IOPES

Indoor-Outdoor Positioning for Emergency Staff

Grant Agreement No. 874391

D4.1: System architecture definition

Lead contractor: CTTC

IOPES

Document status

Call (part) identifier	UCPM-2019-PP-AG
Topic	UCPM-2019-PP-PREP-AG Preparedness in civil protection and marine pollution
Grant Agreement Number	874391
Project Acronym	IOPES
Project Title	Indoor-Outdoor Positioning for Emergency Staff
Deliverable Number	4.1
Title of the Deliverable	System architecture definition
Work Package	WP4
Type	Report
Due date	31/05/2020
Issue date	29/05/2020
Version	1.0
Lead beneficiary	CTTC
Contributors	E. Angelats, J. Navarro and M. E. Parés (CTTC), F. Giust, D. Munaretto (ATHONET), J. Salvador (CATUAV), A. Martinez (Scarabot), S.F. Hinriksson (SAReye)
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Dissemination level	Public

This project has received funding from the European Commission, Directorate-General Humanitarian Aid and Civil Protection (ECHO), under the call UCPM-2019-PP-AG.

Revision history

Version	Date	Description
1.0	*29/05/2020*	First version

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Acronyms

3G	3rd Generation (mobile telephony).
3GPP	3rd Generation Partnership Project.
4G	4th Generation (mobile telephony).
5G	5th Generation (mobile telephony).
API	Application Programming Interface.
AWS	Amazon Web Services.
BSS	Business Support System.
CSS	Cascading Style Sheet.
COTS	Commercial/Consumer off-the-shelf.
CPET	Civil Protection Emergency Team.
DSM	Digital Surface Model.
EC2	(AWS) Elastic Compute Cloud.
eNB	evolved Node B.
EPC	Evolved Packet Core.
eMBMS	evolved Multimedia Broadcast Multicast Service.
EMS	Emergency Management System.
EU	European Union.
GBAS	Ground-Based Augmentation System.
GNSS	Global Navigation Satellite System.
GPS	Global Positioning System.
HD	High Definition.
HSS	Home Subscriber Server
HTML	HyperText Markup Language.
HTTP	HyperText Transfer Protocol.
HW	Hardware.
IMS	IP Multimedia Services.
IMU	Inertial Measurement Unit.
IOPES	Indoor-Outdoor Positioning for Emergency Staff.
IP	Internet Protocol.
LTE	Long Term Evolution (data transmission).
MAVLink	Micro Air Vehicle Link.
MIMO	Multiple Input Multiple Output.
MME	Mobility Management Entity.
OGC	Open Geospatial Consortium.
O&M	Operation & Maintenance.
OSS	Operation Support System.
OTT	Over The Top.
PC	Personal Computer.
PCRF	Policy and Charging Rules Function.
PDOP	Precision Dilution of Precision.
PPK	Post-Processed Kinematic.
PTT	Push-To-Talk.
QoS	Quality of Service.
RD	Reference Document.
RDS	(Amazon's) Relational Database Service.
REST	REpresentational State Transfer (API).
RGB	Red, Green & Blue.
RGBD	Red, Green, Blue & Depth.

RPAS	Remotely Piloted Aircraft System.
RSA	Rivest, Shamir & Adleman (authors of a public key cryptographic system).
RTK	Real Time Kinematic.
RTP	Real-time Transport Protocol.
RTSP	Real Time Streaming Protocol.
SCTP	Stream Control Transmission Protocol.
SDK	Software Development Kit.SIM (card) Subscriber Identity Module (card).
SOC	System-On-Chip.
SPGW	Serving – and packet data GateWay
SR	System Requirement.
SW	Software.
TCP	Transmission Control Protocol
TETRA	TErrestrial Trunked RAdio.
UCPM	Union Civil Protection Mechanism.
UDP	User Datagram Protocol.
UE	User Equipment.
UR	User Requirement.
URL	Uniform Resource Locator.
VIO	Visual Inertial Odometry.
VLC	Video Lan Client.
VoLTE	Voice over LTE.
WCS	Web Coverage Service.
WFS	Web Feature Service.
Wi-Fi	IEEE 802.11x (a trademark).
WMS	Web Map Service.
WP	Work Package
WPA2	Wi-Fi Protected Access 2.

1. Executive summary

This document provides the IOPES' system architecture.

The high-level components integrating the IOPES system as well as the relationships – interfaces – among these components are identified and described in this deliverable.

These elements (components and interfaces) are the result of merging the initial concept of the system together with two set of requirements, those firstly envisaged by the partners of this project as well as those included in the user requirements identification process described in another IOPES deliverable, more specifically "D3.1 - User requirements report" ([RD4]).

User requirements - the wishes of end users - translate to *system* requirements - that is, the technical conditions that the aforementioned elements must fulfill in order to be able to perform their task in the way users expect it will be performed.

This document therefore presents how the user requirements mutate into system requirements and how these define the high-level building blocks (components and interfaces) making the IOPES system.

Some of these components or interfaces will be further refined in additional deliverables, as for instance, "D4.2 - Wearable device - EMS data exchange protocol" that will take care of describing precisely the protocol used to exchange information between the so-called wearable positioning device (section 5) and the Emergency Management System (EMS, see section 6).

2. Introduction

The target of the IOPES project is to provide Civil Protection & Emergency Teams (CPET) with the necessary tools to improve an already operational Emergency Management System (EMS) - developed by one of the partners of this project, more specifically SAReye).

Such improvements consists of, at least, (1) quickly producing and making available updated cartography of the area affected by a disaster (either natural or man-made), so it may be used in real-time (2) to track the positions of the members of the CPETs no matter whether they are located outdoors or indoors, (3) using a lightweight, portable positioning device carried by every CPET member, (4) guaranteeing that all data flows (voice, imagery, videos, location data) may be transmitted independently of any preexisting infrastructures thanks to the use of a portable LTE/5G easily deployable network infrastructure.

The paragraph above is just a declaration of intention of what a system like IOPES should be. Obviously, a system like that must be much more clearly defined in order to make possible its successful implementation. This is the task of this deliverable: defining the architecture of IOPES.

Here, the components making the system (either hardware or software modules or the interfaces connecting these) are described at a level making possible to understand not only the global picture but also what is expected from each of these elements. To do this, this document proceeds as follows:

The user requirements controlling how the system must behave (those collected by deliverable "D3.1 - User requirements report", [RD4]) are translated into system requirements, that is, the wishes of the end-users mutate to describe, technically, what are the conditions that the system must guarantee to make those wishes true. This mapping is described in section 3.

Afterwards, the overall picture of the system is presented in section 4. This includes a short explanation about the several components and interfaces making IOPES as well as brief description of the data flows in the system. The task of this section is helping to identify the system as a whole, making visible the building boxes (software and hardware modules) and their relationships in terms of data exchange (*aka* interfaces).

Sections 5 to 8 take then care of describing in more detail each of these components, namely indoor-outdoor positioning, the emergency management system, communications and mapping. Each section explains the main functionality / task of their respective components going then into detail about how these will be built as well as taking care of describing how the component interfaces with the remaining ones.

Finally, section 9 focuses on what are the risks that the architecture defined in this document may be exposed to, as well as on describing the mitigating actions that should be taken to face the aforementioned risks.

Note that some of the components described at the architectural level in this document will be further refined by means of specific deliverables, such as the protocol (interface) used to exchange data between the wearable positioning device and the EMS ("D4.2 - Wearable device - EMS data exchange protocol").

3. IOPES user and system requirements

This section briefly presents the set of **user** requirements collected during the initial phase of the project. For a detailed description on how these user requirements were obtained and prioritized, please refer to [RD4]. Then, a set of **system** requirements have been derived for being able to achieve the end-user needs.

All user requirements have been tagged according to the following convention:

UR<#>_<code>

Where <#> stands for a unique number for each requirement and <code> may be one of the following:

- *map*: Mapping.
- *pos*: Positioning (including in- and outdoor).
- *ems*: Emergency Management System.
- *com*: Communication.

Consequently, the following are actual examples of tags identifying some of the user requirements:

- *UR3_map*: Requisite number 3, related to mapping.
- *UR11_pos*: This time the requisite is related to positioning;11 is its unique number.
- *UR22_ems*: The number of the requisite is 22, and it is related to the EMS.
- *UR29_com*: Requisite number 29, involving communications.

Table 1 below list the whole set of user requirements grouped by the aforementioned categories (i.e., mapping, positioning, EMS and communications). Note that the numbering of the requirements is not sequential and that some gaps exist – that is, some numbers are not used. This is so because some of the user requirements initially assumed by the project team were discarded by the users themselves.

Note that these requirements are mapped to system requirements, that is, requirements that reinterpret the user ones stating how the system must implement these. See Table 2 for details on how user requirements have been translated to system requirements.

