

Modular Multi-Platform Interface to Enhance the Situational Awareness of the First Responders

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ABSTRACT

Augmented Reality technologies can provide useful information to First Responders in rescue scenarios if their design is properly adapted to their cognitive and circumstantial requirements. Indeed, biosignals and environmental sensors can improve the situational awareness of the professionals working in emergency situations, supporting the decision-making process in critical moments. This study presents the architecture to create a Multi-Platform Interface to Enhance the Situational Awareness of First Responders that can be customized through an external dashboard. The key to individualizing the interface is the flexible configuration of sensor modules, normally manipulated by the Command Center according to the First Responders' rescue context.

Keywords

Augmented Reality, Cognitive Load, Situational Awareness, Angular, MQTT

INTRODUCTION

First Responders (FRs) operate in logistically demanding, mentally challenging, and time-sensitive circumstances. This is why, over the last few decades, there has been a growing interest in the development of technology that facilitates their rescue tasks. Augmented reality technologies, for instance, have been developed to provide important information to officers operating in catastrophic situations, as reflected in studies such as Arregui et al., 2022; Kapalo et al., 2018; Neustaedter et al., 2019. In this context, the International Forum to Advance First Responder Innovation (IFAFRI, 2023) has detected 10 FR common global capability gaps, a list that facilitates the characteristics of the innovative technologies to augment FR safety, efficiency, and effectiveness. Between those gaps, real-time information-sharing seems primordial to track the location of FRs, and monitor and analyze threats and hazards.

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The incorporation of information available from multiple and nontraditional sources has been detected as an important capability gap, including the option to monitor physiological signs of FRs. Apart from sensor-based information, interoperable communications with FRs are supposed to enhance FRs safety and efficiency independent of environmental conditions.

Considering this circumstance, according to Arregui et al., 2022; Kapalo et al., 2018 appropriately designed Augmented Reality (AR) tools provide essential information to FRs to support decision-making and improve their Situational Awareness (SA). On top of this, The organization of the data in modules makes its processing more efficient. Indeed, the comprehension of the information processed by FRs in catastrophic circumstances varies according to their cognitive load as indicated by Meneguzzi et al., 2012. Despite enhancing the abilities of FRs, Gutiérrez et al., 2023 highlights that the volume and manner in which these details are presented can impact their cognitive workload. The modulation of the amount of information displayed in AR interfaces facilitates focusing on the main goal of technology incorporation in emergency cases: the FRs' safety and minimizing risk exposures. The tracking and monitoring of biosignals allow for estimating the cognitive load and, therefore, adapting information exposure as already studied by Frederick et al., 2010; Kahneman and Beatty, 1966.

As identified by IFAFRI, 2023, another essential factor in catastrophic situations is the transmission of instantaneous information between agents present at the scene and the control center. The relevancy of this communication is reflected in the effort programmed by Canada in order to include the sharing of photos and videos between callers and 9-1-1 call centers within Next Generation 9-1-1 programs summarized in Camp et al., 2000; NG911, 2023. Ludwig et al., 2013; Neustaedter et al., 2019 indicate that real-time data exchange is equally significant between the FRs and the control center in emergency scenarios. In this way, the data collected by the sensors and devices of the FRs provides strategic advice in the control centers, as reminded in Ludwig et al., 2013.

Park et al., 2014 insists on the need for ergonomic tools that fit the usual equipment of FRs as a prerequisite for providing maximum efficiency and minimizing the difficulty of their task. A modality that facilitates the ergonomics of the FRs and the transmission of information between operators is voice communication, as remarked by Choong and Salvendy, 2021. When one of the essential tools is in the hands of the user in augmented or virtual reality situations, Monteiro et al., 2021 outlines the efficiency of voice as one of the most efficient interaction means. In this case, the use of voice can provide a double contribution: communication with external operators, and the ability to modulate the display, ensuring a completely hands-free context for the FRs. In this context, recent research as Arregui et al., 2022 shows the benefits of prototypes created according to these circumstances, such as the Smart Helmet presented by Fernández García et al., 2023. This tool combines sensors, artificial intelligence, AR, and personal protection to increase the situational awareness of FRs.

