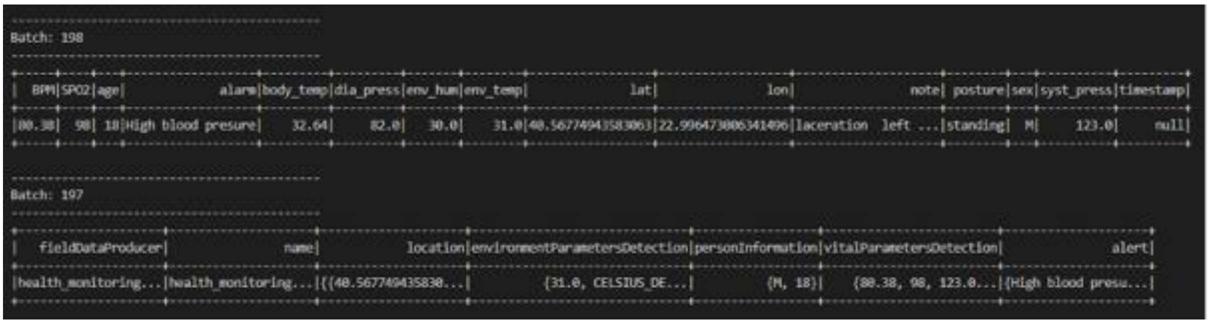
Figure 88. Smartphone display

6.4 Integration with the SnR Platform.

The communication of the signals to the SnR Platform is achieved through an MQTT server.
The signals are stored in a json format as presented below:

{"time": "15:15:15", "lat": "40.567764400503805", "lon": "22.996749734264927", "env_temp": 30.1, "env_hum": 51.0, "body_temp": 36.0, "syst_press": 120.0, "dia_press": 80.0, "BPM": "70.", "SPO2": "96.", "posture": "standing", "alarm": "High blood presure", "note": "laceration left lower arm", "sex": "M", "age": "18"}

This json format is transmitted in the message payload of an MQTT message through the internet and received from the SnR platform as presented in the figure below.



Batch: 198

BPM	SPO2	age	alarm	body_temp	dia_press	env_hum	env_temp	lat	lon	note	posture	sex	syst_press	timestamp
80.38	98	18	High blood presure	32.64	82.0	30.0	31.0	40.56774943583063	22.996473006341496	laceration left ...	standing	M	123.0	null

Batch: 197

fieldDataProducer	name	location	environmentParametersDetection	personInformation	vitalParametersDetection	alert
health_monitoring...	health_monitoring...	{(40.567749435830...	{31.0, CELSIUS_DE...	{M, 18}	{80.38, 98, 123.0...	{High blood presu...

Figure 89. Signals received from the SnR platform

7 Health condition monitor device validation

7.1 Validation tests in the lab

Validation tests took place in the premises of CERTH-HIT.
The validation tests were performed with the use of a medical grade patient monitor. The Contec CMS8000 patient monitor was used for this purpose.

Figure 90. Contec CMS8000 Patient Monitor

The validation was based only on observation of the measured signals (heart rate, temperature, oxygen saturation, and NIBP) and not direct comparison of the ECG and PPG waveforms.

7.2 Validation tests on the field

7.2.1 UC2

Due to COVID-19 infection the ERM device was not tested in UC2 field tests, instead a focus group took place at the premises of CERTH-HIT. The functionality of the device was presented to the Hellenic Rescue Team during a focus group. The discussions focused on the Key Performance Indicators of the device but also on the integration of the device in the rescue protocol. A summary of the discussions and the outcomes will be included in the Deliverable 8.11 (M35).

7.2.2 UC4

The ERM device was also tested in the field during UC4. The function and communication of the device to the MQTT server were evaluated. The device functioned properly but the following problems were detected.

- The Bluetooth connection of the ERM with the smartphone was difficult when there were many other Bluetooth devices around.
- The ear-clip with the PPG sensor was broken.

7.3 UC tests and results.

The Key Performance Indicators that took place during the UC2 and UC4 tests were the following:

1	Detection of all the physiological signals	√
2	Sensors are easy to fix on patients without moving the patient.	√
3	Bio sensor data is transmitted wirelessly.	√
4	Visualization of data on several devices (smart phone, tablet, laptop)	√
5	Alert function in case of critical data acoustically.	√
6	Position of the sensor is transmitted wirelessly.	√
7	ECG can be measured.	√
8	Oxygen saturation can be measured	√
9	Blood pressure can be measured	√
10	Heart rate can be measured	√
11	Temperature can be measured	√
12	Time of alert appears on the display of the rescue person.	X
13	Time of alert appears on display of headquarter.	X
14	Monitoring of sensors in real time available.	√
15	Device can be used for minimum 120 min	√
16	Multiple devices can be used simultaneously	NA

Table 6. Key Performance Indicators

The most KPI were successfully implemented apart from 12 and 13 which were not. The 16th KPI "Multiple devices can be used simultaneously" had no technical restriction to function however there were not more devices available to demonstrate the functionality.

