An Augmented Reality Framework for First Responders: the RESPOND-A project approach

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***Abstract*—Augmented and Mixed Reality are promising technologies that can help First Responders in emergency situations by presenting the information in novel ways, extending situational awareness and supporting decision-making. However, the use of these technologies for heterogeneous types of users and roles in emergency management requires particular approaches. This paper presents an interdisciplinary approach. The proposed framework enhances emergency response operations mainly through: 1) The presentation of geospatial information in heterogeneous and interactive ways; 2) The management of aspects related to the health of First Responders and treatments of casualties of all kinds involved in the emergency; 3) The use of video as a key enabler in decision-making; and 4) Multimodal interaction capabilities to help handle the information with less intrusive ways. We present the set of components that compose this framework running on different types of hardware devices and describe their applicability in multiple challenging situations in collaboration with a larger set of tools.**

***Index Terms*—emergency support, augmented reality, mixed reality, computer applications**

I. Introduction

First Responders (FR) are specialised personnel who arrive first at a scene where an emergency has occurred. Their main objective is to protect life and property with reduced environmental impact. Emergencies and disasters can be as different as explosions, fires, earthquakes, floods, but the main common categories of first responders found in most of them are firefighters, paramedics or emergency medical technicians, law enforcement agents and, search and rescue personnel. They are organised in coordinated teams to carry out specific tasks.

In fact, emergency and disaster management consists of an iterative and comprehensive handling of emergency-related tasks. The fundamental mission of emergency management is to propose an operable, accurate, and cost-effective plan to cope with different unforeseen events. However, the life-cycle of emergency management starts before an outbreak occurs and it may last time for a complete return to normality. Four main stages are usually divided in this management procedure [1]: Mitigation, Preparedness, Response and Recovery.

Thus, the work of a first responder may not be limited to the Response stage. Their needs and operational requirements can vary a lot. Training activities, for instance, are key in order to be prepared for multiple possible situations and to know how to act, where the use of Augmented, Virtual or Mixed Reality technology is raising interest. But due to the heterogeneity of situations they face and the limitations current commercial technology may have, a significant effort is needed to identify suitable solutions that fit best first responders' day-to-day requirements in emergency response.

Heterogeneous technology and tools can be of help to support operations, ensure first responders' safety and minimise exposure to risks. The International Forum to Advance First Responder Innovation (IFAFRI), for instance, which focuses on enhancing and expanding the development of affordable technology and innovative solutions to improve first responder safety, efficiency and effectiveness, has identified 10 Capability gaps [2], from which we will address six gaps: the ability to know the location of responders and their proximity to threats and hazards in real-time (Gap 1); to detect, monitor and analyze passive and active threats and hazards at scenes in real-time (2); to incorporate information from multiple and nontraditional sources into incident command operations (4); to obtain critical information remotely about the extent, perimeter, or interior of the incident (6); to monitor the physiological signs of emergency responders (8); and to create actionable intelligence based on data and information from multiple sources (9).

This paper presents an interdisciplinary approach to using Augmented and Mixed Reality in emergency and disaster response, as part of a global set of tools and sensors envisioned to help first responders in emergency situations. The approach aims to extend situational awareness and support decision-making, enhancing operations while controlling the cognitive load, mainly through:

- The presentation of geospatial information in heterogeneous and interactive ways
- The management of aspects related to the health of first responders and treatments of casualties of all kinds involved in the emergency
- The use of video as a key enabler in decision-making
- Multimodal interaction capabilities to help handle the information in less intrusive ways

II. Literature review

In this section different works and approaches published in the literature are presented, where the use of AR, VR and MR in emergency and crisis management was studied, identifying some of the main benefits and limitations or concerns to consider before adopting the technology.