Within this context, this study aims to introduce an AR interface design characterized by the following objectives: modularity to adjust information exposure according to FRs' cognitive condition; ergonomic or hand-free adaptability; architecture flexibility to enable simultaneous deployment in interconnected distinct devices; and real-time data actualization capability. This presentation includes, on one hand, the description of the main architecture that provides a modular multi-device display, and it details the combination of operational modules connected through an MQTT-based communication protocol. On the other hand, it summarizes the generated prototype that demonstrates the versatility of the generated AR interface. This part includes its deployment inside a display added to an adapted FR helmet and the simultaneous visualization in the control center, which adjusts through a dashboard the tools to be displayed. The last section summarizes the impact of the experience of the pilots on the AR interface design, and finishes with the pending and future work perspectives.

DESCRIPTION OF THE SYSTEM

The Augmented Reality (AR) interface presented in this work, The Modular Multi-Platform Interface (MMPI), proposes a technology to aggregate and display essential information in order to enhance situational awareness and support decision-making. This mechanism improves the transfer of information between the agents in the emergency field and the technicians in the control center. All while keeping from overloading the users with information and preventing mistakes as a result of this extra-information exposure. This data comprises essential details such as the location and orientation direction of First Responders (FRs), the positioning of other FR team members, and noteworthy points of interest—such as targets or alerts regarding potential dangers or events tagged by other FRs or directly from the Command Center.

The design of the AR display is characterized according to the needs of the FRs in the emergency field since the main objective is to extend their capacities when working in crisis zones. Due to ergonomic reasons, the AR is engineered to be projected in the one-eyed transparent AR Head-Up Display (HUD) integrated into a standard helmet enhanced with a processing unit and camera, called Smart Helmet on the Fernández García et al., 2023;

but it is similarly displayable on an opaque screen of a mobile phone or a tablet. This is a result of the flexible design based on the dynamic web application framework Angular detailed by Jain et al., 2014, technology that facilitates the adjustment and duplicated reproduction of the interface on different displays. In this manner, all biosignal, sensor, and positional information displayed on the interface is available simultaneously to the rest of the FRs and the Command Center.

The procedure for transferring information across multiple devices is based on Message Queuing Telemetry Transport (MQTT), a lightweight messaging protocol designed for use in low-bandwidth, high-latency, or unreliable networks. The biosignal, contextual, and positional data recorded by distinct sensors or indicated by the FRs is published through previously defined topics in the MQTT broker. The subscription to those channels enables the real-time update of the information projected in the AR.

On the other hand, the FRs in emergency fields operate in dynamic and demanding operational scenarios, and therefore, it is crucial to equip the FR with comprehensive and adapted information facilitating real-time decision-making instead of over-saturating and complicating the situational awareness and decision-making processes. That is accomplished by adapting the modular configuration of the AR display through a dashboard manipulated in the control center. The cognitive load is the key indicator to avoid information saturation or overloading and provide an assumable data quantity. Gutiérrez et al., 2023 provide measures to approximate it.

The following Global Architecture section includes all the technical requirements involved in the simultaneous deployment of the AR interface in distinct devices, which are distributed in two different physical environments: the Emergency Field and the Control Center.