UR#_code	Requirement description	Priority low/medium/high
UR1_map	Device shall be operable in daylight and at night in all weather	High
UR2_map	Need to have imagery and live video from the RPAS during the whole emergency (day and night period)	Medium
UR3_map	Provide information from victims, affected people, goods, and/or geo-localisation	High
UR4_map	The system shall provide detailed imagery of the damaged structure	High
UR5_map	The user shall be able to detect flood events, damaged areas, traffic jams and road obstructions using information provided by the RPAS	Medium
UR6_map	Capacity to be operational with few hours of daylight per day	High
UR7_map	The user in the field shall be able to feed the system with geo-localised pictures and/or reports from the affected area	High
UR18_map	Capability to load critical asset/infrastructure maps	High
UR19_map	Need to have high resolution cartography produced very quickly following a disaster	High
UR30_map	Capability to load and visualise updated cartography	High
UR8_pos	Autonomy of in- and outdoor positioning	High
UR9_pos	The sensor should be as small as possible, and not disturb the normal motion of the firefighter	High
UR10_pos	Lightweight, portable, wearable and user-friendly geo-localisation device	High
UR11_pos	Working temperature between -10°C to +100°C	High
UR12_pos	Geo-localisation of emergency teams during operation	High*
UR13_pos	Provide degree of confidence about indoor/outdoor geo-localisation	Medium
UR14_pos	Capacity to provide reliable indoor/outdoor geo-localisation for at least 30 minutes	High
UR15_ems	Real-time data and information fusion to support incident commander decision-making	High
UR16_ems	Visualisation and management of simultaneously tracked emergency members	High
UR20_ems	History (memory) of team members' geo-localisations	High
UR21_ems	Storage of conversations and geo-localisations for post-mortem analysis	High
UR22_ems	Collaborative platform allowing multiple users to use it at the same time	High
UR23_ems	Share situational awareness to provide advance notice of resource needs of multiple stakeholders	High
UR24_com	Capability to visualise data from various sources to have situational awareness	High
UR26_com	The user shall be able to rapidly set up communications means in disaster areas	High

UR27_com	Need to have reliable communications independent of civil infrastructures	High
UR29_com	Capability to send data and voice, overcoming limitations of TETRA systems regarding data rate transmission	High
UR31_com	Need to have multiple voice and video to have conversations over the communications network	Medium
UR32_com	Need to have low latency communications	High
UR34_com	Users from at least the EU countries shall be able to use the system	High
UR35_com	Capacity to determine what information should be shared or seen by other actors/agencies	High

Table 1: List of user requirements

As stated above, the list of system requirements may be found in Table 2, which also introduces the mapping between each system requirements and one or more related user requirements. Note that UR11_pos (Working temperature between -10°C to +100°C) has been discarded because it is not feasible from a technical point of view.

All system requirements have been tagged according to the following convention:

SR<#>

Where <#> stands for a unique number for each requirement.

SR#	Requirement description	Related UR(s)
SR1	The RPAS shall provide geo-localized high-resolution imagery and live video from RGB and Thermal cameras.	UR1_map UR2_map UR6_map
SR2	The RPAS shall provide geo-localized RGB and thermal imagery during day and thermal imagery during night in all weather conditions providing that the safe flight conditions are warranted.	UR1_map UR2_map UR6_map
SR3	A first responder shall be able to provide information about victims, affected people, goods, and/or geo-localisation using a set of applications (such as video and voice push-to talk).	UR3_map UR7_map
SR4	The EMS shall allow an end-user to manually annotate/mark interesting objects in the orthophotos derived from RPAS imagery.	UR3_map UR7_map
SR5	The mapping component shall be able to generate high resolution RGB, and thermal orthophotos as well as Digital Surface Models with few centimeters Ground Sampling Distance using RPAS imagery and Commercial/Consumer Of The Shelf (COTS) photogrammetric software .	UR4_map UR5_map UR19_map
SR6	The mapping component shall be able to generate maps covering at least 500 hectares per day.	UR19_map
SR7	The system shall be able to produce and store high resolution RGB and thermal orthophotos and Digital Surface Models in formats appropriate for its handling and display by the EMS.	UR18_map UR30_map
SR8	The EMS shall be able to retrieve and display high resolution orthophotos and asset / infrastructure maps stored in WMS / WFS servers.	UR18_map UR30_map
SR9	The IOPES positioning device shall work with minimum interaction with the user.	UR8_pos UR12_pos
SR10	The IOPES positioning device shall be able to provide seamless indoor and outdoor positioning without the use of pre-deployed positioning technology using only the data provided by the onboard sensors.	UR8_pos UR12_pos
SR11	The batteries of the IOPES wearable positioning device will be replaceable.	UR8_pos UR12_pos
SR12	The IOPES positioning device shall be able to transmit data.	UR8_pos UR12_pos
SR13	When interacting with the EMS, the IOPES positioning device will use the data exchange protocols set by such EMS.	UR8_pos UR12_pos
SR14	The IOPES positioning device shall be able to provide coordinates in a global reference frame.	UR8_pos UR12_pos
SR15	The dimensions and weight of the IOPES positioning devices will be as low as possible to improve its wearability.	UR9_pos UR10_pos
SR16	The IOPES positioning device shall not disturb the normal motion of emergency team members.	UR9_pos UR10_pos
SR17	The IOPES positioning device shall be easy to use and user-friendly.	UR9_pos UR10_pos
SR18	The IOPES positioning device shall provide the standard deviation of the indoor/outdoor geo-localization coordinates as an indicator of degree of confidence.	UR13_pos
SR19	The EMS shall display a circle around positions indicating their degree of certainty. The radius of such circles will be derived from the standard deviation of the positions.	UR13_pos

SR20	The IOPES device shall be able to provide outdoor geo-localisation coordinates with an accuracy better than 2 m for the planimetric coordinates and better than 5 m for the height component.	UR14_pos
SR21	The IOPES device shall be able to provide indoor geo-localisation coordinates with an accuracy better than 10 m for the planimetric coordinates and better than 5 m for the height component, for at least 30 minutes.	UR14_pos
SR22	The EMS shall be able to display simultaneously updated orthophotos, tracked locations of emergency team members, RPAS images or any other relevant information.	UR15_ems UR16_ems
SR23	The EMS shall be able to display and manage the data provided by no less than 20 IOPES positioning devices during at least 7 days.	UR15_ems UR16_ems
SR24	The EMS shall be able to keep and display 10 minutes of historical of team members positions.	UR20 ems
SR25	The EMS shall be able to store at least 90000 positions per day for post-mortem analysis.	UR21 ems
SR26	The communication component shall be able to store 2400 minutes of conversations post-mortem analysis.	UR21 ems
SR27	The EMS shall be able to share information between different organizations.	UR22_ems UR23_ems UR35_com
SR28	The EMS shall allow simultaneous multiple users.	UR22_ems UR23_ems UR35_com
SR29	The portable and lightweight communication component shall be rapidly set up.	UR26_com UR27_com
SR30	The communication component shall be independent of existing communication infrastructures.	UR27_com
SR31	The communication component shall allow to send of data and voice from at least 20 users (devices).	UR29_com UR31_com
SR32	The communication component shall allow simultaneous video push-to-talk calls from 5 users.	UR29_com UR31_com
SR33	The communication latency shall be better than 100 milliseconds.	UR32_com
SR34	The communication component shall be used in different EU countries.	UR34_com

Table 2: List of system requirements and related user requirements

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4. IOPES architecture

4.1. System components

The IOPES system consists of four components – see Figure 1 below. These are:

- Indoor outdoor positioning,
- an Emergency Management System,
- communications and
- RPAS-based fast mapping.

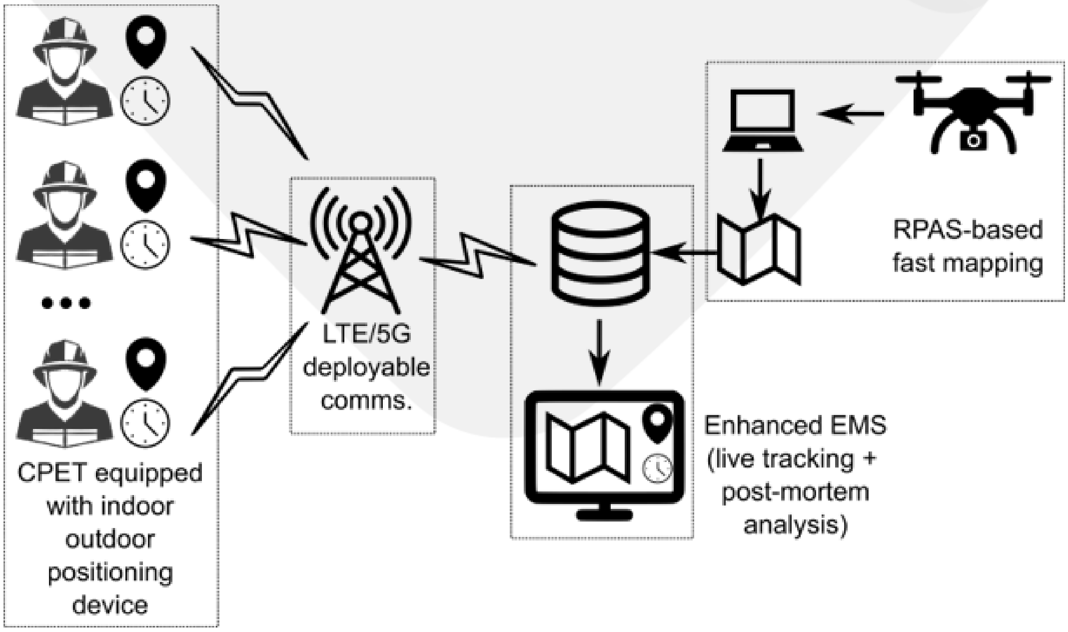


Figure 1: IOPES components.

Indoor / outdoor positioning. Positioning is probably the most innovative part of the system, since IOPES targets at providing the location of the emergency teams working on the field at all times, no matter whether these are located either outdoors or indoors. Outdoor positioning is a problem that, nowadays, is mostly solved by using GNSS receivers – these are found everywhere, being the most notable example the smartphone, even those with the lowest price tag. GNSS positioning relies only on the several satellite constellations deployed specifically for such purpose, such as GPS, GLONASS or GALILEO – among others – and needs no other infrastructures to be available worldwide.

It would not be fair to say that its counterpart, indoor positioning, is not possible nowadays. Several solutions exist that provide positioning in indoor environments, but most of these rely on preinstalled infrastructure (such as beacons with known coordinates), which, usually, are installed only on very specific places – e.g. as factories or laboratories – and therefore are not available everywhere. Moreover, and even in the case that such kind of infrastructure was a common implement in every building, it would not be possible to rely on it the case of a disaster because, for instance, power lines might have been disrupted.