7.4 Final results and considerations.

The ERM was tested in the laboratory, in the field and in a focus group. Specifically, the following improvements were found to be required for the functional and non-functional requirements:
Functional:

- A better integration of the sensors on the ear-clip in order to be easier to place.
- A change in the position of the body sensor on the chest in order to better monitor the core body temperature
- The simplification of the ECG system from three electrodes to two electrodes since only one ECG lead is monitored.
- Non-functional:
- Replacement of the Bluetooth connection or the ERM to the smartphone with a USB connection
- Powering of the ERM controller with the smartphone USB connection.

8 Conclusions and future possible developments.

The task 5.2 of the Search and Rescue project represented a concrete and tangible example of how the collaboration between different disciplines could solve a big challenge in the best possible way. In particular, the close collaboration among design and engineering and the end users allowed to design complex and strategic products for improving the FRs' performance during the rescue activity, which took into consideration the specific users' needs and behaviours during the operations, and the characteristics of the scenario.

Moreover, the involvement of the end-users in the design processes lead to collect several interesting suggestions for future possible improvements and new projects. The smart protective uniform could be highly improved and personalized according to the different scenarios' needs. For example, according to the suggestions given by PROECO, the smart uniform could be modified and improved in order to become also a CBRN protective certified suit.

In relation to the "under the rubble scenario", it would also be interesting to develop a new one-piece uniform as suggested by the FRs after the UC1 and UC5, which can also be implemented with the smart underwear.

Regarding the first aid device for kids, it is relevant to the introduction of a new typology of devices specially designed for kids in rescue operations. It represents a first innovation regarding rescue devices. Their customization and specialization for different kinds of victims could allow a faster and safer rescue, lightening the effort of the FRs.

Moreover, jointly with the expertise of ESDP, the possibility to design a similar product to be used for the rescue of the K9 has been opened.

Regarding the ERM, it was found useful from the Hellenic Rescue Team, the compact size, fast placement and low cost of the device can help to monitor from a distance the health condition of the rescued person while in the area of the rescue operations, however the integration of the device in the rescue protocols must be further established.

Future development could regard the design of new kinds of rescue devices victim-centred.

Furthermore, also following the objectives of the 2030 European agenda, it would be desirable to be able to develop and regulate even new products for rescue activity using both sustainable and high performing materials.

Annex I: References

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Annex II: Questionnaire from UCs

Search & Rescue

Evaluation questionnaire for EMS - UNIFORM

Thank you in advance for completing the following questionnaire!
Please feel free to comment on any question or leave notes regarding anything you want to give as an input for the evaluation of the tools/technologies you have been using in today's scenario. Once you have completed this questionnaire, please hand it back to a member of the evaluation team.

General Questions:

T25S01 What was your role in the scenario? (e.g. paramedic, firefighter, commander…)	
T25S02 What were your tasks in the scenario?	
T25S03 Age: **T25S04** Gender: ☐ Female ☐ Male ☐ Diverse	**T25S05** Please state your experience in your field: How many years of practical experience in your field of expertise do you have?

How satisfied were you as a user with the following characteristics of the **Smart Textile Uniform**? (1 – Not satisfied at all; 5 – Very satisfied)

		1	2	3	4	5
T25Q01	Aesthetics, colour and visibility.	☐	☐	☐	☐	☐
T25Q02	Position of sensors under the outfit.	☐	☐	☐	☐	☐
T25Q03	Connection between sleeves and gloves.	☐	☐	☐	☐	☐
T25Q04	Immediate comfort.	☐	☐	☐	☐	☐
T25G01	Long-term comfort (minimum of 4 hours).	☐	☐	☐	☐	☐
T25Q05	Comfort in progress under rubble.	☐	☐	☐	☐	☐
T25Q06	Comfort when working on your knees.	☐	☐	☐	☐	☐
T25Q07	Friction in the outfit.	☐	☐	☐	☐	☐
T25Q08	Weight of the uniform.	☐	☐	☐	☐	☐
T25U06	Compatibility with other PPE. (Personal Protective Equipment)	☐	☐	☐	☐	☐