A. Emergency preparedness

Prior to being involved in an emergency situation, first responders' training is of great importance, since it helps in preparedness, leading to better emergency outcomes. The work published by Koutitas et al. [3] summarises in detail the most recent literature regarding AR (and VR) technologies for first responders training. Authors describe that "most trainings still follow the traditional exposition-type learning based on theories and examples presented on books and slide decks". Physical memory is found very relevant in order to retain and internalise the scenarios and expected behaviours, something where AR solutions can be of significant help and cost-effective for repeated training exercises when real scenario resources are limited or costly. Their proposal is focused on addressing large-scale mass casualty events by using ambulance buses. The work from [4] presents the use of a Virtual Reality tool for first responder training.

It is not until recently that Mixed Reality (MR) has been integrated into the different aspects of our daily lives. It is widely used in applications for entertainment and games, and it is also used in the medical field as a visualisation or a training tool. MR can be used for training purposes allowing workers to train on how to operate certain tools and to repeat that training without the costs implied by the normal training techniques but also without putting anyone in danger. Training in a risk-free environment also helps to focus more on the core of the information taught during the training sessions making each session more efficient [5]. Furthermore, training with MR technology not only allows to improve the spatial knowledge acquisition [6], it also improves the quality of the visuals presented to the trainees. Using 3D scenes and visuals makes training sessions more interactive and less time-consuming, compared to traditional training in a classroom setting. Also, virtual training sessions can be indefinitely repeated making MR training tools very useful technologies. To the authors' knowledge the use of mixed reality in emergency management is limited to training stages.

B. Emergency Response

Kapalo et al. [7] published an article summarising the potential uses of AR for firefighters' incident assessment, that can be extended to many other types of first responders. Some of the main points that authors identified are 1) Minimising the required user input, 2) Visualising spatial information, 3) Information filtering, 4) Video/Image capture, 5) Multi-perspective views and 6) Predicting future states.

Some other works focused on the applicability for police officers. For instance, Hoevers [8] studied assessing police officers' subjective risk perceptions of using the AR glasses for street policing, and the most appropriate settings were found to be surveillance and patrolling situations, particularly in unfamiliar locations.

A previous literature review [9] examined the application of AR in the field of emergency medicine, identifying specifically its potential in education, telemedicine, risk planning, high-risk map generation for preparedness purposes, or rehabilitation medicine for patients. This review emphasises that the results identified are promising but further application and research is required to establish the use of AR in the field of emergency medicine and preparedness. The application of AR to support paramedics as first responders has been evaluated by limited studies to our current knowledge [10], [11]. In summary, the studies that were identified are focusing on the application of AR to support triage. Broach et al. [10] concluded with positive outcomes about connecting paramedics and physicians in real-time. Collaborative triage in this manner allows to make shared decisions with knowledge of both the total demand (number and severity of casualties) as well as the supply of resources. Optimal matching of resources requires situational awareness. Additionally, knowledge of individual patients and the ability to examine them in real time may provide physicians with the ability to prepare specific resources in the hospital while awaiting the incidents. AR has also been used to visualise a triage algorithm in combination with providing telemedicine assistance by connecting a physician from the hospital to the scene [12]. Even if triage with data glasses required markedly more time AR could have tactical advantages. The authors conclude expecting a high potential in the application of smart glasses in disaster scenarios when using telemedicine and augmented reality features to improve the quality of triage.

C. Summary of limitations

As shown, AR/VR/MR devices can have great potential in the practice in the right context. In general, currently, major limitations under emergency management are: the low maturity level of some services, the extreme environmental conditions (temperature, humidity), technology resource limitations (battery life, lack of network connectivity), the lack of feasibility for the real-time quality rendering of some components and in special, the heterogeneous needs for different types of emergency first responders, which require personalisation. Solutions can be quite limited if this heterogeneity and the first responders' safety and integration at all times are not taken into consideration.