Global Architecture

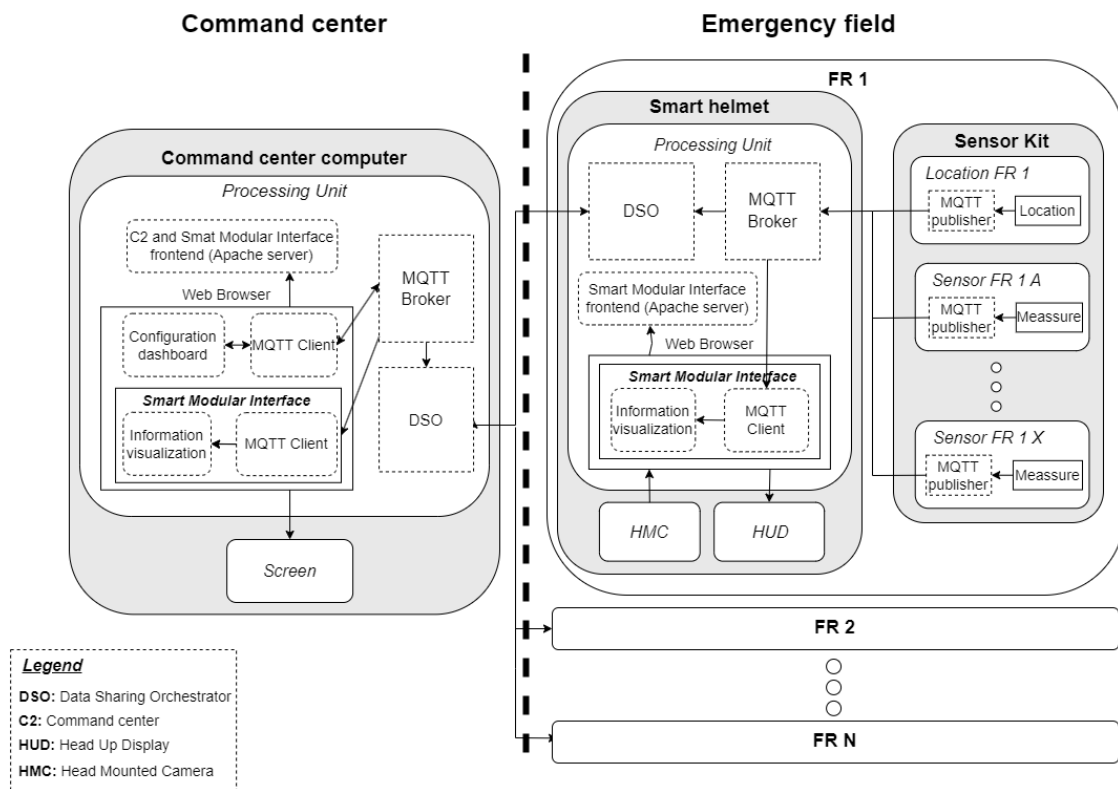


Figure 1. Use case architecture

The Modular Multi-Platform Interface (MMPI), an AR interface, has been designed to perform in a highly adaptable architecture resulting from different emergency scenarios, with changeable FR and Command Center (C2) organization. The presented architecture facilitates the intercommunication between multiple operational nodes in order to retrieve, process, and display information relevant to the FR. The architecture depicted in Figure 1 represents the main technology division that occurs in emergency response services, the digital frameworks corresponding to the Emergency Field and the Control Center. In the Emergency Field, the FRs illustrate the necessary digital configuration to display the AR in each deployed field operator. At the same time, the Central

Operation Computer symbolizes the Control Center and the required technology to overview the information of the FRs and the dashboard to customize their MMPI as depicted in Figure 4.

Both sides of the use case share many components. On the one hand, both contain a processing unit (Laptop, Raspberry, ...) that includes an MMPI, an MQTT broker, and a Data Sharing Orchestrator (DSO). The MQTT broker is responsible for collecting and managing the data flowing within the network established by the FRs and the control center. The MMPI consumes the messages available in the MQTT broker topics to supply the FR display or the control center screen with real-time data. Inside the processing unit, another common component is the Data Sharing Orchestrator. The DSO is a module that fulfills two tasks: forwarding the information from the sensors of each FR to the rest of the MQTT Brokers and filtering the data of other FRs based on the user's cognitive load to avoid overloading Gutiérrez et al., 2023.

On the other hand, the control center and the emergency equipment differ in important characteristics. The Control Center includes a screen, in replacement of an AR device, and a Configuration Dashboard (CD) that personalizes the modular appearance MMPI of each FR. In addition, the CD can provide externally defined coordinates of points of interest in the Emergency field. Since the Smart Helmet does not offer the FR ways to interact with the MMPI, that is the unique manner to update information not registered by sensors. On the other hand, an FR in the Emergency Field carries, apart from a Smart Helmet that includes the Head Mounted Camera and Head Up Display, the necessary rescue equipment. This equipment contains an individualized collection of sensors, denoted as the Sensor Kit in this context. Indeed, the following list highlights the instruments considered within the RescuerR project as part of the Sensor Kit:

- * Smartwatches collecting the wearer's physiological signals
- * Wireless signal detectors encompassing Bluetooth and WiFi frequencies, enabling potential victim localization in obstructed environments (e.g., under debris).
- * Vital sign detectors designed to discern pulsation through solid barriers, facilitating life detection in scenarios where subjects are obscured by walls or similar impediments.
- * Chemical sensors engineered to identify hazardous airborne constituents, such as methane or diminished oxygen levels, contributing to environmental safety monitoring.
- * Localization devices employing GPS Galileo for outdoor positioning and leveraging inertial sensors, specifically mobile phone gyroscopes, for indoor localization purposes.

