NIGHTINGALE upgrading triage components catalogue and ruggedization

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NIGHTINGALE

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HISTORY OF CHANGES

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0.8	15/09/2022	Conclusions and second draft version, refinements
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1.0	30/09/2022	Final version

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4		C4CONTROLS LTD *[TERMINATED]*	C4C *[TERMINATED]*	UK *[TERMINATED]*
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LIST OF ABBREVIATIONS

Abbreviation	Definition
AI	Artificial Intelligence
AMP	Advance Medical Post
App	Application
AR	Augmented Reality
BLE	Bluetooth Low Energy
C3&IMS	Command, Control and Coordination and Incident Management System
CCPs	Casualty collecting points
COP	Common Operational Picture
COTS	Commercial Off The Shelf
ECCs	Emergency Communications Centres
ED	Emergency Department
EMS	Emergency Medical Services
EOCs	Emergency Operation Centres
EU	European Union
EVM	Eulerian Video Magnification
FR(s)	First Responder(s)
GA	Grant Agreement
GDPR	General Data Protection Regulation
GPS	Global Positioning System
IP rating	Ingress Protection rating
LED	Light Emitting Diode
MAC	Media Access Control
MCI	Mass Casualty Incident
MCU	Micro Controller Unit
NFC	Near Field Communication
NIT-MR	Novel Integrated Toolkit for Emergency Medical Response
QR code	Quick Response code
RFID	Radio Frequency Identification
SWAPP	SoftWare mobile APPlication

UAR-SAS	Unmanned Aerial Rapid Scene Assessment System
UAR-TIS	Unmanned Aerial Remote Triage Indicator and vital parameter estimation System
UAV	Unmanned Aerial Vehicle
UID	Unique Identifier
WP	Work Package

Executive Summary

The NIGHTINGALE project aims to develop, integrate, test, deploy, demonstrate, and validate a Novel Integrated Toolkit for Emergency Medical Response (NIT-MR) comprising a multitude of tools and applications at the service of all first responders (FRs), emergency medical services and non-medical civil protection agencies, which will ensure an upgrade to Pre-hospital life support and Triage during Mass Casualty Incidents (MCIs).

The present deliverable has been prepared in the context of Task 2.1 "*Component definition/application sheet, deployment specifics and ruggedization"* of NIGHTINGALE Work Package (WP) 2 *"Upgrading Triage"*. The main objective of the deliverable is to present the output of the work in this task, i.e., a complete catalogue of all NIGHTINGALE triage components which will be incorporated into NIT-MR, along with their conceptual design, subcomponents specifications, and ruggedisation characteristics. This work forms the basis for the development and prototyping activities of all triage devices in WP2.

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Introduction

This deliverable has been prepared in the context of Task 2.1 "*Component definition/application sheet, deployment specifics and ruggedization"* of NIGHTINGALE Work Package (WP) 2 *"Upgrading Triage"*. It aims to describe all triage components that form part of the NIGHTINGALE Novel Integrated Toolkit for Emergency Medical Response (NIT-MR) and the main specifications for every solution, i.e., wearables and related applications, smartphones, drone equipment, thermographic scanning system. The overall conceptual design and main functionalities of every solution are presented, considering sub-components integration and interconnection, shape and enclosures (according to sizes, weights, power needs, etc.) and wear/port-ability. In addition, the current and/or foreseen main ruggedization characteristics of these components are stated and compared with the ruggedization requirements that have been defined by the end user partners in deliverable D1.8 "*User Functional and Non-Functional Requirements*". This work forms the basis for the development and prototyping activities of the triage devices in WP2.The components addressed in the deliverable along with their main functionalities are listed in Table 1.

Note: The conceptual design of the SoftWare mobile APPlication (SWAPP) developed in Task 2.4 *"Development & Prototyping of volunteers based participatory, inclusive and rapid Triage"* is presented in deliverable D3.1 "*Pre-hospitalisation enhancement and continuous triage enablers components catalogue and ruggedisation".* This has been decided in order to achieve a clearer structure in the two deliverables and facilitate the reader's understanding by presenting the SWAPP app along with all its interacting NIT-MR components; D2.1 focuses therefore on triage components deployed on the field by FRs.

Table 1. Triage components and their main functionalities

Triage Component	**Main functionalities**	**Responsible Partner(s)**
Digital Triage Tag	Wristband device to be worn by casualties. • Acts as a unique identifier for a victim • Displays the triage status of the victim • Provides integrated physiological monitoring capabilities	ICCS
Triage and Vital Signs app able to run on: • **smartphone** • **tablet** • **Augmented Reality (AR**) **glasses**	A software application to visualise, manage, temporarily store, transmit and receive data relevant to the triage operations on the field.	ICCS/UPV
Vital Signs Earplug	An additional/alternative wearable device to be worn by casualties. It measures victim vital signs during the triage and post-triage phases for monitoring their status till hospitalization.	UPV
First Responder (FR) wearable	A wristband device to be worn by FRs for offering hands-free functionalities regarding: • Digital Triage Tag initialization • Victim triage status definition • Victim tracking and tracing	ICCS

Triage Component	Main functionalities	Responsible Partner(s)
Drone components for rapid triaging: UAR-SAS, UAR-TIS	Two Unmanned Aerial Vehicles (UAVs) with the aim to: • Assist FRs in scene assessment (UAR-SAS) • Assist FRs in prehospital triage (UAR-TIS) Ground Control Station (GCS)	FOI
Thermographic scanning system	Thermal camera mounted on specialised ruggedised smartphone to assist FRs in physiological parameter estimation	LDO

The deliverable is informed by the following deliverables:

- D1.6 Scenarios and Use Cases
- D1.8 User functional and non-functional requirements
- D1.10 Toolkit’s Specs and Architecture

The rest of the document is structured as follows: **Section 1** presents the conceptual design, main functionalities and specifications of all triage components, and is organised into subsections following the structure of Table 1. **Section 2** focuses on ruggedisation aspects and presents the ruggedisation specifications of Commercial-Off-The-Shelf (COTS) components as well as ruggedisation plans for the hardware prototypes being developed within NIGHTINGALE.

1 NIGHTINGALE triage devices conceptual design and catalogue

1.1 Introduction and state-of-the-art

The conceptual design of the NIGHTINGALE triage devices has been performed considering the end user requirements defined in deliverable D1.8 “*User Functional and Non-functional Requirements*”, the NIGHTINGALE scenarios and use cases presented in deliverable D1.6 “*Scenarios and Use Cases*”, as well as the relevant ethical and legal framework defined in WP1, WP7 and WP8. An additional key concept for the overall triage system design presented below has been the provision of alternative/complementary options for supporting casualty triage and physiological parameters monitoring given the wide range of conditions that can be encountered on an MCI operational scene.