III. Proposed approach

The use of Augmented Reality for heterogeneous types of users and roles in the emergency management required a different set of approaches. A clear distinction between training and operation was done while designing the framework and this paper focuses on the emergency response operation. One of the discussions related to this was the use of Augmented Reality in the Command and Control centre. The relatively safer situation and environment of first responders working at a Command and Control centre differ a lot from the situation of those working in the field, in tougher conditions. It was agreed that the main benefit of using Augmented Reality during the operation was using it in the field instead of in the Command centre. The main reason was that, due to the nature of Augmented Reality capabilities which are devoted to adding extra information to the surrounding, being able to interact with the field situation was sought. Mixed Reality goes a little bit beyond Augmented Reality and it has been chosen together with a specific headset for supervising operations from the Command and Control centre.

Before designing the approach, nine first responders involved in the project were asked a questionnaire about multiple situations and preferences. When asked about the use of smartphones and helmets during their daily operations, six responders (67%) indicated they "do not usually wear a helmet, but could", while three of them (33%) specified that "they already wear a helmet". Six responders (67%) specified that they "can carry a smartphone sometimes", two of them "can carry a smartphone but would not be able to use it (e.g. kept in a pocket), while one responder indicated being able to "carry and use a smartphone most of the time". At the same time, when asked about the willingness or feasibility of using AR or VR devices, four responders (44%) indicated that they "could not use helmets with AR data displays without impeding operations", other four responders indicated that they "could use them sometimes" and only one of them (11%) answered they "could use them most of the time". Five out of nine responders (56%) "could use VR goggles sometimes", while four (44%) stated that they "could not use them without impeding their operations".

Therefore, the use of devices that could interfere with the use of helmets and an intensive use of smartphones were discarded, and a variety of tools with multiple types of commercial hardware devices were analysed. Some commercial devices include full headsets and they were left for the use at the Command and Control centre (Microsoft Hololens 2). Lighter devices such as smart glasses with see-through devices (Vuzix M5000) and smartphones were selected for field use. Thus, the Augmented Reality Framework is composed by multiple software-hardware solutions. Each solution is oriented to solve a specific need and handles different types of data, but they are envisioned to be horizontal across heterogeneous use cases. The set of components is shown in Fig. 1:

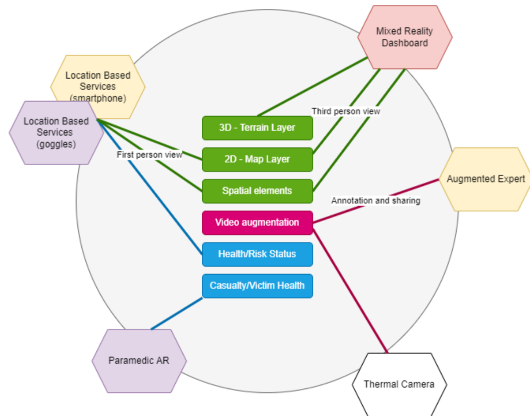

Fig. 1. Main capabilities provided by the different components

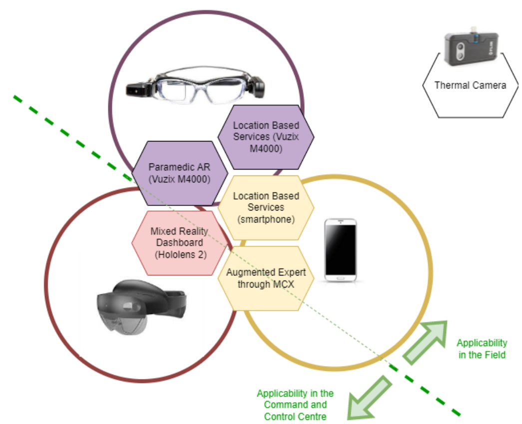

Fig. 2. Hardware devices for each solution and their applicability

- Paramedic Augmented Reality
- Location Based Services (with wearable sensor alert status). It includes two device types versions.
- Augmented Expert through Mission Critical Communications
- Thermal Camera
- Mixed Reality Dashboard for Command and Control centre

The set of solutions with the selected hardware devices and their applicability in the emergency operations in the field or in the Command and Control are depicted in Fig. 2.