In order to ensure the transference of the data recorded by these sensors to the AR interface, the MMPI in this case, is necessary to publish those values in a previously agreed message format and topic for the MQTT. These topics shape the modules that are visualized in the MMPI, thus characterizing the modularity of the AR interface.

The Modular Multi-Platform Interface, the main contribution of this paper, is the technological cornerstone that facilitates the integration of all data gathered from different Sensor Kits. Its modularity, according to FR's cognitive load and adaptability to distinct devices, is characterized by its Angular-based front-end development. The main advantage of using Angular is its flexibility and structure that is specifically designed to generate individual components that can be grouped, nested or even replicated and reused in multiple sites. In addition, it is a widely used framework on which multiple libraries have been created (including a dependency inspector to facilitate their integration) that facilitates the development of more complex solutions. These characteristics fit the objectives of AR interface design, as mentioned above, a generation of an extensible and adaptable interface depending on the equipment assigned to each FR. Deployment options permit its installation on either an Apache server within the local device interfacing with the display or on a server interconnected within the shared network.

In addition to this, like many other JavaScript frameworks, its results are accessible from any modern web browser offering a lot of flexibility in terms of where to display the information. In this case, being an interface designed specifically for AR displays, the background of the application by default is a black background. Normally, AR displays interpret the black color as a transparent pixel allowing to combine reality with an artificial scenario. When the interface needs to show more information, such as a camera feed, the AR display can function as a regular opaque screen. Nonetheless, its functionality relies upon the interconnection between the display and the processing units, alongside the camera requisites delivering the camera feed.

Prototype

This section describes the different elements that conform complete architecture of the use case either on the Control Center side or in the emergency field side: The MMPI, the Configuration Dashboard and the Smart Helmet.

Modular Multi-Platform Interface (MMPI)



Figure 2. Example of the Modular Multi-Platform Interface (MMPI) visualization in a FR helmet HUD

The MMPI, has been generated to test its adaptability across the display in different devices, the implementation of the distinct-format data, as well as the connectivity of the components responsible for data management. As summarized in the Methodology section, the same AR interface is deployed on distinct displays: a laptop and a Head-Up Display (HUD) integrated into an FR Helmet, representing the communication segmentation of catastrophic circumstances. This duplication facilitates direct transmission of the information gathered by the FRs in the Emergency Field. The AR interface depicted in Figure 2 exhibits crucial information for First Responders (FRs) to navigate crisis scenarios effectively. Within this display, two distinct categories emerge: the passive data and the Tool-associated Information. The former encompasses data that is directly transmitted to the FR without requiring his interaction: for example, biosignals, location, or network status. Conversely, the Tool associated Information section includes the output of devices manipulated by the FRs during the rescue operation; for example such as radars or gas detectors (see Table 1 for further description of some examples applied during validation). The segmentation of all this information in modules facilitates a comprehensive overview of both passive and tool-related data, empowering FRs to make informed decisions while engaging with diverse tools and technologies. These Situational Awareness enhancing Modules and corresponding sensors are detailed in Table 1.

The information distribution on the screen is important to focus the attention of the user according to contextual needs. The focus of a First Responder (FR), for example, typically lies in the lower field of vision as they concentrate on locating victims. Therefore, in this case, the AR layer is required to be positioned at the top of the field of view to ensure the lower part remains unobstructed, as visualized in Figure 2.

During concrete moments in rescue operations, the FRs necessitate a distinct kind of information visualization, a configuration not summarizable with small icons and values in a small space fraction of the AR interface. Instead, this critical information needs to be displayed over the complete AR scene or screen. Therefore, two opaque interfaces have been included, display modes changeable from the Control Center. The two non-AR modes integrated are the Camera Feed mode, which allows the direct reproduction of camera output on the FR display (useful for infrared cameras or IA-generated image processing, Fernández García et al., 2023) or full-screen map mode that illustrates the position of the FRs and points of interest, as depicted in Figure 3.

Configuration Dashboard

This web tool has been designed to enable the Control Center to modify the depiction of modules for a specific FR and to facilitate the transmission of information updates necessary to keep the emergency field agent on track of their mission. This configuration could be adjusted further using communication via walkie-talkies with the Control Center for clarifications. The protocol established for this configuration operates as follows: The Control Center initiates a current status request to an FR identifier through the MQTT broker. If there exists an MMPI associated with that identifier on the network, it responds with an MQTT message containing its present configuration and the currently displayed points of interest on the screen. These parameters are integrated into the Configuration Dashboard, allowing modification by the Control Center. Subsequent alterations can then be transmitted to the FR using a new MQTT message.