MCI triaging systems commonly use paper tags for categorizing injured persons. Some examples of commercially available systems using electronic triage tags are Triage-Plus [1] (a software platform which aims at enhancing MCI operations through the use of triage tags with embedded Radio Frequency Identification-RFID chips and a mobile app where the user can manually add data or get triage-related instructions), RescueWave [2] (a software platform accompanied by digital triage “cards” manually recording and transmitting information about a casualty’s triage category and location), and Tag & Trace by Prometech [3] (based on slap wrap tags and RFID technology, developed in the context of the EU-project Respond-A). These systems provide digital tagging and location solutions but do not integrate vitals sensors. Some characteristic examples of research efforts on enhancing and supporting the triage process in MCIs include [4]-[10]. These efforts have mainly focused on one or a few of the following items: electronic tagging of casualties, automatic detection and/or visualisation of triage category based on a combination of manually inserted user input data and measured vital signs, recording information on injuries and treatment/medication administered, real-time monitoring of physiological parameters and corresponding alerts, casualty tracking, transmitting casualty-specific or aggregated information to mobile devices and/or backend systems, offering text or video guidance to the FR during the triage process. The triage devices of NIGHTINGALE along with the rest of the components of the NIT_MR toolkit will provide a comprehensive solution for addressing these capability gaps as a whole, including multiple vitals monitoring, and providing enhanced triage features as described in the following paragraphs.

In relation to the use of Unmanned Aerial Vehicles (UAVs) in triage, studies have indicated that the quality of tele-triage with drones may be comparable to traditional triage. In a study by Jain et al. [11], drones were used to send live imagery from an accident scene to a remote site for victim status assessment by personnel not on the site. No significant difference was found concerning triage accuracy and overall evacuation time compared to traditional modus. A plethora of approaches for automated stand-off estimation of vital parameters using different sensor techniques (visual cameras, thermal cameras, radars, etc) have been suggested and commercialized. For example, see [12] for a review on contactless estimation of respiratory rate. However, the vast majority of approaches target controlled environments, such as hospital or home settings and NIGHTINGALE will explore how such techniques can be leveraged for MCIs in challenging, uncontrolled environments.

Finally, some efforts to assess vital signs, such as heart rate and respiratory rate, without contact, using a webcam and even a smartphone can be found in the literature [13]. The NIGHTINGALE thermographic scanning system will focus on the recently proposed Eurelean Video Magnification (EVM) method [14].

In the following paragraphs these NIGHTINGALE solutions are described in more detail.

1.2 Digital Triage Tag with integrated vital signs sensors

The Digital Triage Tag constitutes one of the technological solutions of NIGHTINGALE for upgrading triage. It is a wearable device that will be placed by the FR on the victim's wrist and will be used as a unique identifier for victims. It will indicate the triage status of the victim and will also have integrated vital signs capabilities to monitor several health-related parameters. The device will be able to act as a master device, associated to secondary devices: the Vital Signs Earplug (section **Error! Reference source not found.**) and other digital triage tags (e.g., for victim family members). Such associations will be supported by the Triage and Vital Signs App (section 1.5).

Figure 1. Digital Triage Tag. Early prototype v0.1
(Does not yet include all submodules).

1.2.1 Unique victim identification capabilities

The Digital Triage Tag device (see Figure 1 for an early prototype) will include a passive Near Field Communication (NFC) Tag for fast and reliable Bluetooth pairing with NFC reader devices (the FR wearable and/or the mobile device running the Triage and Vital Signs App). The NFC tag module can be used for uniquely identifying, tracing (through the NFC Unique Identifier -UID- and the tag's MAC address) and tracking (through FR wearable/mobile device GPS) victims. This NFC unique identification mechanism presupposes an action by the FR: approaching the FR wearable or the mobile device to the Digital Triage Tag.

The Digital Triage Tag together with the Triage and Vital Signs App will also provide a complementary method for unique identification, based on the capability to attach on the Digital Triage Tag and scan using the app a QR (Quick Response) code corresponding to a unique identifier. The Unique ID can be any alphanumeric sequence defined according to the users' needs, such as, the Système d'Information Numérique Standardisé - SINUS [15] used in France.

1.2.2 Victim triage capabilities

The Digital Triage Tag will provide:

- The functionality for the FR to define the victim's triage category during the first triage phase (first encounter with the casualty).
- A LED indicating the triage status of the victim with a LED colour code according to the corresponding end user requirements

It should be noted that after the first encounter of the FR with the victim, it will be impossible for the victim to change the triage colour manually on the Digital Triage Tag. Such a change will be possible only by using the FR equipment (FR wearable and Triage and Vital Signs App).

1.2.3 Integrated vital signs capabilities

The following sensors will be integrated in the Digital Triage Tag to cover the end user requirements for monitoring victim vitals:

- **Photoplethysmography (PPG)** sensor: MAX30101 [16], a high-sensitivity sensor for wearable health, for continuously monitoring Heart Rate (HR), Heart Rate Variability (HRV), Respiratory Rate (RR) and oxygen saturation (SpO_2).
- **Skin temperature** sensor: MAX30205 [17], a clinical grade temperature sensor for thermometer applications
- **Blood pressure sensor**: BGT60TR13C XENSIV™ 60GHz radar sensor [18].

In addition, an **Inertial Measurement Unit** (3D Accelerometer and 3D Gyroscope) module (ST LSM6DSL) (I2C interface) for motion tracking and gesture detection will be integrated [19]. This module is important in terms of investigation of possible motion artifacts that can impact vitals measurements [20].

The device will be able to send processed data of casualty vitals over Bluetooth to the mobile device of the FR (smartphone/tablet/AR glasses) that will feature the Triage and Vital Sings App (section 1.5). In case the FR is not within the Bluetooth range, the device will be capable to store values for a time period up to 30 minutes. Subsequently, the oldest data will be overwritten by newer vital measurements.

At the core of the device lies the **nRF52840 System-on-Chip (SoC)** [21], which meets the challenges of sophisticated applications that need protocol concurrency and a rich set of peripherals and features. It offers generous memory availability for both Flash and RAM, which are prerequisites for demanding applications.