The IOPES' positioning component relies therefore on a *wearable portable device*. Such device will be carried by the members of the emergency team and will be able to compute and deliver their locations either indoor or outdoor; to perform this task, this device will integrate a GNSS receiver, a visual inertial odometry device (including a stereo fisheye camera and the required algorithms to provide positioning), a communications interface and a lightweight, low power consumption system-on-chip integrating all these components.

The task of the visual inertial odometry (VIO) component will be to provide coordinates when the device is either indoors or outdoors; the GNSS will provide not only coordinates when the device is outdoors but also the necessary corrections to the drift that visual systems undergo when working over some period. The system-on-chip will decide, how to fuse both positioning solutions (VIO and GNSS) thanks to the logic implemented in the algorithms specifically developed for this project and will take care of sending the location of the device using the communications interface.

Emergency Management System. All the information related to the management of a disaster must be timely collected, stored, and presented in the most effective way to the people in charge of the coordination of the emergency. Emergency Management Systems are the tool used to accomplish this task, becoming, therefore, *the cornerstone of the decision-making process during the management of emergencies.* An EMS may take care of so disparate aspects as information on available resources, how these are being used, contingency plans for several kinds of emergencies, simulations on the effect of the disaster or – among others – the tracking of the personnel involved in field tasks.

Emergency Management Systems are not a novelty; these have been routinely used for some time by several organizations for some time now; IOPES is no exception and will rely on the one developed by SAReye to store and present the information to the emergency managers. In this case, however, this EMS will be improved to be able to collect and display the information about the positions of the emergency teams (provided by the positioning component introduced above) in real time.

The EMS is a central component in IOPES' architecture; it will retrieve and display the cartography generated by the fast mapping component (described later on this same section), and will also take care of retrieving and displaying the positions of the teams (as well as many other management tasks already implemented in this component).

Communications. Communications are crucial in the management of emergencies. These make it possible the exchange of information between all the members of the team, no matter what their tasks are.

Currently, emergency teams have at hand several ways to communicate; among these, some have been specifically designed to be used in disaster management – such as the TETRA system – while others belong to the general public market (as, for instance, 4G mobile communications). However, TETRA has some important limitations concerning bandwidth (such as the transmission of images or videos) and the set of services it offers, especially when guaranteeing Quality of Service (QoS) is a must; with regards to the common, public mobile 4G and 5G services, it is not convenient to rely on preexisting infrastructures since these may have been severely damaged or even completely destroyed as a consequence of the disaster. Another disadvantage is that, for using the public network, special agreements with operators to prioritize your traffic are needed.

The IOPES system includes its own private mobile network for enabling broadband communications using the latest mobile technology available. It is a *portable* system providing *in situ, independent* LTE / 5G mobile communications to all the components making IOPES. This includes not only the possibility to share voice but also data (positions, images, videos) among the devices connected to the network, guaranteeing the QoS and the efficient use of applications. This private mobile network is compact and transportable, while it offers backhaul links to wired, LTE and satellite communications, thus making possible to connect the members of the team not only among themselves but also offering the possibility to link with public network services around the world if necessary, even in the case that the public 4G networks have been destroyed or cut-off.

Setting up this portable component is a matter of few minutes and, its lowest size version, it is implemented by a rucksack that may be carried by one of the members of the team first arriving to the site; heavier, more powerful versions are also available, offering large-coverage communications to bigger teams.

RPAS-based fast mapping. Positioning the members of the emergency team means identifying where on the field these members are. Arriving to the place where the emergency took place implies being able to get there, maybe crossing bridges, using some not so well-known paths or having to avoid roads that are too narrow to allow big vehicles to pass, for instance. Knowing precisely what the environment is where a disaster takes place is thus of paramount importance when managing it. An earthquake may have destroyed one or more bridges, impeding the use of the road that one would normally take to get there; or new obstacles may have appeared due to the disaster.

These are the reasons why it is so important to have *updated* cartography of the area when an emergency occurs. And here, updated does not mean the latest available version, since the terrain may have changed after (and due to) the disaster. Updated, on the contrary, means knowing how the terrain is exactly when the emergency must be handled. Obviously, this means that having updated cartography – in the sense just defined – implies producing maps of the area just after the emergency happened and, desirably, as fast as possible to avoid stopping or delaying the work of the emergency teams.

Currently, RPAS are used routinely to perform such tasks. The generation of orthophotos is a well-known process that, when flying at low altitude – the ones flown by RPAS – may deliver pixels as small as 1 cm over the terrain, thus providing very detailed maps. Moreover, covering 200 hectares per hour is also common nowadays. Thus, it is not only possible to satisfy the goal of having detailed information about the scenario of the disaster, but it is also possible to do it in very short times. The RPAS-based cartography is made accessible to the EMS via WFS / WMS, thus providing vital information about the environment of the disaster.

An additional role assumed by the RPAS is the continuous monitoring of the disaster area by taking new images or providing a live video streaming. This role may be taken either by extra RPAS teams or by the one responsible for the fast mapping task once it is finished, to have an extra point of view explaining how the situation evolves.

4.2. Components' interfaces

This section provides a high-level overview of all interfaces. A more detailed explanation of the interfaces among the IOPES components can be found in sections 5.3, 6.3, 7.3 and 8.3.

From the perspective of the Positioning component:

- Interfacing Positioning device (client) with the EMS (server) via REST http-based Application Programming Interface (API).

From the perspective of the Mapping component:

- Interfacing RPAS telemetry and images (client) with EMS (server) via REST http-based API.[1]
- Interfacing of mapping products generated from RPAS imagery (server) with EMS (client) via a WMS service.

From the perspective of the EMS:

- Interfacing of the EMS (server) with the Positioning component, RPAS' (client) telemetry and images
- Interfacing of EMS (client) with mapping products via a WMS service (server).

Figure 2 depicts the whole set of interfaces above.

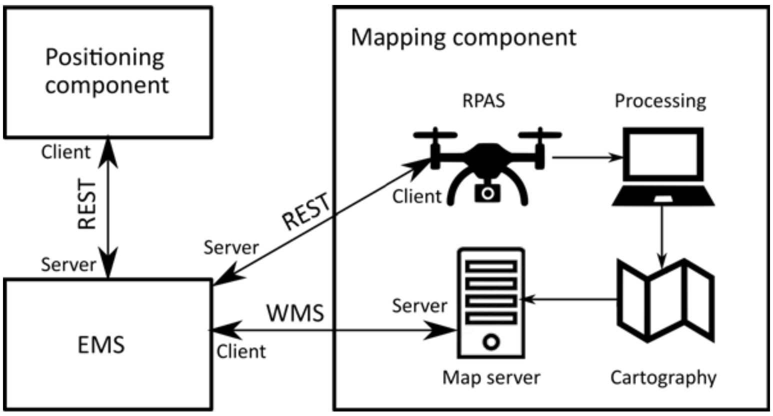


Figure 2: Application level IOPES' interfaces.

All these interfaces rely on a private mobile network solution (rucksack). This network provides the following physical and network interfaces:

[1] This is not exactly true. The RPAS connects to a ground control station using the protocols and mechanisms provided by the manufacturer, so these two components are the ones actually exchanging information as a first step. Then, it is the ground control station who connects to the EMS to send the appropriate data, thus working as a rely. However, and for the sake of clarity, this has been simplified, showing a direct connection between the RPAS and the EMS. This is so in Figure 2 too.

- IP-based backhaul link to the EMS-control room, via e.g., ethernet, LTE, satellite link
- APIs for easy integration between IOPES' EMS and the Operation & Maintenance (O&M) interface of the 4G system in the rucksack
- 4G radio coverage for User Equipment (UE)s equipped with SIM cards (provisioned in the 4G system), thus including smartphones, tablets, indoor-outdoor positioning device, RPAS, laptops.

Figure 3 depicts the network interconnections between the different components of the IOPES system.

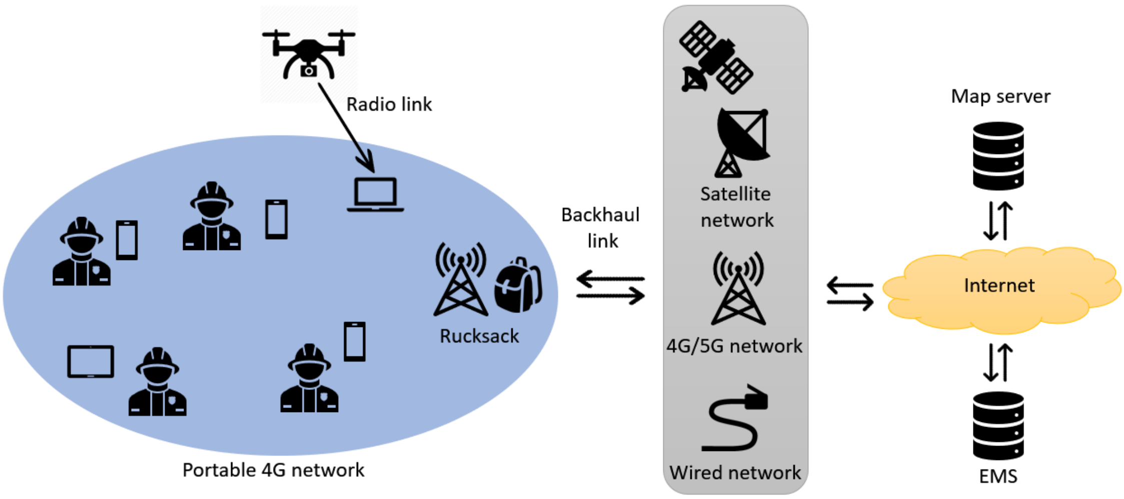


Figure 3: End to End connectivity.