How strongly do you agree with the following statements about the **Smart Textile Uniform?** (1 – Do not agree at all; 5 – Strongly agree)

		1	2	3	4	5
T25U01	The uniform is suitable for Urban Search and Rescue operations. (Suitability)	☐	☐	☐	☐	☐
T25U03	The uniform is easy to wear. (Understandability)	☐	☐	☐	☐	☐
T25U04	I could easily understand how to use all functions of the uniform and put it on. (Learnability)	☐	☐	☐	☐	☐
T25U05	I could easily put on the uniform in 5 minutes. (time)	☐	☐	☐	☐	☐

1

JOAFG Grant Agreement No. 882897

Room for comments, suggestions, other feedback
for the **Smart Textile Uniform**:

How satisfied were you as a user with the following characteristics of the **Wearable Strain Sensors?** (1 Not satisfied at all – 5 Very satisfied)

		1	2	3	4	5
T29G01	Adjustability of sensors due to gender and size.	☐	☐	☐	☐	☐
T29G02	The sensors did not disturb the wearing comfort of the uniform.	☐	☐	☐	☐	☐
T29G05	Speed of communication of the device with your Android App.	☐	☐	☐	☐	☐
T29U04	Weight of the sensors.	☐	☐	☐	☐	☐
T29U05	Flexibility of the sensors.	☐	☐	☐	☐	☐
T29U06	Integration of the sensors in the uniform.	☐	☐	☐	☐	☐
T29U07	Improved safety for the first responder through integration with the COncORDE.	☐	☐	☐	☐	☐

Room for comments, suggestions, other feedback for the **Wearable Strain Sensors**:

How satisfied were you as a user with the following characteristics of the **Wearable ECG/EMG?** (1 Not satisfied at all – 5 Very satisfied)

		1	2	3	4	5
T23G03	Adjustability of sensors due to gender and size.	☐	☐	☐	☐	☐
T23G04	The sensors did not disturb the wearing comfort of the uniform.	☐	☐	☐	☐	☐

T23G05	Speed of communication of the device with your Android App.	☐	☐	☐	☐	☐
T23U01	Flexibility of the sensors.	☐	☐	☐	☐	☐
T23U03	Weight of the sensors.	☐	☐	☐	☐	☐
T23U04	Integration of the sensors in the uniform.	☐	☐	☐	☐	☐
T23U05	Improved safety for the first responder through integration with the COncORDE.	☐	☐	☐	☐	☐

Room for comments, suggestions, other feedback for the **Wearable ECG/EMG**:

Evaluation questionnaire for RESCUE SYSTEM FOR CHILDREN

Search & Rescue

Thank you in advance for completing the following questionnaire!
Please feel free to comment on any question or leave notes regarding anything you want to give as an input for the evaluation of the tools/technologies you have been using in today's scenario. Once you have completed this questionnaire, please hand it back to a member of the evaluation team.

General Questions:

T24S01 What was your role in the scenario? (e.g. paramedic, firefighter, commander…)	
T24S02 What were your tasks in the scenario?	
T24S03 Age: **T24S04** Gender: ☐ Female ☐ Male ☐ Diverse	**T24S05:** Please state your experience in your field: How many years of practical experience in your field of expertise do you have?

How strongly do you agree with the following statements about the **Rescue System for Children?** (1 – Strongly disagree; 5 – Strongly agree)

		1	2	3	4	5
T24G01	The device is quickly usable by one person.	☐	☐	☐	☐	☐
T24G02	The device is easy to decontaminate and/or clean.	☐	☐	☐	☐	☐
T24G03	I believe the interaction with the child is possible.	☐	☐	☐	☐	☐
T24G04	The device is adaptable to different weights and heights of a child.	☐	☐	☐	☐	☐
T24G05	The device is light and not bulky.	☐	☐	☐	☐	☐
T24G06	The device is shockproof (fall from 50cm high – without child).	☐	☐	☐	☐	☐
T24U01	The device ensures a correct spinal immobilization of the child.	☐	☐	☐	☐	☐
T24U03	It is easy to place the child on the device.	☐	☐	☐	☐	☐
T24U04	It is easy to fasten the belts for the correct and safe placement of the child.	☐	☐	☐	☐	☐
T24U05	It is easy to adjust the device according to the child's size.	☐	☐	☐	☐	☐
T24U06	The device is suitable for carrying an injured child in urban search and rescue operations. (suitability)	☐	☐	☐	☐	☐
T24U08	The device is easy to use. (understandability)	☐	☐	☐	☐	☐
T24U09	The rescuer can easily understand how to properly use the device. (learnability)	☐	☐	☐	☐	☐
T24U10	The device is compatible with other pre-existent equipment. (co-existence)	☐	☐	☐	☐	☐