The nRF52840 is fully multiprotocol capable with full protocol concurrency. It has protocol support for Bluetooth LE, Bluetooth mesh, Thread, Zigbee, 802.15.4, ANT and 2.4 GHz proprietary stacks. It therefore gives us the capability to configure it for BLE communications, and more specifically it has the capability of setting the transmission power of the wristband to -20dBm, providing us with two key advantages. First, the extremely low transmission power resulting in a very low communication range, which makes it very hard for other devices to eavesdrop on sensitive biomedical data. Second, it results on very low power consumption, which, together with its sophisticated on-chip adaptive power management system, significantly increase the wristband battery lifetime.

The nRF52840 is built around the **32-bit ARM® Cortex™-M4 CPU** with floating point unit running at 64 MHz. This powerful processing core is supported by a 1MB Flash with cache. The **ARM TrustZone® CryptoCell cryptographic** unit is included on-chip and brings an extensive range of cryptographic options that execute highly efficiently independent of the CPU. This feature can provide a strong cyber security foundation to wireless communications, together with the extremely short-range links of BLE.

nRF52840 has **numerous digital peripherals and interfaces** such as high-speed SPI and QSPI for interfacing to external flash and displays, PDM and I2S for digital microphones and audio, and a full speed USB device for data transfer and power supply for battery recharging.

All functionalities of the system are supported by a **rechargeable flat battery**, which has a capacity (400mAh), and maximum current dissipation that can support all sensing, processing and communication functionalities.

Device size and weight estimation: 4,5 x 4,5 x 1,5 cm, ~80gr.

1.3 First Responder Wearable

This wearable device (see Figure 2 for a very early prototype) can be used alternatively/ complementarily to the mobile device featuring the Triage and Vital Signs App for offering to FRs hands-free functionalities for:

- Digital Triage tag initialisation
- Victim triage status definition
- Victim tracking and tracing

The First Responder Wearable also has the nRF52840 System-on-Chip as its core. The device will be equipped with:

- an NFC Reader, for quick and effortless device pairing with the Digital Triage Tag
- illuminated buttons for quick and easy triaging
- a GPS module (hornet-org1510 [22]), either acting as a primary GPS device or supplementary to FR’s mobile device GPS
- a small dot matrix screen for displaying information such as patient’s vitals or notifications coming from operation command centre.

Battery specifications for the first FR wearable prototype are identical with the one of Digital Triage Tag.

The First Responder Wearable will be always connected with the Triage and Vital Signs app through Bluetooth and its main use is to act as an intermediate in a pairing procedure between the casualty’s Digital Triage Tag and the Vital Signs App.

This will simplify the operation performed by the FR as much as possible, by requiring only a wrist movement and touch through NFC. With this quick movement, the Digital Triage Tag will establish a Bluetooth connection with the Triage and Vital Signs App.

Device size and weight estimation: 4,5 x 4,5 x 1,5 cm, ~80gr.

Figure 2. FR wearable. Early prototype V0.1.
The final prototype dimensions are estimated to be 4,5 x 4,5 x 1,5 cm

1.4 Vital Signs Earplug

The NIGHTINGALE project environment will provide data of interest for the follow-up of patients in the triage phase, such as the analysis of their vital signs and temperature. The extraction and real-time monitoring of this information is relevant during the triage phase of the project. It will be developed solely and exclusively within the framework of NIGHTINGALE.

All this information will be provided by a wearable sensor called "Cosinuss Two" [23] (Figure 3). The sensor has been chosen not only because it is an easy-to-use device, but also because it is easy to fit in the ear due to its light weight. The sensor head, which is located in the external ear canal, does not affect hearing.

Figure 3. Vital Signs Earplug

The sensor measures the following elements:

- Core Body Temperature
- Heart Rate
- Blood Oxygen Saturation
- Respiration Rate

Derived from the prior, it can calculate:

- Interbeat R-R interval

This device accurately measures heart rate, heart rate variability, core body temperature and arterial blood oxygen saturation continuously and accurately from inside the ear canal. The heart rate values are calculated by intelligent algorithms and transmitted wirelessly. The 2.4 GHz band or Bluetooth will be used for transmission.

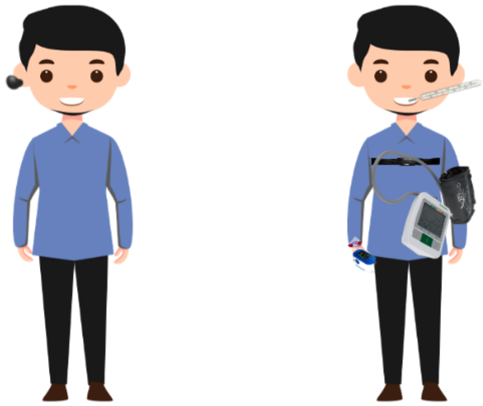

Figure 4. Vital Signs Earplug VS classic state of art

Thus, one could relate the comparison between the conventional state of the art, in which a casualty would have to wear a blood pressure monitor, a thermometer, a band and a watch to measure the pulsations and a pulse oximeter (Figure 4). In contrast, with the solution provided, a way is found to be able to incorporate all the devices into one in a non-invasive, mobile, and very low-cost way. *Cosinuss* is a very innovative and non-intrusive way to monitor a patient in the initial phase and for continuous monitoring of the patient status after the first triage. With all this information, it will be possible to perform automatic analysis for detecting quick changes in the patient status, perform studies and send alerts, if necessary, when something out of the ordinary is happening (Figure 5).

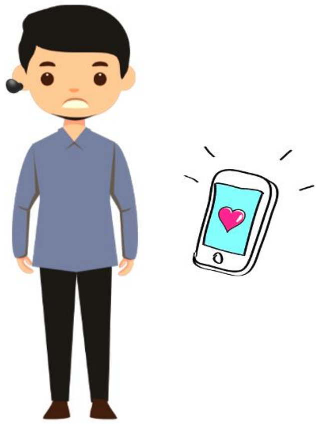

Figure 5. Vital Signs Earplug alert

Therefore, the solution will allow:

- Eliminating unnecessary hospitalizations.
- Minimize the risk of contact infections for healthcare professionals and patients
- Improve continuous monitoring and risk assessment for patients

- Enabling timely intervention

1.5 AR Glasses

One innovative triage concept and solution that the NIT-MR toolkit will comprise is the Augmented Reality (AR) Glasses which will facilitate a hands-free operation experience. This is considered important as it will allow the FR to focus primarily on their operational duties rather than spending time to manually update/handle information on their equipment. Through the AR glasses various types of information will be displayed directly in the FR's field of view (see section 1.5). The AR Glasses will therefore serve as a Head Up Display (HUD).