The set of interfaces above allow the exchange of information among the several components of the IOPES system. See next section for details about how data flows among the aforementioned components.

4.3. System workflow

This section describes how information flows among the different components of the system. Information exchange, however, is a process that is hardly sequential in time, and its description might start most at any of the components of the system. In this case, however, an approach following the usual sequence of events occurring when an emergency is managed will be used for, hopefully, a better understanding of the flows.

Usually, the first task implying the generation (and handling) of data is the preparation of the cartography of the area. The RPAS fly over the zone and shot a series of images covering it. These images are downloaded to a computer equipped with COTS / open source photogrammetric software to produce orthophotos, which, once ready are copied to a cartography repository. Note that this process may be repeated if necessary (because of further changes of the environment).

Once the situation is assessed by the leader of the emergency and the members of the emergency team have been assigned tasks on the field, these proceed to the places where their help is needed. The wearable positioning devices – each member carries one of them – must be switched on.

No matter whether the field personnel is indoors or outdoors, the portable positioning device constantly sends its position to the EMS via the ad-hoc communications component. Positions are stored by the EMS and displayed on the screen using the cartography produced by the RPAS (and stored in a map server accessible via WMS / WFS) as the base layer.

Extra information may be sent by the positioning device like special messages, such as “victim found at the current position” or “member of the team in danger at the current position”. Ideally, these special messages should be sent just by touching a specific button in the case of the device.

An additional role assumed by the RPAS is the continuous monitoring of the disaster area. This role may be taken either by extra RPAS teams or by the one responsible for the fast mapping task once it is finished. Monitoring the area means that the RPAS may observe the area taking new images or videos. Such information – used by the control center – is sent to the EMS so the responsible of managing the situation may have an extra point of view explaining how the situation evolves.

Other data flows may occur, such as video push-to-talk communications between the members of the field team or between these and the responsible at the control center. Such data takes place using regular equipment (as mobile phones) connected by means of the 5G/LTE portable communications network.

So, in short, the data flows are:

- Between the RPAS and the EMS – cartography, continuous monitoring data (images, telemetry).
- Between the members of the field team and the EMS – positioning, extra messages.
- Between the members of the team (whatever its role) – video push-to-talk communications.
- Between the RPAS and the members of the team (whatever its role) – live video feed.

All data flows take place thanks to the ad-hoc communications network (see section 4.2 and Figure 3 above).

5. Indoor-Outdoor Positioning Component

5.1. Description and main functionalities related to IOPES

The positioning sensors used to build the positioning device are a tracking camera and a GNSS receiver. The camera tracking combines data coming from an IMU and stereo fisheye camera to provide, by means of visual-inertial odometry (VIO), the location, either indoor or outdoor, of its carrier. The addition of a GNSS receiver immediately enables such device also for outdoor environments and for providing global positioning coordinates. A data fusion algorithm that relates GNSS and camera-based positioning is the heart of the system. This algorithm allows to keep the positional drift of the visual tracking process under control when good GNSS conditions are available. The output frequency of the fused data (VIO / GNSS) is 10 Hz. All these components (both hardware and software) are mounted and running on a light, battery powered system-on-chip computer (also with low power requirements). The next subsections introduce further details from the Hardware (HW), Software (SW) and operational points of view.

5.2. Component architecture description

5.2.1 Hardware and Software

The portable, low weight positioning device is made of COTS hardware components, that may be mounted on a helmet or integrated somehow in the clothing – avoiding any nuisance that might interfere the movement of the carrier.

- A battery powered System-On-Chip (SOC) board will be used to run the sensor fusion & positioning algorithm and to integrate the required sensors - the tracking camera and GNSS module. The SOC board will have communications connectivity by using an LTE/4G dongle or LTE/4G board such as Huawei E3372 [ID1] or Sixfab 3G/4G & LTE Base HAT [ID2].
- The GNSS module is the ublox NEO-M9N [ID3]. It has been chosen because it is able to provide meter-level accuracy and receive signals from up to four different single-band GNSS constellations. This GNSS chipset have been selected with the idea to have reliable GNSS position coordinates even in weak GNSS conditions such as urban canyons, exploiting its capability to select the best signals. The output rate of positions is 20 Hz, matching the targeted operational fused positioning mode rate (10 Hz).
- Regarding COTS cameras, a new family of cameras have appeared in the market, such as the Intel T265 and T261 ones [ID4] and the Microsoft Hololens 1st and 2nd generation [ID5], which perform a trajectory computation in a local reference frame using on-board SOC modules and, providing the user the locations using a predefined API and a SDK tool. The Intel T265 is selected for this project due to a much lower price than Microsoft's Hololens. The Intel T265 tracking camera provides the current pose (position and orientation) with an output rate of 200Hz. The pose is estimated using Visual Inertial Odometry proprietary algorithm, running on board, combining images from two fisheye lenses and measurements from an IMU Sensor [ID6].
- Finally, an unobtrusive SOC (also with low power requirements) is needed to complete (and integrate) the set of components making the system. Its task, to provide the necessary computing resources and storage capacity. The word unobtrusive above means lightweight and small footprint in this context, since the positioning device must not be a nuisance to its wearers. Obviously, the low consumption requirements lead to longer operational times, thus reducing the need to replace batteries so often. From the computing power standpoint, a

powerful GPU is not needed, since the visual-inertial odometry computations are performed by the camera device itself. A candidate for the SOC is the Raspberry Pi 4 [ID7].

The Software, written in the C++ language and running in the SOC, is composed of three modules (Figure 4). The "Sensor acquisition and time synchronization" one is responsible for establishing communication with the GNSS and camera devices using the serial and USB ports of the SOC; receiving the sensor data and assuring a proper time synchronization of GNSS and VIO data. The "Sensor fusion" module implements the algorithms to provide seamless indoor-outdoor location coordinates. Further details can be found in section 5.2.2. The "Communication" module implements the API that allows to send to the EMS the geolocation coordinates of the emergency personnel, through the portable communication network. Further details about the communication and EMS interfaces can be found in section 5.3.

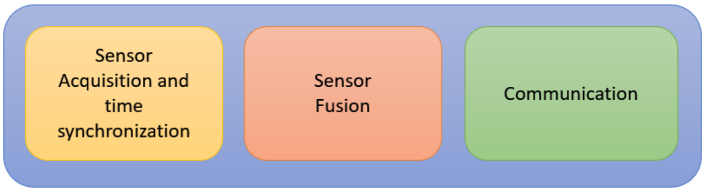


Figure 4: Indoor-Positioning component SW modules

5.2.2 Sensor fusion software approach

The key part of the positioning system is an algorithm able to fuse GNSS and VIO positions providing a single trajectory, regardless of whether it runs indoors, outdoors, or both. The flowchart of the proposed algorithm is detailed in Figure 5.

Firstly, a common temporal reference frame is necessary to deal with data coming from these two sources - the internal clock of the SOC will be enough for the purposes of the positioning device. Secondly, the VIO camera is considered in our approach as the primary sensor, due to the capability to provide a trajectory in both indoor and outdoor areas. The GNSS solution is used to convert the positions provided by the VIO from local to global coordinates and to correct the temporal drift of VIO data.

If the portable positioning device starts to acquire data in an indoor area, the system is designed to store the VIO positions (in local coordinates) and three attitude angles in the internal disk till absolute (GNSS) positioning is available. When the positioning device moves to an outdoor area and the number of GNSS satellites allow to provide reliable GNSS-based positions, a local to global transformation can be estimated, and so VIO positions in global coordinates can be provided since this moment. The criterion to consider a GNSS position as valid is that the Precision Dilution of Precision (PDOP) of the GNSS solution has a value lower than 4, thus indicating a good GNSS satellite geometry.

To estimate the local to global transformation, at least two valid consecutive GNSS positions in different locations are needed to have not only the transformed positions themselves but also to estimate the heading angle. In our approach pitch and roll angles are assumed to be close to zero although this may introduce some positioning errors. Then, a rotation matrix can be computed and then a global VIO position, the lever arm offset between the GNSS and VIO devices and the local VIO coordinates can be estimated using this rotation matrix.

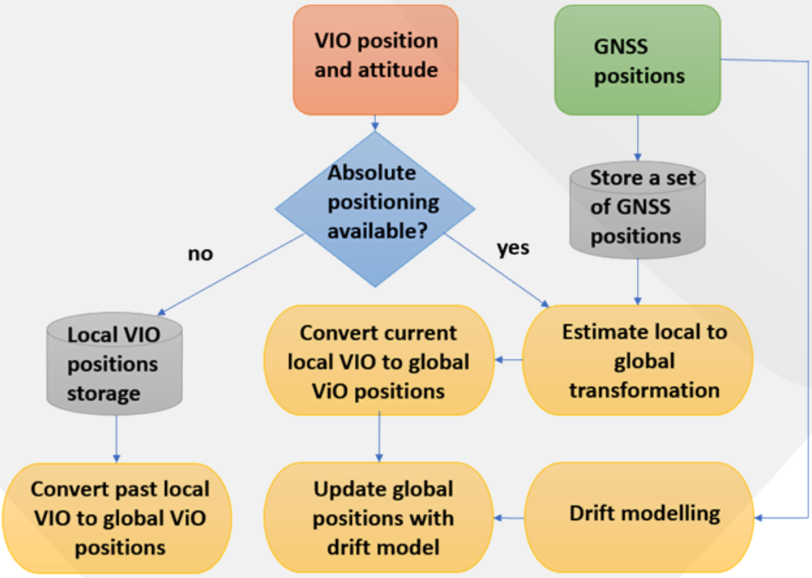


Figure 5: Flowchart of sensor fusion approach

If the rotation matrix between GNSS and VIO devices is known and consequently global VIO positions are available, the GNSS based solution is used (in outdoor areas) to estimate the temporal drift of the VIO. This is done comparing the coordinates of the global GNSS position and the global VIO estimates for a temporal window of *n* seconds. After these *n* seconds, a linear drift is estimated for each positioning component.