Figure 3. Map view

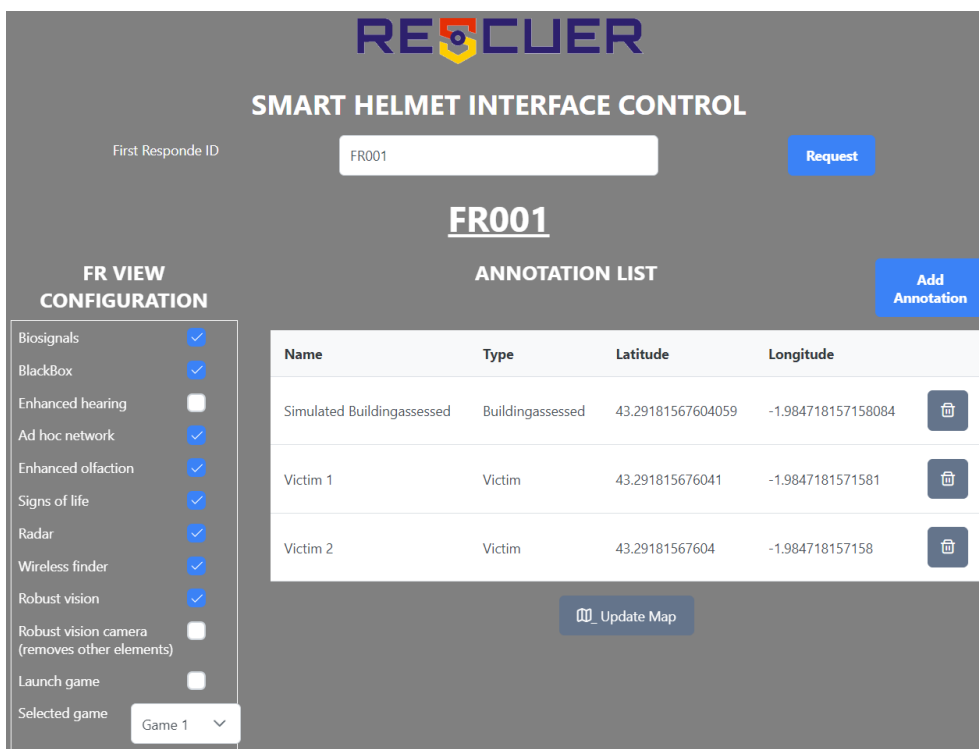


Figure 4. Interface configuration dashboard accessible from the Command Center

Smart Helmet

The Smart Helmet is a concept introduced in Fernández García et al., 2023 that refers to a regular FR helmet that has been enhanced with a display, a camera, and a processing unit in order to create a tool that can transmit information to the FR in the less invasive way possible. Each of these components has the following characteristics.

Head Up Display

A micro OLED transparent one-eyed display, integrated in a non-intrusive manner into the existing protective gear of the FR, capable of projecting AR information congruent with the environment. It includes a microcontroller in charge of controlling the brightness and orientation of the display. The HUD is mounted on a 5-degree-of-freedom mount that can be adjusted according to the user’s ergonomics. This mount is affixed on the front side of the strap attached to the helmet.



Figure 5. Draft concept of the system installed on user's helmet and the final prototype in Fernández García et al., 2023

Helmet Mounted Camera

In some situations, such as search and rescue, cameras operating at different wave frequencies, such as infrared or ultrasound, are used to penetrate through debris or adverse conditions and detect the presence of trapped people. Similarly, thermal cameras detect heat emitted by objects and people rather than relying on visible light. They are essential in situations such as fires, earthquakes, or avalanches, as they can detect bodies or heat sources even in conditions of smoke, darkness, or debris. In this case, as the objective is to verify the transmission of the frames received from any type of camera, the considered prototype integrates a GoPro, and the flow of the received frames.

Processing Unit (Edge Unit) and an External Battery

Lightweight, energy-efficient, and integrated into the FR protective gear, it will provide an efficient processing platform with capabilities to develop rendered camera images and auxiliary sensory information, resulting in an AR processing unit.