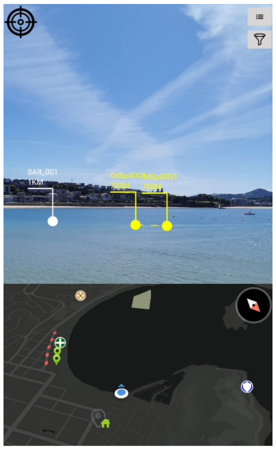

Fig. 3. Relative distance and orientation to FR and risks.

A. Global architecture

The proposed AR/MR set of components is part of a bigger platform composed by a common data middleware, a Sensor Platform, a Triage Platform, Command and Control application and Mission Critical Communications among others. Multiple sensors and wearables are able to measure and feed other components with data. In addition, drones and robots are also part of the global architecture. The details of these tools are out of the scope of the present paper.

B. Geospatial Information for location and distances

Being aware of absolute and relative location of FRs, risks, resources and task objectives is of great importance during the emergency response.

1) In the field: The main function of this component is providing and displaying geolocation-based information around each first responder using it (heading and distance to other nearest FRs, location of risks, victims...). The Location Based Services application is oriented to FRs working in the field, instead of the Command and Control centre. Mainly because Augmented Reality provides information superimposed to the surrounding scenario, not applicable, in general, to the Command and Control centre. The Android applications (for both smartphone and smart glasses version) receive all first responders' location as well as wearable sensor data indicating their health status. The smart glasses version is a simplified application and the information presented to the user is reduced to the minimum.

The FRs location information includes orientation and distance to the nearest first responders (Fig. 3), which can be of great help in low visibility situations, or when due to the distance or position, a direct line of sight is not available. Self-location is computed by the application and location from other FRs are received through a common data middleware. In addition to FR locations, augmented information regarding the position of risks and vulnerable citizens is also represented if their location has been recorded by any supporting tool (Command and Control application, drones or robots).

Polygons representing an area in the AR view are displayed as a line on the camera line of sight horizon in the smartphone version. This line is displayed at its largest width relative to the user position. For that, the algorithm creates a straight line between the user location and the centre of the polygon. Then, the furthest vertex on each side of the line is selected to obtain the largest width. While the FR is moving, their position and the relative reference points of the polygon are dynamically updated according to a configured refresh rate.

2) In the Command and Control centre: Designed for FRs operating from the Command and Control centre, an application has been especially developed for Microsoft HoloLens 2 hardware. It is a dashboard application that provides a Common Operating Picture of the situation, showing the location of all first responders and their associated information.

C. FR health/risk and casualty treatments

Monitoring health of the personnel involved in the emergency can safe lives if threatening situations are detected in advance. In addition, handling a correct traceability of victims and casualty treatment may be challenging in disaster scenarios. The following capabilities have been developed to address these challenges:

1) Self-assessment display: The sensor data provided by the Sensor Platform allow indications of the health/risk status of other first responders and the risk of themselves if they are wearing wearable sensors. To take advantage of this functionality, first responders are equipped with an alert mechanism, that will be generating alarms if specific data from wearable sensors reach certain thresholds (such as Heat Stroke risk level, Carbon monoxide poisoning level, toxic gases concentration level and radiation level). Three types of alarm are deployed in the wearable systems, with three operational states: a) No danger (green light led, no other activity), b) Moderate danger (yellow light led, low frequency beeping sound) and c) High danger (red light led, high frequency beeping sound and vibration). However, the first responder has no way to know the source of the danger, as it can be either of the four sensors mentioned above. The Location Based Services AR application is able, by using these data, to produce relevant messages on first responder AR glasses and smartphone application, informing them about the exact danger they are facing.

2) Paramedic Augmented Reality: This component allows for heads-up display for paramedics and medical first responders to display the medical history of the casualty they are treating. This history is tracked within a Triage Platform by using a digital identification tag attached to each casualty which is read by the glasses. Using this data, paramedics can have access to the casualty's history data, such as vital signs and provided treatments (Fig. 4). The paramedic accesses the casualty's health record by scanning the tag the casualty is wearing. The Vuzix AR glasses are used as an information overlay.