The positional drift is then applied to the newer global VIO positions till a new positional drift is computed. If no valid GNSS positions are available for the new window (transition from outdoor to indoor), the older positional drift is maintained until new GNSS positions become available (transition from indoor to outdoor). The *n* number is a parameter that must be set up prior to the use of the system.

Finally, the stored local VIO positions are also converted to global coordinates to be able to have the historical track of global positions. This track can be used during the management of the emergency or once it is over to perform a post-mortem analysis.

From the operational standpoint, using the system in indoor and outdoor environments implies no difference for the members of the emergency teams. Their position will be computed in real-time. This position is sent using the communication interface to the EMS (see section 5.3).

5.3. Interfaces with other IOPES components

5.3.1 Communications.

To transmit location data of the members, an LTE dongle and an appropriate SIM are required to have network connectivity. Then, the location data can be transmitted using a TCP/IP based protocol.

No special thing must be done in the portable communication network. To be able to transmit the data from the IOPES positioning device to the EMS (running on the cloud), a backhaul connection between LTE/5G portable network and the Internet network is required. This could be a Satellite backhaul connection (limited data rate), 5G Network if available (high-speed data rate) or by connecting the portable network to a system, such as laptop or personnel computer, with an already available Ethernet network connection.

5.3.2 Interfacing with Emergency management

The communication interface between the EMS and the positioning device will be done through an API based on Representational State Transfer (REST) architecture and using the Hypertext Transfer Protocol (HTTTP). The REST architecture is a software style that propose and define a set of constraints to be used for creating web services, allowing the interoperability of systems on the Internet [ID8]. In the context of IOPES, this interoperability means the capability to exchange information between IOPES components. HTTP is designed to enable communications between clients and servers. Web service APIs that adhere to the REST architectural constraints are called RESTful APIs.

Within this API, standard HTTP GET and POST methods will be used to enable the communication and to exchange information - e. g., positions - between the wearable positioning device and the EMS.

In the frame of the IOPES, RESTful APIs are defined to exchange information between the wearable indoor-outdoor device, the RPAS and the EMS. Further details can be found in D4.2: Wearable device / EMS data exchange protocol [RD5]. From the SW point of view, a library such as restc-cpp [ID9] can be used to provide this functionality to the IOPES wearable positioning device.

6. Emergency Management System Component

6.1. Description and main functionalities related to IOPES

The SAReye EMS system is an all-in-one cloud-based software solution for Incident- and Emergency management. This solution was born in organizations that battle daily with high priority situations where time is essential, in one of the most disaster-prone countries in the world.

SAReye's unique approach is combining day-to-day project management and daily operations with crisis management, preparedness and asset monitoring, assuring smooth transition from managing small incidents up to national calamities.

The SAReye EMS system will be used as the main data consolidator and aggregator for the IOPES project. Users and devices are registered to the EMS system where the two can be linked together. The EMS system receives the location data of the devices (wearable portable devices and RPAS) and stores them in a database and are displayed live on SAReye's map viewer. The map viewer can additionally receive and display multiple sources of base-layers and overlays such as the flight paths of the RPAS devices and the generated orthophoto maps.

6.2. Component architecture description

The Sareye IMS is split into a frontend and a backend. The front end being the part that the user interacts with directly, sometimes referred to as the client side. The backend, sometimes referred to as the server side is the part of the application that deals with logic, and data. The backend parses incoming data from the frontend and stores it in the database. It also deals with requests for data from the front end and responds with data fetched from querying the database. Splitting the application in to two very well-defined roles allows for validation of incoming data and ensures that no data be served to unauthorized users.

The backend of the system is written in Ruby on Rails and the database system is PostgreSQL. The frontend of the web application is written in HTML, Javascript, Jquery and CSS. The SAReye mobile app is written in React Native and utilizes Expo for both iOS and Android.

The system is hosted on AWS (Amazon Web Services) and is containerized using Docker. The database is hosted on AWS RDS. The app is developed in the Expo development tool and is distributed through the iOS store and the Google Play store. Live updates for the app are distributed through Expo.

All requests, both from the web application, the SAReye mobile app, or other 3rd party API requests (such as those used within the IOPES project) are sent to a routing server managed in AWS. The routing server then sends the requests to a load balancer (AWS load balancer) that distributes the traffic across multiple application instances (AWS EC2 instances). The application interacts with a PostgreSQL database (AWS RDS) and a Redis caching server (AWS ElastiCache). Static files uploaded by users to the SAReye EMS system (such as images or PDF files) are hosted on AWS S3. All Amazon entities are hosted and stored in Europe. A component architecture overview is depicted in Figure 6

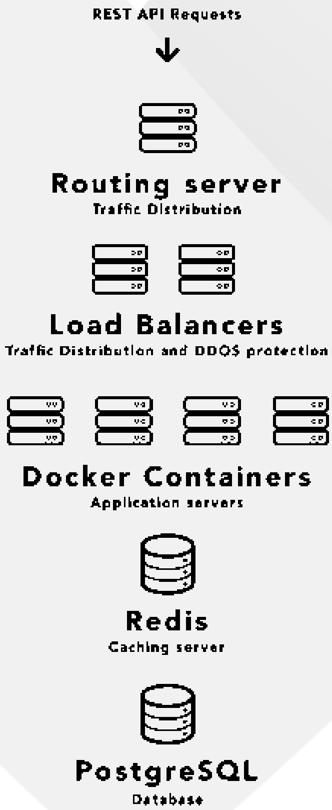


Figure 6: SAReye's EMS system component architecture

6.3. Interfaces with other IOPES components

SAReye will develop an API interface to be used by external parties such as IOPES. This API interface will be developed as a REST API service. It will use a secure but simple and non-intrusive authentication method similar to Basic authentication with permission scopes that are defined in the SAReye EMS system. This API will allow to exchange data between other componets of the system, such as the wearable positioning device or RPAS, with the SAReye EMS.

6.3.1 Interface with the wearable portable device

On top of the API interface, some endpoints will be created to allow the wearable portable devices to communicate and send the data required to the EMS system. Location data will be sent to an API endpoint as a collection of multiple location datapoints. Events, such as a notification when the user has found something of interest, will be sent to another endpoint that will also be able to take images, represented using jpg/png format.

6.3.2 Visualization of RPAS telemetry data, images, positions

The telemetry and positional data generated by the RPAS devices use the same approach as the portable wearable devices.

6.3.3 Ingestion of orthophoto maps and Digital Elevation Models, needed format.

Before the EMS system can display the orthophoto maps they first need to be uploaded to a Geoserver. The Geoserver can either be used as a WMS server or as a tile server that generates MBtiles. The EMS system provides users with access to the generated maps via URL and the maps are viewable using SAReye's integrated map viewer.

7. Communications Component: LTE/5G

7.1. Description and main functionalities related to IOPES

The rucksack is a portable 4G private mobile network to allow local LTE communications in disaster areas where mission critical and public safety forces need to rapidly act and communicate without relying on the public infrastructure.
The rucksack solution (Figure 7) comprises an LTE smallcell (1W+1W) together with the Athonet ruggedized server hosting the core network functions virtualized along with Over The Top (OTT) applications needed for the use case. The rucksack is designed to be transportable and battery powered. Alternatively, if required, it can be powered with external resources. This solution creates a compact dedicated LTE network that can run with or without external connections and work everywhere. The LTE network is responsible of routing of the data packets to guarantee the low latency exchange of applications such as push-to-talk (voice, data) and positioning data between all the elements connected to the network.

Figure 7: Portable network rucksack solution

This portable 4G private network provides:

- Complete LTE, IP Multimedia Service (IMS) and Push-To-Talk (PTT) network
- Solution fully outdoor pole-mounted based on compact rugged server and 5+5 Watt small cell
- Complete data, video, voice solution
- Crypto communications
- Connection with RPAS
- HD (High Definition) real time video images from RPAS
- Voice and video communications between people on-field
- Work-force management from control room
- Backhauling by Satlink communications

For the standard solution, we use a commercial small cell radio which provides the following:

- Power (Outdoor):1W+1W, 2x2 MIMO
- Bandwidth:3, 5, 10, 15, 20MHz
- Max Active Users: 400 (20Mhz)
- Max Throughput: Downlink: 110 Mbps, Uplink: 41Mbps (FDD20MHz BW basic configuration)

The rucksack solution can be used as is without any external connections. Optionally, it is possible to connect an IP67 external power supply 180W AC/DC (90-264Vac / +12Vdc-10A). For data connections, an Ethernet (RJ45 female connection) interface is available which can be used to connect to the local intranet or to the internet for any type of backhauling.