Testing in Realistic Scenario

This prototype was tested as part of the RESCUER, 2023 project, where a series of pilots were planned in which the FRs tried first-hand the technology developed in the project in different use case scenarios. Three of these international events were located in Weeze (Germany) where an earthquake scenario was simulated, Navacerrada (Spain) for mountain rescue operations, and Modane (France) for tunnel rescue situations, in the consecutive months of November, January, and October of the period 2022-2023. Among other technologies, the AR interface was tested as a displaying tool for the Smart Helmet. These tests include a first phase to train the FRs to familiarize them with the interpretation of the display. In the second phase, the FRs operated in a simulated Emergency Field and performed a series of rescue tasks: dragging victims, detecting and transmitting the presence of dangerous products, and rescuing in smoke and darkness, among others. Finally, the FRs provided feedback evaluating their experience. The statistics of FRs feedback collected during the first two pilots are published in Fernández García et al., 2023, while the third round of Modane is in progress. This feedback has been essential to evolve the AR design according to the FRs requirements. The modules of data designed for this validation use case include the following information:

Location Information

The visualization of objectives and the positions of other First Responders (FRs) is a key parameter in rescue operations. In the RescueR project, this information is represented within an outer circle (depicted in Figure 2), illustrating the names and distances to the agents and objectives, such as other FRs, victims, and dangerous obstacles. This visual representation resembles the perspective commonly observed in video games. Notably, the orientation of the FR influences the adjustment of this circle, aligning it accordingly, and facilitating an intuitive orientation in the emergency field. For instance, when the object appears at the top of the circle, it signifies its location as being directly in front of the FR, establishing an intuitive and dynamic display mechanism for spatial awareness.

Sensor Kit Simulator

The modular development of the RescueR architecture enables simultaneous progress on various fronts, allowing each center to concentrate on advancing its own technology. Yet, particularly within a European project, coordinating for testing and validating distributed work from diverse consortium members demands considerable effort. This necessity sparked the inception of the Sensor Kit Simulator concept. This software is purpose-built to simulate messages from various sensors and tools used in the project within an MQTT broker. The paper focuses on the AR interface, where the relevance of the data simulated in the MQTT broker lies in its adherence to the original messages' structure, keywords, and frequency, rendering their origin inconsequential. To achieve this, the consortium standardized a common structure, enabling each partner to determine the requisite information to transmit from their sensors. This approach facilitated the independence of tool development and progress. The design of the icons-system as a representation of the distinct modules in Table 1 has been defined in collaboration with the *Ecole nationale supérieure des officiers de sapeurs-pompiers* (ENSOSP), in order to facilitate the comprehension and integration of this tool of firefighters within their rescuer tasks. Indeed, the icons in Table 1 are distinguished in two levels, since some modules provide information registered in more than one sensor. In these cases, as shown in Figure 2, the icons of the sensors are grouped in boxes, so that the symbols of the modules are in the upper left edge (Bio-signals, Black box, Ad-hoc network, and Augmented olfaction), and the symbols of the sensors (heart and breath rate, temperature, humidity, ...) inside the boxes. This distinction of these symbols is precise in Table 1: the left column contains the icons of the modules, while the right column incorporates the icons of the multi-sensor modules to the module descriptions.

















In fact, the pilot of Mountain Rescue indicated the need to improve the AR interface in order to reduce the amount of information displayed and avoid distractions in the rescue tasks. To do this, one of the keys of the Rescuer project was to calculate the cognitive load and regulate the projection of information. Considering the recent results of Gutiérrez et al., 2023, with the available sensor kit it was not possible to measure the cognitive load directly, but it is possible to derive it from bio-signals such as respiration, blood volume pulse, and electrocardiogram. Therefore, the modularity of the interface has been designed, i.e., the selected information can be projected from the entire data stream received (see Figure 6 in the Appendix for modularity explanation purposes). An automated modularity according to the cognitive load has also been considered in the project. But without robust and sufficient results to create such automation on the DSO, it was decided to use the Control Dashboard, through which, having direct communication with the FRs of the field plus their bio-signals, the Control Center operators customize the visualization of the AR. This AR has been tested in the Tunnel scenario pilot, but due to the processing status of the statistics, the present study is considered a work in progress.