This solution is envisioned only for paramedics working with victims and casualties that are treating during the emer-

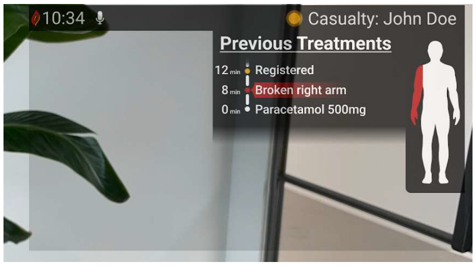

Fig. 4. Casualty treatment traceability using see-through glasses

gency. The data received will come from the Triage Platform's client application, also running in the same Android device, and will be reading the wristband information through NFC.

D. Augmented Video Components

Video enables delivering high amounts of details and information about the situation in an emergency. The proposed framework uses two ways of augmenting video: 1) enabling to add expert indications in a collaborating video streaming group of first responders and, 2) using a specific video camera with thermal capabilities.

1) Augmented Expert through Mission Critical Communications (MCX): Previous works have studied the integration of smart devices with Augmented Reality and broadband connectivity [13] to benefit during industry maintenance operations by allowing multi-user collaboration. This feature enables transmitting the difficulties encountered in solving issues and receiving answers from experts in remote locations in real-time (which action to perform, which hardware or button to press and in which order) to solve together the issue. We apply this concept to emergency management in order to put together First Responders and Experts in the same group of communication to share coordination-related indications. The group offers voice communication, video or data transmission, and added a set of tools allows for discussion enhancement among them and decide together about the actions and the order in which they will be performed. At the same time, experts are able to follow the different actions and in case of an inappropriate result ask to stop and wait or escape. Developed for Android devices, it is connected to the MCX Critical Collaboration platform developed within the project. First Responders are able to share their local video in real-time, or the Command and Control centre can share a drone video, to a specific group communication in which experts are connected. Based on the video shared in real-time, experts can point out or draw specific information which is useful for the local management to take a decision and share it with first responders in the field (Fig. 5). Experts can continue to follow the real-time video and exchange it with local management depending on the evolution of the situation.

2) Thermal Camera: A thermal camera is a device that detects electromagnetic radiation emitted from any matter that has temperature greater than the absolute zero (the thermal radiation), and converts it into visible image for the human.