7.2. Component architecture description

In the diagram below we report the main network functions provided by the portable private network:

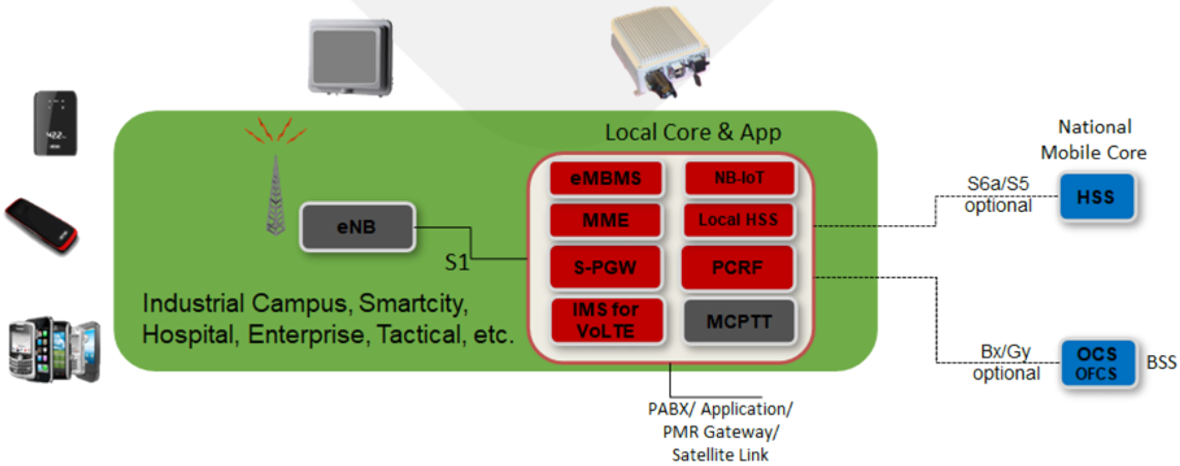


Figure 8: Portable private network functionalities

- The 4G radio (evolved Node B (eNB)), I.e. a small cell, to provide access to the User Equipment (UE)s;
- The local Evolved Packet Core (EPC) core, including network functionalities such as Home Suscriber Server (HSS), Mobility Management Entity (MME), Serving – and packet data GateWay (SPGW), Policy and Charging Rules Function (PCRF);
- Optionally IMS for Voice over LTE (VoLTE), evolved Multimedia Broadcast Multicast Service (eMBMS) and PTT (from third party).

Please note that the smartphones can run VoLTE calls only if enabled by the phone manufacturer and by the national Public Land Mobile Network. eMBMS as well should be enabled in the phone.

For PTT, while the application server can be virtualized in the server inside the rucksack as virtual machine, the client will be installed in the phones/terminals. Our default PTT provider allows to run the client on Android-based phones.

The system can interoperate via 3rd Generation Partnership Project (3GPP) standard interfaces with public national networks and external Operation Support/ Business Support systems (OSS/BSS) (such as IOPES EMS). More on the interfaces exposed to external components are described in the next section.

7.3. Interfaces with other IOPES components

The main interfaces exposed by the compact LTE portable private network (rucksack) are as follows:

- IP-based backhaul link to the EMS-control room, via e.g., ethernet, LTE, satellite link, for the exchange of data traffic between UEs connected via LTE to the rucksack and applications/services deployed in the control room;
- APIs for easy integration between IOPES EMS and the O&M interface of the 4G system in the rucksack, for the ease of management and to retrieve performance indicators;
- 4G radio coverage for UEs equipped with SIM cards (provisioned in the 4G system), thus including smartphones or tablet, sensors, LTE dongles, RPAS, etc., to allow local communications.

8. RPAS mapping and real time video feed

8.1. Description and main functionalities related to IOPES

One of the user needs identified in the project is the lack of updated information about the emergency scenario, which leads to transport teams finding unexpected obstacles (such as closed accesses or damaged buildings) or not being able to locate where the victims may be. Remotely Piloted Aircraft System (RPAS) will be used in order to supply emergency teams with real time data and updated cartography in order to supply these needs.

Thanks to its small size, RPAS can be carried by the emergency teams and deployed anywhere when needed, giving a tool of great flexibility that can provide valuable information. Moreover, their low flight capability allows the acquisition of high-resolution imagery where each detail of the emergency environment situation can be seen. This combined with the capability of carrying different sensors (RGB, thermal, multispectral, among others) gives the emergency teams a tool to update their situational information and take in advance the better decisions.

The RPAS used in the IOPES project have the following functionalities that make them suitable for this emergency applications:

- Autonomous: they can fly completely autonomous following predefined flight plans that can be edited on the go. This allows their operation by any emergency drone professional without having to be an expert.
- Remotely Controlled: As their name indicates, RPAS can be controlled from a safe distance, allowing the emergency response teams to get field information without being deployed in the dangerous areas. Systems can be either controlled using a radio link with a range of operation than can reach around 20 km or have a 4G/5G link allowing its control from any place.
- Multi-platform: The RPAS fleet used in IOPES has multirotor and fixed-wing systems which have multiple endurance ranges (from 30 minutes to 14 hours) that allow them to cover from small areas with great resolution with the multirotor up to a full region with the bigger fixed-wing. This also allows emergency teams to first get the big picture of the emergency area and then focus in those spots that require more detail.
- Multi-sensor: Their payload can be easily interchanged in order to adapt its needs to the emergency requirement, for example being able to carry a high resolution RGB camera during daylight operation but changing it to a thermal camera to get night vision.
- Live stream: the user may receive live video up to 12 km distance.
- Full Payload Control: in multirotor RPAS, the sensors are mounted in a gimbal. This allows the user to control the orientation of the payload and allow not just to perform orthophoto maps, but also structured scans of for example a collapsed building.

8.2. Component architecture description

8.2.1 RPAS platforms and sensors for image acquisitions

The typical system architecture (Figure 9) of an RPAS is composed of the following subsystems:

- RPAS Platform: The airframe of the system providing lift and mobility capabilities.

- Onboard control hardware: it's the brain of the RPAS, allowing to fly it in an autonomous way following predefined flight plans and send all the information acquired to the Ground Control Station.
- Ground Control Station: Allows the operator to remotely control all RPAS functionalities.
- Payload: Sensor or any useful tool to acquire valuable information.

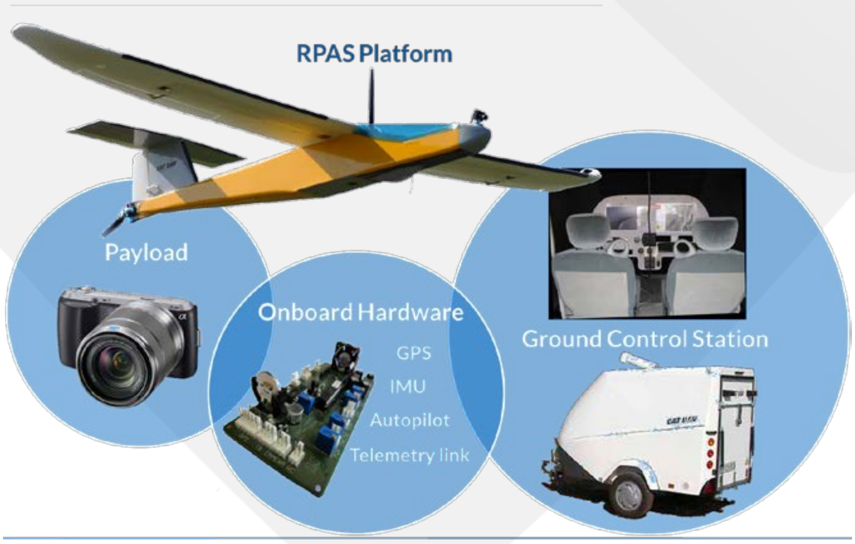


Figure 9: RPAS system architecture

CATUAV systems used in the project will be the ones shown in Table 3. The platforms detailed in Table 3 can carry any of the payload sensors described in Table 4. The payload way of both systems is configurable, so apart from the two mentioned sensors other systems can be integrated into the RPAS if they are found of the interest of the project. Systems can also integrate an additional video link that will transmit real time data to the ground control station. Usually cameras are nadir pointed for map generation and video data is forward pointing to give situation awareness to the operator.

All images acquired are geotagged with information from a GNSS receiver with multi-constellation and Ground-Based Augmentation System (GBAS) capabilities, having a typical precision of less than 2 meters. Higher precision GNSS receivers could be installed -double frequency, Real Time Kinematic (RTK), Post-processed Kinematic (PPK)... - if required.

Fixed-wing workflow will be as follows:

- Flight plan and preparation.
- Take-off and operation over the area of interest to acquire all data.
- Landing and image download.
- Image processing.

After the analysis of "User Requirements" was performed, it was stablished that the end users or Civil Protection Emergency Teams (CPET) work in extreme weather conditions. Therefore, all equipment used by these teams have to be adequate for this purpose. At this moment the ScaraBot x8 RPAS is not suitable for this purpose.

Atmos-7		
Type	Fixed Wing	
Endurance	90 minutes	
Hectares per flight	300 ha	
Km per flight	75 km	
Payload	0,5 kg	
MTOM	2 kg	
Argos		
Type	Fixed Wing	
Endurance	14 hours	
Hectares per flight	4.000 ha	
Km per flight	1100 km	
Payload	5 kg	
MTOM	25 kg	

Table 3: Fixed-wing RPAS platforms and main features

The ScaraBot team is working hard in a new RPAS frame, the ScaraBot Monocoque, which should be able to support extreme weather conditions.

According to these guidelines for the IOPES project, the ScaraBot team will be using two different systems, prototype 1 and 2. The difference between are detailed in Table 5.

The ScaraBot x8 is an already product on the market. Therefore, it will just need minor development to be integrated in the IOPES architecture.

The workflow within IOPES will be the following:

- Flight plan and preparation
- Perform a specific mission and collect all data[2].
- Return to launch and download the sensor data.
- Data processing to generate orthophoto maps.

[2] The data is collected and saved on an internal memory. Live stream is at every time available for only one of the sensors at a time. The end user is able to change, at any time, which of the sensor is being streamed.