The AR glasses that have been selected after analysing end user requirements (deliverable D1.8) are the **Vuzix Blade 2 AR Glasses** (Figure 6) [24]. Table 2 provides the technical specifications of the device.

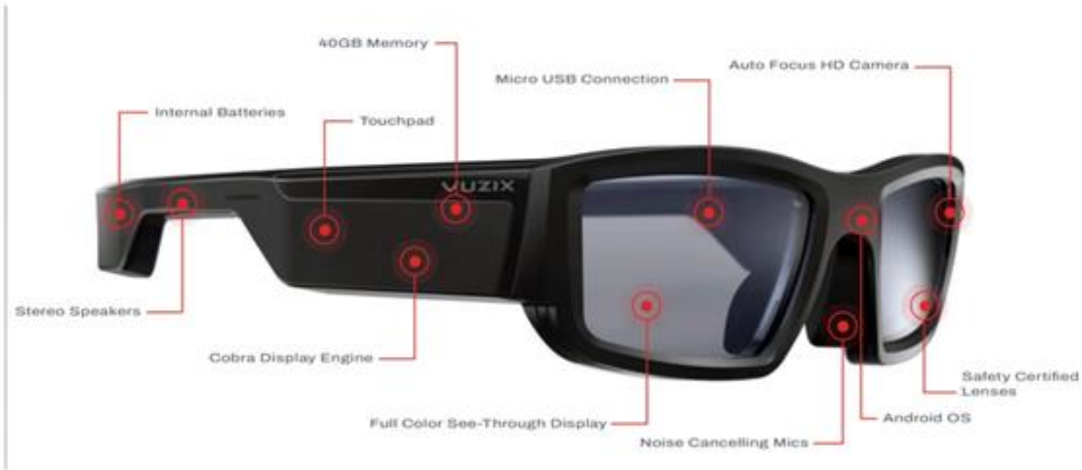

Figure 6. ***AR Glasses:*** *Vuzix Blade 2.*
Source: https://www.vuzix.eu/products/vuzix-blade-2-smart-glasses

Table 2. Vuzix Blade 2 technical specifications.
Source: https://www.vuzix.eu/products/vuzix-blade-2-smart-glasses

Optics	Display resolution: 480x480 color display Display type: Wave Guide Projection Technology Aspect: 1:1 ratio Field of View (diagonal): 20 degrees, equivalent to a 6 in. mobile device held at arm's length (17 inches) Brightness: > 2000 nits 24-bit color Right eye display Prescription inserts available All lenses UV protected
Certifications	ANSI Z87.1 safety certification Full UV protection lenses
Controls	Multilingual voice control capabilities 2-axis touchpad with multi-finger support Companion app for Android & iOS device

System	Andriod 11 OS 40GB built-in memory Quad Core ARM CPU Internal LiPo rechargeable batteries
Audio	Integrated stereo in-temple speakers Dual noise-cancelling microphones
Connectivity	5.0 and 2.4GHz WiFi and Bluetooth wireless USB 2.0 Micro-B
Camera	8-megapixel camera Auto-focus Streaming video Integrated barcode scanner
Integrated Head Tracker	3-degree of freedom head tracking 3 axis gyro 3 axis accelerometer 3 axis mag/integrated compass
Environment	Operating temperature 0ºC to 35ºC Operating humidity 0% to 95% RH Storage temperature -30ºC to 70ºC Storage humidity 0% to 95% RH

1.6 Triage and Vital Signs App

This is the mobile app that will be used by the FR on the field and its main purpose is to visualize, manage, (temporarily) store and transmit the data it receives from the Digital Triage Tag and the Vital Signs Earplug placed on a victim. To achieve its purpose, the application will offer the capabilities described below.

- **Controlling the Digital Triage Tag (by declaring/modifying the victim's triage status)**
  Using this device, the FR will be able during the first assessment of the victim's status, to digitally classify the victim into one of four possible triage categories: green, yellow/orange, red, black. Each one of the aforementioned categories will light up a correspondingly coloured LED on the Digital Triage Tag (technical solutions for the dead/expectant black category are under investigation).
- **Inserting additional information about the victim** (e.g., name, age, sex, performed interventions, administered medications etc.) Through the Triage and Vital Signs App, it will be possible to collect the victim's data (whenever communication is technically possible).
- **Receiving data over Bluetooth from both the Digital Triage Tag and the Earplug Vital Signs Wearable.** The application will receive data at regular intervals via the Bluetooth protocol to manage, store and forward it.
- **Providing the FR with navigation instructions to the selected victim's location**
- **Visualising predefined instructions for the FR through user-friendly interfaces**
- **Visualising information on victim vitals and other victim data on the FR wearable/ smartphone/tablet/AR glasses.**
  It will be possible to immediately visualize in real time a casualty's biometric data sent from the Digital Triage Tag so that the FR can make real-time assessments of the victim's condition. This includes being ableto detect abrupt changes in physiological parameters which might imply a change in triage category or necessitate further actions

- **Storing the sensor and other data**
  Wristband devices such as the Digital Triage Tag have limitations on the amount of data they can store internally. The application will be able to retrieve data that may be cached in the wristband's memory as well as real-time information and store it in the internal storage of the device where it runs (smartphone, AR glasses), where the storage capabilities are much larger and easier to be handled. A list of stored data will be available if the FR wishes to check a victim's information progress over time through the mobile app.
- **Forwarding data over the available network to the interoperable data lake of NIT-MR** to be subsequently received/processed by other NIT-MR components.
- **Receiving and visualising alerts generated by other NIT-MR components**
- **Supporting full duplex multimedia capabilities (e.g., streaming video and audio, receiving audio)**
  Since ruggedisation is not relevant for a software application, ruggedisation will be addressed in terms of the devices that will be used to run the application, i.e., the FR smartphone, the FR rugged tablet and the FR AR glasses (see section 2).

Finally, the NIGHTINGALE triage devices will be supported also by a web-application (**Triage and Vital Signs Dashboard**) which will collect and visualise information about the victims in a user friendly and GIS-based user interface. Apart from aggregated data and statistics, the dashboard will be able to provide detailed information about each casualty.

Figure 7 provides a schematic overview of the triage devices described above and their main interconnections.