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How satisfied were you as a user with the following characteristics of the **Rescue System for Children**? (1 – Not satisfied at all; 5 – Very satisfied)

		1	2	3	4	5
T24Q01	Dimension of the device in relation to the child.	☐	☐	☐	☐	☐
T24Q02	Carrying the device without a child inside.	☐	☐	☐	☐	☐
T24Q03	Carrying the device with child inside.	☐	☐	☐	☐	☐
T24Q04	Adequate positioning of the handles.	☐	☐	☐	☐	☐

Room for comments, suggestions, other feedback:

Annex III: Materials' technical charts

11/03/2021

ΔTechs

Ref. 8627

JACKAL

ProtectiveWear

PARAMETER	METHOD	VALUE		UNITS	TOLERANCE
Weave	UNE 40.161	RipStop			
Composition	UNE-EN ISO 1833-1:20	Meta-aramid 55% Lenzing ™ FR 38% Para - Aramid 5% Antistatic Fiber 2%			+/- 3%
Weight	UNE 40.339	220		g/m²	+/- 5%
Total width	UNE-EN 1773	160		cm	+/- 1
Usable width	UNE-EN 1773	158		cm	+/- 1
		WARP	WEFT		
Tensile strength	UNE-EN ISO 13934-1	800	600	N	
Tear strength	UNE-EN ISO 13937-2	50	50	N	
Pilling	UNE-EN ISO 12945-2	4			
Abrasion	UNE-EN ISO 12947-2	50.000 @ 12 kPa		cycles	
Dimensional stability	UNE-EN ISO 5077 5 x 75 °C	-3		%	

AREAS

Police and Security Services

Electric power industry

Firefighters and Wildland firefighters

FINISHINGS

FC finish needed for EN 13034 garment certification. TECHSHIELD finish needed for EN 469 garment certification.

REMARKS

Available after 100 cycles of industrial wash (ISO 15797):
- ISO 11612
- ISO 11611

Available after 50 cycles of industrial wash (ISO 15797):
- ISO 15384

(*) Result obtained in combination with any of the following articles: TECHSALEXANDRA 150 (ref 8435) or TECHSALEXANDRA K200 (ref 28337)

STANDARDS	LEVEL
UNE-EN ISO 11612:2018	A1 A2 B1 C1 F1
UNE-EN ISO 11611:2018	Class 1
UNE-EN 1149-5:2018	PASS
UNE-EN 13034:2005+A1:2009	Type 6
UNE-EN 469:2006	Outershell
ISO 15384:2018	PASS
UNE-EN 16689:2017	PASS
UNE-EN 61482-1-1:2010	ATPV = 10,9 cal/cm²
IEC 61482-2:2018	APC = 1 APC = 2 (*)
AS/NZS 4399:2017	50+
AS/NZS 4824:2006	PASS

In case of industrial laundry, make sure to perform trials to addapt washing and drying conditions to each product.

SANTANDERINA GROUP

ΔTechs

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PRINTED: 11/03/2021

IISG

TEST REPORT: 18.48508a **dated 03 October 2018**

Cadmium content	
Method:	EN 1122:2001 (Method B)
Instrument:	Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES)

Identification Parts	Cd
Plasticized textile seat	<0,001

Legend: The results are expressed in % (percentage weight).
The symbol < followed by a number indicates that the concentration of the cadmium is less than the detection limit expressed by that number.
Cd = cadmium

Requirements: No more than 0.01% (100 mg/kg)

Reference: Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 23.1 (Cadmium and its compounds)

Conclusion: The results found **COMPLY** with the requirements above reported.

IISG

TEST REPORT: 18.48508a **dated 03 October 2018**

Tin content	
Method:	CPSC-CH-E1002-08.1 (Modified)
Instrument:	Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES)

Identification Parts	Sn
Plasticized textile seat	<0,01

Legend: The results are expressed in % (percentage weight).
The symbol < followed by a number indicates that the concentration of the Tin is less than the detection limit expressed by that number.
Sn = tin

Requirements: No more than 0.1% (1000 mg/kg)

Reference: Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 20 (Organostannic compounds)

Conclusion: The results found **COMPLY** with the above requirements.