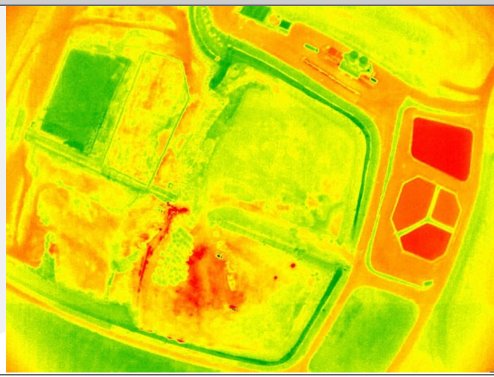
RGB Camera – Foxtech Map01		
Bands	RGB	
Resolution @ 120m	3 cm/pixel	
Generated Products	Images	
	High resolution orthophotomap	
	High resolution 3D point cloud	
	Digital Surfaces and Terrain Models	
Thermal Camera – Flir Vue Pro R		
Bands	7,5 a 13,5 µm	
Resolution @ 120m	15 cm/pixel	
Generated Products	Images	
	Orthophotomap	
	3D point cloud	
	Digital Surfaces and Terrain Models	

Table 4: Fixed-wing mapping sensors

The basic specifications of this RPAS do not differ from the original ScaraBot X8. The ScaraBot Monocoque is an ambitious project aimed to full filth the output from the User Requirement document.

The main advantage between the ScaraBot Monocoque and its predecessor is the rain and dust protection. It is built all 100% high-strength and extremely light carbon fiber composite. Another important output from the User Requirements document is the quick response and usability of the RPAS for disaster scenarios. Therefore, the workflow its being developed to be easier and quicker than its predecessor:

- Flight plan and preparation
- Perform a specific mission and collect all data[3]. Live stream of two sensor in different UDP ports.

An approach of the integration of the RPAS with the IOPES system is presented in Figure 10.

[3] The data from the sensor should also be transmitted in another UDP port. This allow the orthophoto map to be generated as the photos arrive and keeping update the map as more photos keep arriving.

ScaraBot X8 – Prototype 1		
Type	Coaxial Octocopter	
Endurance	60 minutes (200gr Payload)	
Max. Data Link Range	12Km	
Max. Speed	45 km/h	
Max Wind Load	5 Bft, 11 m/s	
Max. Takeoff Weight	5 kg	
Dimensions	B600xT600xH402 mm	
ScaraBot Monocoque – Prototype 2		
Type	Coaxial Octocopter	
Endurance	65 minutes (200gr Payload)	
Max. Data Link Range	12Km	
Max. Speed	45 km/h	
Max Wind Load	5 Bft, 11 m/s	
Max. Takeoff Weight	2 kg	
Dimensions	B 600 x T 600 x H 402 mm	

Table 5: Rotary-wing RPAS platforms and main features

The payload will be the same for both systems, prototype 1 and 2, previously exposed. This payload is also modified to fulfill the output provided by the User Requirement documentation.

The payload will be mounted in a 2-axis gimbal image stabilization system, IOPES-BLG400. The user will have full capability to operate the axis position of the gimbal manually. During a mission plan it will be previously specified the angle required. The IOPES-BLG400 is composed of a 30x optical zoom, 20 MP camera capable of providing live video and providing high resolution photos to generate orthophoto maps, a thermal camera with a spectral range from 7.5 μm – 13.5 μm and an array format of 640*512 also capable to providing live video and providing high resolution photos to generate orthophoto maps. As addition it will include a small spotlight of 500 Lumens. The ScaraBot RPAS are hot swappable protected. This means any payload is as easy to change as changing the battery of the systems. The End User may find this payload too overloaded or too heavy. In this case the user can change the payload to any other compatible payload to for example achieve more flight time, obtained data from other sensor among other possibilities.

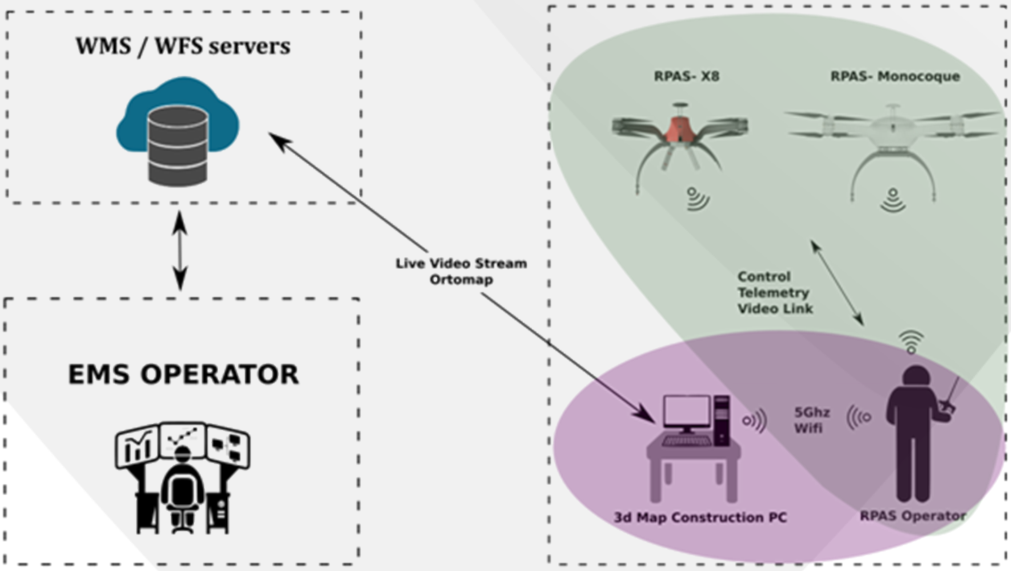


Figure 10: integration of the RPAS with the IOPES system

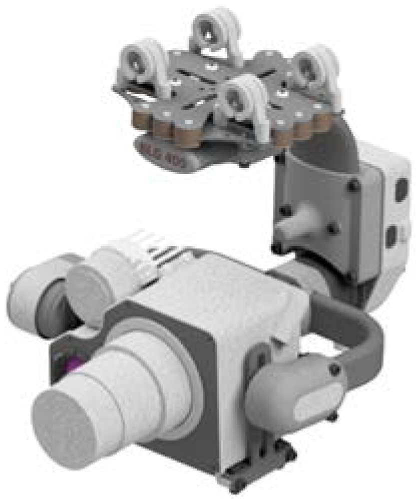
IOPES-BLG400		
Weight	800gr	
Axis	2	
Dimension	170x170x170mm	
Pitch Rotation	45 km/h	
RGB Camera		
Zoom	30x Optical	
Pixels	20.4MP	
Live View	1080p60	
Thermal Camera		
Zoom	8x digital	
Spectral range	7.5 µm – 13.5	
Array format	640*512	
Live View	1080p60	

Table 6: Rotary-wing mapping sensors.

Another objective within IOPES is to proof, with an RPAS, whether it is possible to track such a vehicle in indoor situations the same way the IOPES project aims to do with the CPET's. For this purpose, a third RPAS will be used (Figure 11). This RPAS will integrate the previously explained technology used to track indoor position of a person. The RPAS will include too its standard hardware a T265 stereo camera and companion computer with a similar SW used in the wearable positioning device This SW will have to be modified according to the needs of the RPAS internal software.

Figure 11: RPAS used for indoor tracking

8.2.2 Rapid Orthophotos and Digital Elevation Models generation

In order to generate orthophotos and Digital Elevation Models (DEM) two software suits will be used:

- Pix4Dreact: This software is specially designed for emergency response teams. It is light weight and can quickly process the data to generate the maps. However, it has some limitations: it generates maps with a lower accuracy which, however, is enough to fulfill the needs of the IOPES project; this software, furthermore, can only be used with RGB data.
- Pix4Dmapper: This software will be used to process thermal imagery and high-resolution accurate maps.

Input of both software tools are the geotagged images acquired from the drone. Depending on the configuration and required information, the following outputs can be acquired by both RGB and thermal camera:

- Orthophotomap
- 3D point cloud.
- Digital Surface Model.
- Digital Elevation Model

There are two approaches in order to process the data:

Offline Processing: the RPAS fulfils the entire flight plan storing the images on-board. Once landed the imagery is downloaded from the drone and processed to generate the maps. This approach is slower but allows working with the full resolution data without requiring big bandwidth communications.

Figure 12: Offline Rapid Orthophotos and DEM generation flowchart

Online Processing: the RPAS sends the imagery during the flight, so the map can be generated while the system is still in the air capturing more data. The map is continuously updated with new data arriving from the drone. This approach is faster than the offline processing, but the resolution acquired can be limited by the communication link, especially when working at long ranges with high resolution data, which will need some sort of compression.

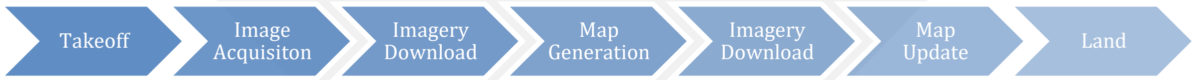


Figure 13: Online Rapid Orthophotos and DEM generation flowchart

Both approaches will be tested during IOPES project, being able to compare which is the most suitable for each case.

8.2.3 Real-time video streaming

Real time video stream is one of the points considered as most important for the CPTE's, as in this way they can have a better overview of the whole scenario. For these purposes the IOPES project aims to integrate this feature in its architecture.

In order to provide a stable, small latency and long-range video feed the system is separated into three architectures:

a) Communication between RPAS and RPAS operator.

This is transmitted within a closed and RSA 256 encrypted link at 2.4Ghz using a User Datagram Protocol (UDP) stream.

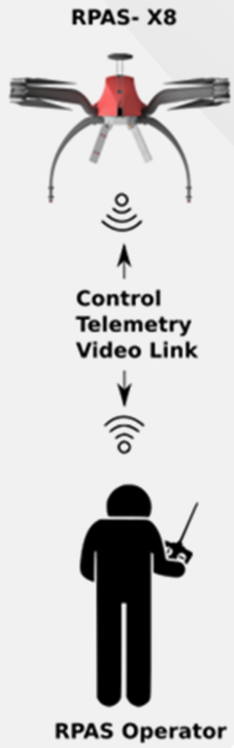


Figure 14: Communication between RPAS and RPAS operator

b) Communication between RPAS operator and ground control station (orthophoto map ground station)

This is a bidirectional communication between the RPAS operator ground station and any other ground control station within a range of about 20m. The technology used is Wi-Fi at 5Ghz and WPA2 password protected. The data exchange is based on Micro Air Vehicle Link (MAVLink) UDP for telemetry data and Real Time Streaming Protocol (RTSP) for video streams.