CONCLUSION AND FUTURE WORK

This developed modular platform has already been tested, and the main conclusion has been that it provides real-time information to the FR that aims to facilitate their decision-making without augmenting the cognitive load of the user. Indeed, the modularity of the created interface allows the deployment of adapted information exposure respecting FRs' physiological limitations and capacities in the Emergency Field. Furthermore, the participation of the FRs in the definition of icons and colors to represent the situational awareness-enhancing modules facilitates the training process of the FRs. Integration of previously recognized symbols in rescuer vocabulary makes more innate the information understanding through an AR interface. All these characteristics made the MMPI an AR interface, in adequate circumstances, capable of augmenting the situational awareness of the FRs interfering in a minimal way in their rescuer maneuvers. However, there may also be situations in which the technology is not supportive. A blow can damage the equipment and disorient or confuse the FR, but these are inconveniences that, regardless of the technology, can not always be prevented.

One of the next objectives is the implementation of an automatized modular exposure based on the biosignals of the FRs. This smart modular adaptivity will be an optional display mode, in order to ensure that the AR does not overload the FRs and interfere with their operations. This should be an advanced Data Sharing Orchestrator version, considering the FR working team configurations in the Emergency Field and providing appropriate information distribution. For example, there may be three distinct configurations for situations such as exploration, rescue operation, and survival mode. Each one of those would provide a distinct data layout. For exploration or victim-finding operations, all FRs may receive the complete set of situational awareness modules, especially tools that facilitate the detection of people under low visibility circumstances. On the other hand, once victims are detected, for rescue operations, individual biosignals may be displayed, but there may be an information reduction in a manner that one FR may receive contextual information (temperature, humidity, and the number of surrounding people), while a team-mate obtains other specific tool derived data. In extreme situations, minimal data should be

Table 1. Symbol description of the situational awareness modules and sub-modules

Situational Awareness enhancing MODULES	Description of corresponding sensors
	<p>Biosignals: Description of the biological signals of the FR. The color of the icons will change from green to red depending on if the values received are good or bad.</p> <p> Heart rate: Measure of the heartbeat per minute.</p> <p> Breath rate: Number of breaths per minutes done.</p>
	<p>Black Box: The black box is a device that has some environmental sensors inside; temperature, humidity and number of people around it.</p> <p> Temperature: Temperature from the environment around the Black Box.</p> <p> humidity: Humidity of the environment around the Black Box.</p> <p> People: Number of people currently surrounding the Black Box.</p>
	<p>Ad-hoc network: Information of the wireless network generated by the gateways that each FR carries during an operation. It provides information about the battery level of the gateway and the status of communications between the C2 and other FRs.</p> <p> Battery level: battery level of the gateway that both connects and is part of the generated network. The image is updated depending on the amount of battery left.</p> <p> C2 connection: Flag showing if the control center is reachable through the Ad.hoc network. If so, the C2 could send coordinates of points of interest or modify the view on the interface.</p> <p> FR connections: Number of FRs reachable within the Ad-hoc network.</p>
	<p>Augmented olfaction tool: It provides the concentration values on up to 5 type of gases, turning from green to yellow to red depending on if the gas levels are dangerous or not.</p>
	<p>Signs of life: This tools provides information if it detects life (through walls for example) it provides an estimated value of the distance to the found individual.</p>
	<p>Radar: This device shows the amount of objects that are approaching to the FR. The interface blinks when an object is approaching.</p>
	<p>Wireless finder: This device measures the distance to devices that produce wireless signals such as Bluetooth or Wi-Fi, that usually come from Mobile phones from victims under the rubble. The interface guides the FR in the initial calibration phase also.</p>
	<p>Robust vision: Displays the type and amount of objects detected by the object-detection module. It can be switched to a full camera view that will show the IR video feed with the red squares instead of the transparent view.</p>

displayed in order to ensure the safety of the FRs, e.g. providing exit location points. Therefore, the priority of modules should be analyzed according to biosignals and the risky level of the circumstances of the Emergency Field.

In summary, this approach intends to replace the necessity for manual adaptation of information by the control center, thereby implementing an intelligent version of the current Modular Multi-Platform Interface.

APPENDIX

Figure 6 illustrates the reduced information exposure in the Modular Multi-Platform Interface (MMPI). This modular characteristic of the interface intends not to overload the First Responder when its cognitive load is high.



Figure 6. Example of the Modular Multi-Platform Interface (MMPI) visualization with high cognitive load and reduced information exposition

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