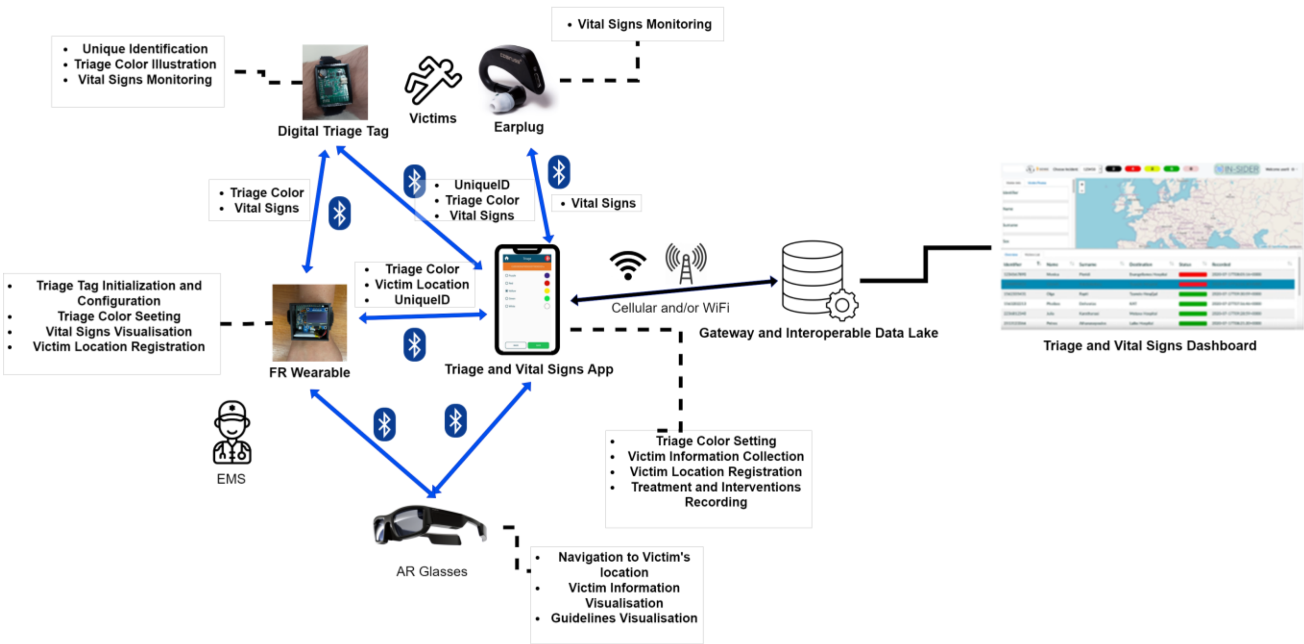

Figure 7. NIGHTINGALE triage devices: main characteristics and interconnections

1.7 Drone components for rapid triaging

In the early stages of the MCI, rapid and accurate scene assessment is of utmost importance. Scene assessment allows the FRs to obtain a Common Operational Picture (COP) containing images of the disaster site, an estimate of the number casualties, and their positions. When the FRs have a COP they may start with the operations planning, individual assessment of each casualty, evacuations, and resource distribution. In an MCI, time is of the essence and technology enabling a fast scene and individual casualty assessment is of great value. NIGHITINGALE aims at combining advancements concerning drones and sensor-based vital parameters estimation, and exploring how increased levels of drone autonomy and novel data analysis techniques can further improve MCI triage.

The Unmanned Aerial Vehicle (UAV) capability of the NIGHTINGALE project will allow for rapid scene and casualty assessment, in the first stage; quickly canvasing an area, detecting and locating victims, counting and positioning them. In the second stage, a UAV can reach hard to get to casualties and aid in the assessment of their status. Examples of potential functionalities to be explored and evaluated are:

- Exploration of the affected area
- Artificial Intelligence (AI)-based detection of injured persons based on body position, movement, sound data, temperature, image-based extracted features such as blood or bones
- Body position analysis
- Autonomous navigation around possible injured people
- Detection of catastrophic bleeding
- Respiration Rate detection
- Pulse detection
- Consciousness detection
- Detection of walking individuals

The drone components consist of three main parts:

- UAR-SAS (Unmanned Aerial Rapid Scene Assessment System)
- UAR-TIS (Unmanned Aerial Remote Triage Indicator and vital parameter estimation System)
- GCS (Ground Control Station)

The UAS-SAS and the design of UAR-TIS can be seen in Figure 8. UAR-SAS is built on a commercial UAV and is intended for the collection of image data to obtain an overview assessment (e.g., object detection and localization). UAR-TIS is a custom-built UAV with possibilities to explore non-standard sensor and onboard computing capabilities. The GCS has two main purposes; first to collect data from UAR-SAS and UAS-TIS and perform AI-computations that are not possible to perform on onboard devices. Second, it serves as a relay and control station for the UAVs. An example is a scenario with potentially injured persons. In this scenario UAR-TIS is sent to the positions for detailed data collection based on previous detection and localization data collected by UAR-SAS. UAR-TIS receives coordinates to fly to a particular location or an area to be searched. The output is collected data (imagery, sound), analysis results, e.g., estimated vitals parameters and alerts, and UAV position and status.

For deployment, the user brings the UAV-components to just outside of the affected area, prepares them (connects batteries, initiates start-up sequence via computer, etc), inputs region of operation and launches the drone components. The concept can consist of one, two or several drones. The typical scenario is one providing overview imagery of the area where people are automatically detected and positioned, and the other flying to those locations and providing detailed data for the respective persons/victims.

The status of the system is currently at TRL 3-5. AI-based data analysis functions for vitals parameters estimation exist, but proven only in other, less complex contexts. Drone concept exists but needs to be modified to encompass additional sensors and autonomous navigation and data collection behaviour around detected persons/victims.

Figure 8. The drone components UAR-SAS (photograph) and UAR-TIS (design view).
UAR-SAS is built on a commercial UAV and is intended for the collection of image data to obtain an overview assessment (e.g. object detection and localization). UAR-TIS is a custom-built UAV for exploration of non-standard sensor and onboard computing capabilities. The UAR-SAS and UAR-TIS weights are respectively < 500 g and 2.0 kg (design weight). Both drones are each designed to fit in a carry-on sized luggage (UAR-TIS in folded position).