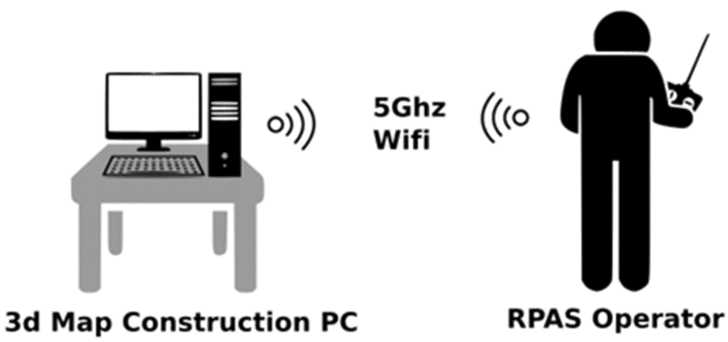


Figure 15: Communication between RPAS operator and ground control station

c) Communication between ground control station and Emergency Management System.

A cloud server will be used as intermediary between the data collected, telemetry and live video from the RPAS and the EMS.

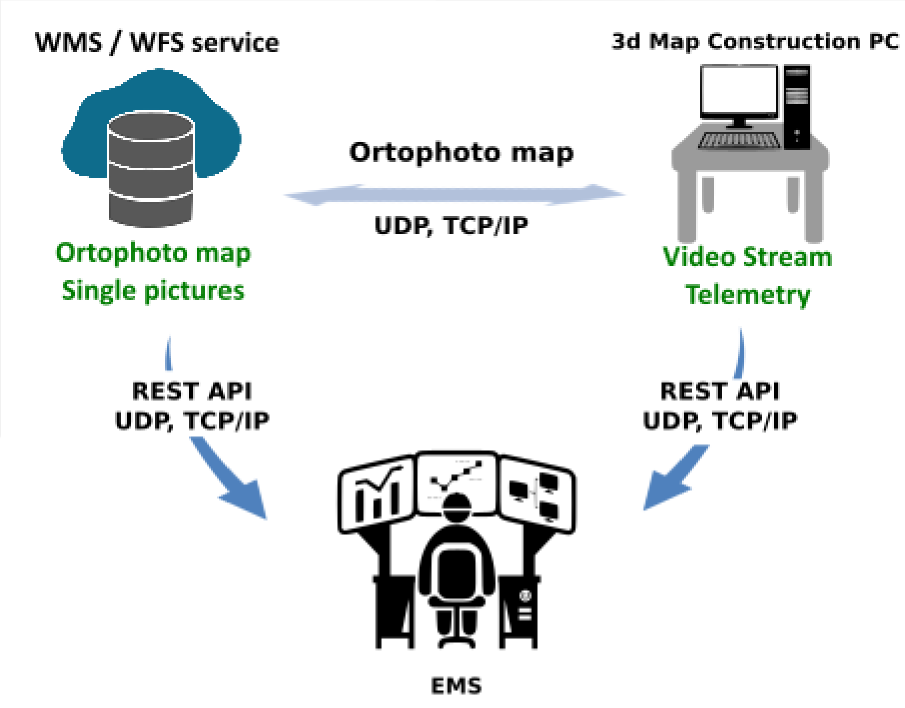


Figure 16: Communication between ground control station and EMS

It is not intended to integrate the live video into the existing EMS system. This will be displayed in another optional application which will get the live video stream direct from the RPAS. The intended option is to use either the Video Lan Client (VLC) or a stripped version of the existing Scarabot's software. VLC technology appear to have a high video latency for live stream of about 5 seconds.

8.3. Interfaces with other IOPES components

8.3.1 Interfacing RPAS telemetry to Emergency Management System

According to the above exposed and to the user requirements, the most important RPAS data for EMS and CPET is the following:

- Telemetry data: global position of the RPAS, extended battery status, flight mode, altitude, status of the mount (payload).
- Live Video Stream: live stream of one or two sensors depending on the bandwidth available.
- Orthophoto and Digital Surface Model maps.
- Single pictures: single pictures will be sent to the EMS to make them available for their visualization by the CPET at any time.

Data, like telemetry, orthophoto map data or single shot images is sent via a protocol, that supports reliable data transmission, like TCP or Stream Control Transmission Protocol (SCTP). SCTP is a transport layer protocol, which has similarities to both UDP and TCP, but is less known, than TCP. SCTP has some features, that UDP does not have (ordered frames, better support for streaming) and in contrast to TCP it can be configured to do reliable and unreliable (no retransmission) communication. Reliable communication is useful for critical events, unreliable communication is useful for data, that arrives at regular intervals, like MAVLink.

Live Video stream data is most likely sent via a protocol upon UDP. RTP is a good choice for video streaming (i.e. in conjunction with udpsink/udpsrc of gstreamer[4]). The Real-time Transport Protocol (RTP) is a video network protocol for delivering audio and video over IP networks. It is often used in conjunction with Real Time Streaming Protocol (RTSP) to control stream sessions.

8.3.2 Storage of orthophotos in a server and WMS / WFS service.

The rapid orthophotos and Digital Surface Models (DSM) generated using the photogrammetric SW flowchart (see section 8.2.2) are stored in a standard personal computer (PC) or laptop. This PC shall have a public IP address and shall run 24 hours / 7 days per week. The PC includes a map server software service such as GeoServer [ID10].

GeoServer is software map server, programmed in the Java language. The users can view, edit and share maps and any geospatial data using Open Geospatial Consortium (OGC) standards. Among them, Geoserver *"conforms Web Feature Service (WFS) standard, and Web Coverage Service (WCS) standard which permits the sharing and editing of the data that is used to generate the maps. GeoServer also uses the Web Map Tile Service standard to split your published maps into tiles for ease of use by web mapping and mobile applications."* [ID10].

The cartography output by the mapping component may be shared – and therefore, used by any software application or system such as SAREyes' EMS) thanks to the WFS / WMS services offered this server.

Two options are available to configure and update this service with new or updated maps:

- Using a GeoServer web-browser interface.
- Using a GeoServer REST API interface.

The first option is already available, but it requires an operator to update the maps on the server. The second option allows for the automation of the process, thus reducing the human intervention, but it requires specific SW development.

[4] Software applications for streaming and video display.

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9. Architecture risks and mitigation actions

This section describes the possible risks and difficulties related to the implementation of the proposed architecture. The probability and impact for each risk is indicated as well as some measures/strategy for addressing them.

Risk Number	Risk description	P	I	Risk mitigation measures
1	Underestimation of effort needed to complete activities.	Low	Medium	Continuous monitoring of progress status together with recovery activities will be carried out.
2	Incomplete, unattainable or not well-expressed end-user requirements.	Low	High	Continuous communication with end-users to ensure that their needs are not misunderstood and that these are feasible and may be fulfilled.
3	Inability to fulfill the required performance parameters, such as throughput, accuracy, precision, bandwidth, etc.	Low	Medium	Suitable HW and SW algorithms exist. The consortium will monitor the state-of-the-art continuously to implement new algorithms if needed.
4	Lack of reliability in the system, that is, the inability to maintain it working uneventfully, providing a continuous service to its users.	Medium	Medium	Component and whole system testing will be carried out to check and improve (if needed) reliability.
5	Disqualification of methodologies or techniques.	Low	Medium	Suitable HW and algorithms exist. The consortium will be aware of the state-of-the-art to implement new algorithms if needed.

Reference documents

[RD1] IOPES – Grant Agreement (GA) – GA 874391.
[RD2] IOPES – Consortium Agreement (CA) – Version 1.0.
[RD3] Union Civil Protection Mechanism. Prevention and Preparedness Projects in Civil Protection and Marine Pollution. Call for proposals document UCPM-2019-PP-AG - Version 1.0.
[RD4] IOPES – Deliverable D3.1, "User requirements".
[RD5] IOPES – Deliverable D4.2, "Wearable device / EMS data exchange protocol"

Informative documents

[ID1] HUAWEI 4G Dongle E3372. https://consumer.huawei.com/en/routers/e3372/specs/ . (22nd May 2020).
[ID2] Raspberry Pi 3G/4G & LTE Base HAT. https://sixfab.com/product/raspberry-pi-base-hat-3g-4g-lte-minipcie-cards/. (22nd May 2020).
[ID3] NEO-M9N module. https://www.u-blox.com/en/product/neo-m9n-module. (22nd May 2020).
[ID4] Intel® RealSense™ Tracking Camera T265, 2019. https://www.intelrealsense.com/tracking-camera-t265/. (22nd May 2020).
[ID5] Microsoft Hololens. https://www.microsoft.com/en-us/hololens/. (22nd May 2020).
[ID6] Tsykunov, E., Ilin, V., Perminov, S, Fedoseev, A., Zainulina, E, 2020. Coupling of localization and depth data for mapping using Intel RealSense T265 and D435i cameras. Pre-print version: https://arxiv.org/abs/2004.00269.
[ID7] Raspberry Pi 4. https://www.raspberrypi.org/products/raspberry-pi-4-model-b/. (22nd May 2020).
[ID8] RESTFUL API. https://restfulapi.net/. (22nd May 2020)
[ID9] C++ REST Client library, https://github.com/jgaa/restc-cpp. (22nd May 2020))
[ID10] GeoServer, http://geoserver.org/. (22nd May 2020)

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