IISG

TEST REPORT: 18.48508a **dated 03 October 2018**

Determination of chlorinated paraffins	
Method:	ISO 18219:2015
Instrument:	Gas chromatograph with MS detector (GC/ECNI-MS)

Identification Parts	Short chain (SCCPs) C10-C13
Plasticized textile seat	<50

Legend: The results expressed are in mg/kg.
The symbol < followed by a number indicates that the concentration of the element is less than the limit of quantification (LOQ)

Requirements: 1500mg/kg (0,15%)

Reference: Short-chain chlorinated paraffins - POP Regulation n. 850/2004

Conclusion: The results found **COMPLY** with the above requirements.

IISG

TEST REPORT: 18.48508a **dated 03 October 2018**

Mercury Content	
Method:	CPSC-CH-E1002-08.1 (Modified)
Instrument:	Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES)

Identification Parts	Hg
Plasticized textile seat	<0,001

Legend: The results are expressed in % (percent weight).
The symbol < followed by a number indicates that the concentration of the element is less than the detection limit expressed by that number.

Hg: Mercury

Requirements: No more than 0.01% (100 mg/kg)

Reference: Regulation (EC) n. 1907/2006 (REACH), Annex XVII, Point 62 (Mercury compounds)

Conclusion: The results found **COMPLY** with the above requirements.

IISG

TEST REPORT: 18.48508a **dated 03 October 2018**

Evaluation of polycyclic aromatic hydrocarbon (CAT II)	
Method:	AfPS GS 2014:01 PAK
Instrument:	Gascromatograph with Mass Detector

Identification Parts	Compound	Results
Plasticized textile seat	Benzo(a)pyrene	<0,2
	Benzo(e)pyrene	<0,2
	Benzo(a)anthracene	<0,2
	Chrysene	<0,2
	Benzo(b)fluoranthene	<0,2
	Benzo(j)fluoranthene	<0,2
	Benzo(k)fluoranthene	<0,2
	Dibenzo(a,h)anthracene	<0,2
	Naphthalene	<0,2
	Acenaphthylene	<0,2
	Acenaphtene	<0,2
	Fluorene	<0,2
	Phenanthrene	<0,2
	Anthracene	<0,2
	Fluoranthene	<0,2
	Pyrene	<0,2
	Indeno(1,2,3-cd)pyrene	<0,2
	Benzo(g,h,i)perylene	<0,2
	Sum of 18 PAH	<0,2
	Acenaphthylene, Acenaphtene, Fluorene, Phenanthrene, Pyrene, Anthracene, Fluoranthene	<0,2

Legend: The results are expressed in mg/kg.
The symbol < followed by a number indicates that the concentration of the analyte is less than the detection limit expressed by that number.
Details of determined compounds: see list of PAHs indicated in AfPS GS 2014:01 PAK method.

Requirements: Benzo(a)pyrene, Benzo(e)pyrene, Benzo(a)anthracene, Benzo(b)fluoranthene, Benzo(j)fluoranthene, Benzo(k) fluoranthene, Chrysene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene, Indeno(1,2,3-cd)pyrene: 0,2 mg/kg
Sum of Acenaphthylene, Acenaphtene, Fluorene, Phenanthrene, Pyrene, Anthracene, Fluoranthene: 5 mg/kg
Naphthalene: 2 mg/kg
Sum of 18 PAH: 5 mg/kg

Reference: Aromatic Polyciclic Hydrocarbons (PAH) - AfPS GS 2014:01 PAK - Category 2 - Materials not covered in cat. 1, with foreseeable contact to skin longer than 30 seconds (long-term skin contact) or repeated short-term skin contact

Conclusion: The results found **COMPLY** with the above requirements.

IISG

TEST REPORT: 18.48508a **dated 03 October 2018**

Content of Certain Polycyclic Aromatic Hydrocarbon (PAH)	
Method:	AfPS GS 2014:01 PAK
Instrument:	Gas Chromatograph with Mass Selective Detector (GC-MS)

Identification Parts	Compound	Results
Plasticized textile seat	Benzo(a)pyrene	<0,2
	Benzo(e)pyrene	<0,2
	Benzo(a)anthracene	<0,2
	Chrysene	<0,2
	Benzo(b)fluoranthene	<0,2
	Benzo(j)fluoranthene	<0,2
	Benzo(k)fluoranthene	<0,2
	Dibenzo(a,h)anthracene	<0,2

Legend: The results are expressed in mg/kg.
The symbol < followed by a number indicates that the concentration of the analyte is less than the detection limit expressed by that number.

Requirements: 0,5 mg/kg for each PAH listed

Reference: Regulation (EC) n. 1907/2006 (REACH), Annex XVII, point 50.6 (Aromatic Polycyclic Hydrocarbons)

Conclusion: The results found **COMPLY** with the above requirements.