The UAR-TIS contains/is equipped with:

- An NVIDIA Jetson Xavier NX 8 Gb Core - for navigation and data processing.
- Batteries - for power.
- A WiFi card - for communications.
- Sonars - for the UAV navigation and obstacle avoidance.
- Visual camera - Working in the visual spectrum producing RGB Images.
- Thermal camera (Teledyne FLIR BOSON 640 x 512 4.3mm 95° HFoV) with a LWIR Thermal Camera Core - for casualty detection in low light conditions and occlusion conditions.
- Gimbal for stabilizing the visual and thermal cameras.
- A Speaker and microphone - for communication.
- Enveloping cages around propellers – for safe drone operation.

1.8 Thermographic scanning system

The Thermography Scanning solution can be used in the prehospital setting, where there are no X-ray facilities and a reliable, inexpensive, and transportable diagnostic test is needed. The goal is to extract physiological information, such as body temperature, heart and respiratory rates, using machine learning algorithms run on a smartphone device that enhances Eulerian Video Magnification (EVM). As the Eulerian Video Magnification method has been proposed recently, its implementation has not yet been sufficiently tested on smartphones. Therefore, the performance of the EVM method for colour amplification will be optimized to run on an Android device at a high speed.

The proposed solution is based on the Cat S62 Pro device (Figure 9). The Cat S62 Pro is powered by the highest resolution FLIR lepton available today, the FLIR Lepton 3.5 professional-grade sensor, which brings a huge 4x increase in the number of thermal pixels. Combined with FLIR's VividIR

technology, the Cat S62 Pro delivers enhanced image quality, sharper image, and higher thermal resolution.
Thermal imagery can be blended with the visual image from the S62 Pro's 12MP dual pixel Sony camera or used with FLIR's variable intensity MSX (Multi-Spectral Dynamic Imaging) technology that overlays linear detail from the scene onto the thermal image, providing greater context to help understand thermal images.

VividIR improves image quality and thermal sensitivity; the CAT S62 Pro Thermal Imaging Smartphone is highly sensitive to slight temperature differences enabling it to deliver a detailed thermal map with a modern, rugged design. The Cat S62 Pro is protected by a high-grade aluminium body, and toughened scratch-resistant Corning® Gorilla® Glass 6.

Figure 9. Cat S62 Pro

The Cat S62 Pro is an advanced tool, providing instant access to professional-grade thermal imaging in a rugged smartphone – always on, always ready. Providing even more thermal detail to help locate and diagnose the damp, the draught, the leak, the hotspot, the electrical short, the blockage or the elevated temperature.

The following schema lists the main characteristics of Cat S62 Pro:

Table 3. Cat S62 Pro specifications

BODY	Dimensions	158.5 x 76.7 x 11.9 mm (6.24 x 3.02 x 0.47 in)
	Weight	248 g (8.75 oz)
	Build	Glass front (Gorilla Glass 6), plastic back, aluminum frame
	SIM	Single SIM (Nano-SIM) or Dual SIM (Nano-SIM, dual stand-by) IP68/IP69 dust/water resistant (up to 1.5m for 35 mins)

		Drop-to-concrete resistance from up to 1.8m MIL-STD-810H compliant
DISPLAY	Type	IPS LCD
	Size	5.7 inches, 83.8 cm^2 (~69.0% screen-to-body ratio)
	Resolution	1080 x 2160 pixels, 18:9 ratio (~424 ppi density)
	Protection	Corning Gorilla Glass 6
PLATFORM	OS	Android 10
	Chipset	Qualcomm SDM660 Snapdragon 660 (14 nm)
	CPU	Octa-core (4x2.2 GHz Kryo 260 Gold & 4x1.8 GHz Kryo 260 Silver)
	GPU	Adreno 512
MEMORY	Card slot	microSDXC (dedicated slot)
	Internal	128GB 6GB RAM
MAIN CAMERA	Dual	12 MP, f/1.8, (wide), 1/2.55", 1.4µm, dual pixel PDAF
		FLIR thermal camera (Lepton 3.5 module)
	Features	Thermal imaging, heat palettes, temp. spot meter, LED flash
	Video	1080p@30fps, gyro-EIS
SELFIE CAMERA	Single	8 MP
	Video	1080p@30fps
SOUND	Loudspeaker	Yes
	3.5mm jack	No
COMMS	WLAN	Wi-Fi 802.11 a/b/g/n/ac, dual-band, Wi-Fi Direct, hotspot
	Bluetooth	5.0, A2DP, LE
	GPS	Yes, with A-GPS, GLONASS, GALILEO, BDS
	NFC	Yes
	Radio	FM radio
	USB	USB Type-C 2.0, USB On-The-Go
FEATURES	Sensors	Fingerprint (rear-mounted), accelerometer, gyro, proximity, compass
BATTERY	Type	Li-Ion 4000 mAh, non-removable

2 Ruggedization characteristics of NIGHTINGALE triage devices

This section presents the ruggedization characteristics of the NIGHTINGALE triage devices. These include ruggedization characteristics of commercial components as specified in their data sheets, as well as the ruggedization plan for the prototype devices developed in NIGHTINGALE. In case of software applications, ruggedization concerns the hardware devices where the applications will be run. In addition, these characteristics will be compared with the ruggedization requirements stated by the end users for being able to use these triage devices under real conditions, as defined in Deliverable D1.8 "*User Functional and Non-Functional Requirements*".

Specifically, the end user ruggedization requirements for the triage devices are included in the following table

Table 4. User-defined ruggedization requirements for the triage devices
(See Deliverable D1.8)

Req ID	Description	Priority
NFR-8	Max temperature for correct performance: < 35°C	Must
NFR-9	Min temperature for correct performance: > -10°C	Must
NFR-10	Device environmental protection (IP37) Check table in the appendix	Must

The environmental protection requirement is based on the IP (Ingress Protection) Standard by the International Electrotechnical Commission IEC [25]. IP ratings are explained in Table 5.

Table 5. IP Ratings

Level	Solids (X)	Liquids (Y)
1	Protected against solid objects over 50mm (example: hands).	Protected against vertically falling drops of water.
2	Protected against solid objects over 12mm (example: fingers).	Protected against direct sprays of water up to 15 degrees from the vertical.
3	Protected against solid objects over 2.5mm (example: tools and wires).	Protected against direct sprays of water up to 60 degrees from the vertical.
4	Protected against solid objects over 1mm (example: small wires).	Protected against water sprayed from all directions.
5	Dust protected — limited ingress of dust permitted.	Protected against jets of water from all directions.
6	Dust-tight — no ingress of dust permitted.	Protected against powerful jets of water from all directions.
7	/	Protected against the effects of immersion in water — between 15 cm (5.9 inches) and 1 meter (3.3 feet) for up to 30 minutes.
8	/	Protected against the effects of long periods of immersion in water under pressure. Usually 1.5

		meters (4.9 feet) of immersion for up to 30 minutes.