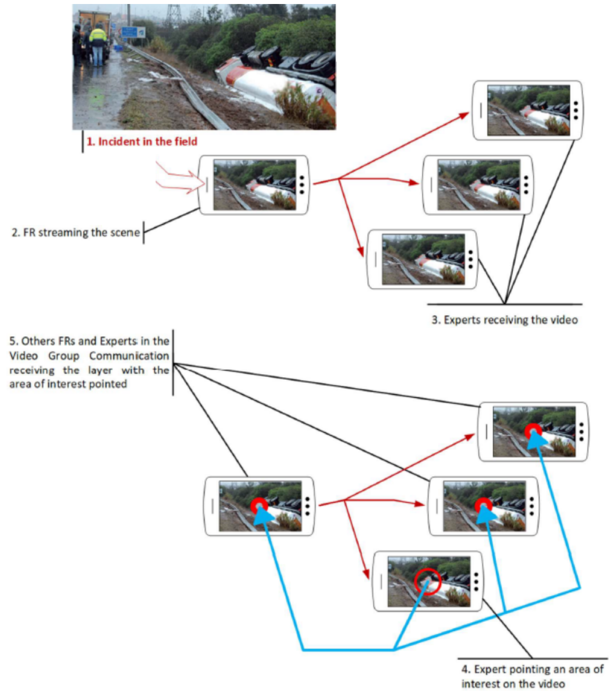

Fig. 5. Augmented expert data flow

We propose the use of a thermal camera to augment the visual capability of the first responder. Depending on the scenario and first responder needs a thermal camera can be attached to either a mobile phone, to a companion computer (e.g. Raspberry Pi) or to the AR glasses. In the first case, where the camera is connected to a mobile handset, the thermal image is shown on the FR's mobile screen or/and transmitted wirelessly to the video server of the Command and Control center. The video stream can then be acquired by any other system elements. In cases where a FR cannot hold a mobile phone, the thermal camera can be connected to a companion computer, like a Raspberry Pi. The latter, will send the thermal image to a video server through either its onboard WiFi modem or a specialised HAT or USB dongle for cellular connection. Especially for achieving a 5G connection, the SIM8200EA-M2 5G HAT for Raspberry Pi is used. In this implementation, there is an extra option of sending the thermal image from the video server directly to the FRs glasses, by using Web Real-Time Communication (WebRTC) Technology.

E. Multimodal interaction capabilities

The application within the HoloLens is managed with hand and eye gestures as well as voice recognition. This way, the navigation through the maps and different menus is done by moving hands. Voice recognition is provided by the smart glasses application for localisation services and paramedic augmented reality so that the FR can interact hands-free and can carry on with their duties. These technological capabilities were provided by the commercial devices used and our contribution was to integrate them into the flow of the software application, according to the user needs.

IV. Applicability and Expected Impact

The developed set of components is envisioned to provide additional information to help first responders during their work in a wide range of tasks. Table I describes some usual challenges and how the proposed framework could impact.

TABLE I
USE CASE APPLICABILITY

Scenario	Main challenges
Fire	High temperatures, low visibility, difficulty to reach objectives, fast response needed, very high health risks for FR. *AR/MR:* Thermal Camera, Location based services, Paramedic AR, Wearable sensors' alert status. *Supporting tools:* Robots, Wearable sensors
Smoke, toxic gases	Low visibility, limited human access, very high health risks for FR *AR/MR:* Location based services, Paramedic AR, Wearable sensors' alert status *Supporting tools:* Robots, Triage system, Wearable sensors
Missing victims or FRs	Difficulty to trace an extensive outdoor area *AR/MR:* Thermal Camera, Location based services *Supporting tools:* Drones
Hazards in critical infrastructure	High expertise needed *AR/MR:* Thermal Camera, Augmented Expert *Supporting tools:* Robots, Drones
Collapsed buildings	Difficulty to locate people, possible high number of victims *AR/MR:* Location based services, Augmented Expert, Paramedic AR *Supporting tools:* Indoor localization system, 5G, MCX
Maritime spills	Unknown extent of the spill, difficulty to estimate displacement, locate bathers and risks from the coastline. *AR/MR:* Location based services *Supporting tools:* Drones, AI

The proposed applicability is being evaluated in specific scenarios under three pilot across Europe. Two pilots have been completed in Greece and Cyprus covering a simulated earthquake and a forest fire respectively. The last pilot will be held in Spain for a truck accident with an oil spill. Therefore, the collection of the results for the complete validation is still a work in progress.

V. Conclusions

We have presented the various needs and challenges of first responders in order to be able to get advantage of new technologies, and in special augmented, virtual and mixed reality. The tasks to solve and the gears they wear may interfere when using them in some situations. Then, we have proposed an interdisciplinary approach covering the main options of using Augmented Reality as a flexible technological asset that can support first responders in their operations in multiple ways.

A unique solution to fit all needs and situations, some of them life-threatening, is not realistic at the current state of the technology and commercial devices and, therefore, different software components have been particularly designed and adapted in order to enhance emergency management with additional information sources that can be presented in novel ways. The presentation of the information has been done trying to reduce the cognitive load understanding the different tasks, situations, and varying surrounding environments that the first responders may face. We must note that the proposed framework is part of a bigger set of tools, so that they can work in collaboration.

Future work will cover full integration of the proposed approach with hands-on tests carried out by first responders in pilot scenarios covering situations such as an earthquake, a forest fire and a truck accident with oil spill near ports and maritime environments.

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