2.1 Triage devices ruggedization characteristics

2.1.1 Digital triage tag and FR wearable

The Digital Triage Tag and the FR wearable are multifunctional equipment with a very important role to monitor victims' vital signs and support the triaging process. For that reason, their normal operation even in harsh usage environments is important. These two devices are prototypes being developed during the project, with a target Technology Readiness Level (TRL) of 6. The major focus is therefore placed on the functionalities that the devices will offer to the FR. Nevertheless, the targeted IP estimation is IP54, with a temperature range as follows: -20°C to 60°C. For corresponding ruggedisation tests the provisions of the international standard CEI IEC 60529 [26] will be considered.

Specifically, ICCS will implement a series of laboratory stress tests on the wearables, aiming to achieve IP54 rating: protection against dust limited ingress, protection against water splashed from all directions, and endurance to high and low temperatures. The ruggedization plan consists of the following four stress tests that are described in more detail in the corresponding subsections:

- Temperature tests
  - o Heat test
  - o Cooling test
- Dustproof test
- Waterproof test
- Drop test

The ruggedisation testing plan is described in more detail below.

Temperature test

Smart wristbands must be able to work in conditions of high and low temperature. The specifications of electronic COTS components, such as system on chips and batteries, have limited temperature range during their use. Usage out of the range may cause malfunction of components or breakdown in the worst-case scenario. Therefore, verification of heat and cooling resistance is necessary for all the electronic components to reduce the risk of failure during the missions.

Triaging and rescue operations are usually performed in temperature conditions where human first responders (FRs) can safely work. For this purpose, we assume the ambient air temperature between -10 to 30 degrees Celsius. Furthermore, the absolute temperature constrictions arise from the operation of LiPo batteries which can operate properly in temperature between -20 to 60 Celsius. Therefore, the range of temperature for the tests was specified between -20 to 60 degrees Celsius. On both tests the temperature will be monitored by placing a temperature sensor Sensirion SHGTC3 with precision of 0.1 degrees of Celsius, near the wearables.

Heat test

The purpose of this test is to verify the normal operation of the two developed wearable devices on very high temperatures. The test procedure is as follows:

1. Place the wearable in the oven while their power is on, and they are operating normally.
2. Place the temperature sensor on the oven.

3. Adjust the temperature to 30, 40, 50, 55 and 60 every 10 minutes.
4. Check functionality of the smart wristband and all its electric components (MCU, BLE communication, LEDs and vital sensors) at every temperature setting.
5. Take the device out of the oven and check the damage on the casing, the PCB and the battery visually.

Cooling test

The purpose of this test is to verify the normal operation of the two developed wearable devices on low temperatures. The test procedure is as follows:

1. Place the wearable in the freezer while their power is on, and they are operating normally.
2. Place the temperature sensor on the oven.
3. Adjust the temperature to -5, -10, -14, -18, and -20 every 10 minutes.
4. Check functionality of the smart wristband and all its electric components (MCU, BLE communication, LEDs and vital sensors) at every temperature setting.
5. Take the device out of the oven and check the damage on the casing, the PCB, and the battery visually.

Dustproof Test

There are use cases in which the environment is expected to be full of dust of small size (e.g., due to collapsed buildings or structures). Even in such situations, the smart wristbands must work with reliability. We decided that the needed specification is IP5X (protected against dust limited ingress). The following test procedure equivalent to IP5X will be followed. It should be noted that an official certification is out of the scope of the project due to time and cost limitations.

1. Place the device inside a box in multiple positions to achieve multidirectional exposure.
2. Throw talc powder to the device for 10 minutes in multiple positions.
3. Take the smart wristband out and wipe, sweep the talc powder stuck to the outer body.
4. Check functionality of the smart wristband and all its electric components (MCU, BLE communication, LEDs and vital sensors).

Waterproof test

Smart wristbands may be used in disaster sites under rain conditions. Therefore, IPX4 (protected against water splashed from all directions) is the necessary performance. The following test procedure equivalent to IPX4 will be followed. It should be noted that an official certification is out of the scope of the project due to time and cost limitations.

1. Fix the posture of the smart wristband in multiple positions to achieve multidirectional exposure.
2. Pouring water against the device with a 3mm/min water flow, for 10 mins.
3. Wipe off the water with the towel and then check functionality of the smart wristband and all its electric components (MCU, BLE communication, LEDs and vital sensors) at every temperature setting.

Drop test

It is very possible that during a mission and all the havoc that may be evident there, the victim’s or FR’s wristband will drop from their wrist. On that occasion the devices should be able to continue operating properly and be replaced on their owner’s arm. Considering a drop from a person’s hand the test will comprise the following steps:

1. Hold a powered on and operating smart wristband vertically at 1 m high.
2. Drop the wristband from 1 m high.
3. Check the mechanical damage after the drop.
4. Check the functionality and electrical damage after the drop.
5. Repeat the above steps for heights of 1.5m and 2m.

2.1.2 Vital Signs Earplug

According to the device provider [27] the IP of the Vital Signs Wearable device is (IP47). This fact makes compatible this device with the ruggedization requirements stated by the end users. On the other hand, according to the same evaluation mentioned, the Vital Signs Wearable device temperature working range is -15°C to 55°C, which is larger than the temperature working range stated by the end user.

With these figures in mind, the Vital Signs Wearable device is fully compliant with the ruggedization requirements stated by NIGHTINGALE end users and it could be used in real emergency operations for these end users.

2.1.3 Triage and Vital Signs App: Smartphone, rugged tablet, and AR glasses as triage hardware devices

The Triage and Vital Signs App is a software component. The hardware triage device in this case is the mobile device that will be handled by the FR and run/execute this App. Therefore, the ruggedization capabilities that will be stated in this section are those of the potential mobile devices capable to run/execute the Vital Signs App on field during real triage operations, i.e., a smart phone, AR glasses and/or a rugged tablet. In this section, the ruggedization capabilities of these devices will be compared with the ruggedization requirements stated by the end users.

2.1.3.1 <u>Smartphone</u>

An example of a common smartphone that could run/execute the Triage and Vital Signs App on field during a real triage operation is the iPhone 13. According to the provider information [28], this smartphone has a classification of IP68, which is clearly larger than the ruggedization requirements stated by the end users. In addition, the temperature working range of this device is -20° to 45°C, which is also wider than the temperature working range declared by the end users.

Taking these figures in mind, an iPhone 13 or a smartphone with similar ruggedization capabilities could be used as triage device running the Triage and Vital Signs App during a real emergency operation, since it accomplishes the ruggedization requirements stated by the NIGHTINGALE end users.

2.1.3.2 <u>Rugged tablet</u>

An example of rugged tablet that could run/execute the Triage and Vital Signs App on field during a real triage operation is the RT01 Rugged Android Tablet [29], which is an 8-inch display rugged and portable tablet with high performance: Android 10.0. This industrial tablet PC is fully waterproof with an IP67 and a temperature working range of -20 °C to 50 °C.

According to the information taken from its technical datasheet, this tablet has both IP classification and temperature working ranges. Those ranges are higher than the ruggedization requirements stated by the end users and therefore this device or a similar one with the same ruggedization capabilities could be also being used for triage during a real emergency operation.

2.1.3.3 AR Glasses

Within the scope of NIGHTINGALE project, our focus will be on the development of functionalities that can support a hands-free operation for enhancing triage processes in MCIs, and the investigation of what constitutes a meaningful context of use of such devices. It is therefore outside the scope of the project to offer ruggedized custom-made AR glasses. The project will use the commercially available **Vuzix Blade 2 AR Glasses** [24] which according to their specifications are operational under the following environmental conditions: Temperature: 0°C to 35°C, Humidity: 0% to 95% RH.

2.1.4 Drone components supporting Rapid Triaging

Two different drones and a ground control station will be used to provide information for first responders regarding the status and location of victims.

2.1.4.1 Unmanned Aerial Rapid Scene Assessment System (UAR-SAS)

Being a commercial and fully operational product, the ruggedness of the drone itself sits well above practical operational requirements posed in NIGHTINGALE, except for the IP classification where this drone (along with virtually all other drones) does not withstand full submersion in any liquid. One may argue that an IPX7 requirement is not highly relevant for a flying platform. If needed, the risk of being damaged by submersion, e.g., when landing on water, is better addressed by attaching a simple buoy system to the drone.

2.1.4.2 Unmanned Aerial Remote Triage Indicator and vital parameter estimation System (UAR-TIS)

The UAR-TIS system is developed and custom-built by FOI exclusively for NIGHTINGALE. When fully developed, it will be an autonomous drone capable of navigating to detected people, while avoiding obstacles, and having a safe flight mode where it seeks to always avoid flying above people on the ground.

As a novel concept, UAR-TIS will be constructed from components that are carefully selected to provide the drone with the requested capabilities, while keeping the size small and weight reasonably low. An effect of this early-stage development and necessary trade-offs is that operational requirements concerning weather-proofness cannot be explicitly addressed nor verified. Nevertheless, UAR-TIS is designed to be deployable and validated in all of the project's field trials and experiments. It should be mentioned that none of the requirements are such that cannot be accomplished in a future product stage if the concept itself is deemed promising.

2.1.4.3 Ground Control Station (GCS)

The UAR-SAS system consists of two drones one ground station that analyses incoming data, e.g., to create image mosaics, detect persons and localize them in a global coordinate system.

The ground station is foreseen to be a standard computer/laptop, and thus not intended to be exposed to adverse weather conditions, electrical shocks, or sudden impacts. Since the UAR-SAS development concerns algorithms, not physical tools, ruggedization of the ground station computer itself is not motivated at this point; algorithms could easily be moved to any computer that is rugged in itself or otherwise protected.

2.1.5 Thermographic scanning camera S62 Pro

The S62 Pro is protected by a high-grade aluminium body, and the latest toughened scratch-resistant Corning® Gorilla® Glass 6. Its robustness features are as follows:

- *Drop proof from 1.8m:* drop tested multiple times onto concrete & solid steel from up to 1.8m (6ft) to prove their rugged credentials.
- *Dust proof:* designed to exceed MIL-SPEC 810H protection against dust, as well as shock, water, vibration and extreme temperatures.
- *Waterproof to 1.5m:* IP68 & IP69 rating system proves your phone can handle not just a brief dunk in water but also complete submersion.
- *Temperature range:* -20°C to +400°C

2.2 Summary of ruggedization characteristics and comparison with requirements

As a summary of the ruggedisation data provided in section 2.1, Table 6 presents the ruggedization capabilities of all NIGHTINGALE triage devices compared with the ruggedization user requirements and stating their usability for the NIGHTINGALE exercises according to the end users.

Table 6. Comparation of triage devices ruggedization capabilities with end user ruggedization requirements

Triage device	IP classification	Temperature range	Accomplish Req.
Vital Signs Earplug	IP47	-15ºC to 55ºC	YES
Digital Triage Tag, FR Wearable	IP54 (estimated)	-20ºC to 60ºC	PARTLY^{+}
FR Smartphone (e.g., iPhone 13)	IP68	-20ºC to 45ºC	YES
FR Rugged tablet (e.g., RT01 Rugged Android Tablet)	IP67	-20°C to 50°C	YES
AR glasses	-	0ºC to 35ºC	PARTLY$^{''}$
UAR-SAS drone	IP54 (estimated)	-10ºC to 35ºC	PARTLY*
UAR-TIS drone	IP41 (estimated)	-10ºC to 35ºC	PARTLY**
Drones GCS	IP41 (estimated)	-10ºC to 35ºC	PARTLY***
S62 Pro	IP68 & IP69	-20°C to +400°C	YES

$^{+}$ TRL6 prototypes developed with a focus on functionality
$^{''}$ Commercial AR glasses offering an alternative hands-free option for running the Triage and Vital Signs App
*Commercial drone, not protected against submersion or power jets of water
**Custom-built prototype drone for proof-of-concept
***Standard computer/laptop for proof-of-concept of data analysis capabilities

Conclusions

This deliverable has presented the conceptual design, main specifications, subcomponents, as well as ruggedisation characteristics of the NIGHTINGALE triage devices developed in the context of WP2: "*Upgrading Triage*". The conceptual design of the solutions has been performed by considering the defined end user requirements as well as the NIGHTINGALE scenario and use cases. This work will constitute the basis for the development and prototyping activities of all WP2 triage components.

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