Augmented reality points of interest for improved first responder situational awareness

Kyriaki Christaki*
Visual Computing Lab (VCL),
Information Technologies Institute (ITI),
Centre for Research and Technology - Hellas (CERTH),
Thessaloniki, Greece †
kchristaki@iti.gr

Dimitrios Tsiakmakis
Visual Computing Lab (VCL),
Information Technologies Institute (ITI),
Centre for Research and Technology - Hellas (CERTH),
Thessaloniki, Greece

Ivanka Babic
Research Development (R&D) Lab,
Engineering Ingegneria Informatica S.p.A.,
Belgrade, Serbia

Guillaume Inglese
Defense and Security Business Line,
CS Group,
France

Konstantinos Konstantoudakis
Visual Computing Lab (VCL),
Information Technologies Institute (ITI),
Centre for Research and Technology - Hellas (CERTH),
Thessaloniki, Greece

Gabriele Giunta
Research Development (R&D) Lab,
Engineering Ingegneria Informatica S.p.A.,
Palermo, Italy

Anastasios Dimou
Visual Computing Lab (VCL),
Information Technologies Institute (ITI),
Centre for Research and Technology - Hellas (CERTH),
Thessaloniki, Greece

Olivier Balet
Defense and Security Business Line,
CS Group,
France

Petros Daras
Visual Computing Lab (VCL),
Information Technologies Institute (ITI),
Centre for Research and Technology - Hellas (CERTH),
Thessaloniki, Greece

*corresponding author
†http://vcl.iti.gr/

ABSTRACT

Situational awareness is a vital component of any disaster response mission, both in terms of first responder (FR) safety and efficiency. Points of interest (POI) can pertain to hazards known beforehand, risks discovered during the course of a mission, victims, entry and exit routes, important equipment, and more. Although communications and technical means can expand an individual FR's situational awareness, they depend on clarity and can increase cognitive load, as this expanded volume of information must be held in each FR's memory.

Augmented reality (AR) can visualize POIs in context with the environment in a clear and intuitive way and reduce cognitive load as the don't rely on a user's memory. This paper presents an AR solution for FR team situational awareness, comprising four interconnected and collaborating situational awareness tools sharing a common pool of virtual POIs, alongside a range of different functionalities particular to each.

Keywords

First responders, augmented reality, point of interest, UAV

INTRODUCTION

First responders (FRs) often operate in chaotic environments fraught with risks, both for civilian victims and the FRs themselves. Situational awareness (SA) is defined as a person's general knowledge about a dynamic environment and comprises 3 main phases: perception of the relevant elements (or Points of Interest - POIs), their relation to the operation goals and projection of the operation environment future states (Endsley 1995). POIs relevant to response missions can include hazards, victims, entry and exit routes, important equipment, and more. In the course of a response mission good situational awareness can have a very significant impact on FR safety, the minimization of casualties, and the overall mission's success.

Besides an individual's own, live perception, situational awareness can be enhanced by pre-existing knowledge (e.g. known static hazards, such as a shaft drop), memory (elements perceived earlier which are not currently perceived, such as a victim located in a room the FR has now exited) and the perception of other team members, command and control (C2), or technical equipment (e.g. cameras). Although the above can greatly increase an FR's situational awareness, they also raise concerns of communication clarity (how accurately a team member can communicate what they perceive) and cognitive load, as communicated information will need to be parsed, interpreted, classified, and held in memory. Information influx can reduce efficiency even as it increases the capacity for situational awareness.

Augmented Reality (AR) can visualize information in context with the real environment, and keep this information clearly stand out even in conditions of reduced visibility (e.g. smoke, low light, or changing environment). These qualities make it an ideal technology for supporting complex operations with enhanced situational awareness, while offering new perspectives for optimised cognitive load and information sharing. This work presents an AR solution for team situational awareness, acting as an semi-automated shared virtual notepad for mission POIs. Providing AR visual markers to mark the location of POIs and a collaborative system to view and manage them, FRs can have a more precise and more intuitive understanding of mission-relevant elements.

The solution includes four interconnected and collaborating tools developed in the context the EU-funded project FASTER [1], each of which participates in the creation and viewing of the shared POIs, while also featuring a range of additional functionalities:

1. A Common Operational Picture (COP) web-based application, on which POIs can be managed in the C2.
2. A situational awareness AR app that allows FRs to view the shared POIs in their corresponding location in the real world and create new POIs, while also tracking the user's location and providing additional situational awareness and navigation aids on an AR minimap.
3. An integrated UAV control app, which includes gesture control, live video feed projected in AR, and the ability to create POIs perceived by the UAV.
4. An on-demand UAV-driven mapping and AI-annotation tool, which directs a swarm of UAVs to scan and photograph an affected area, merges the photographs into a geo-localized map, automatically detects possible victims, and generates the respective POIs.

[1] https://www.faster-project.eu/

The presented solution can have multiple benefits to response missions, resulting in greater safety and efficiency:

- Reduced cognitive load, as FRs don't need to remember exactly all the POIs - they can see them on their AR displays.
- Increased intra-team communications precision, as FRs don't need to interpret verbal descriptions ("there is a risk on the first floor, about 3m beyond the stairs").
- Increased team cooperation, as individual FRs, the C2, and UAV pilots can all contribute to the team's situational awareness.

The rest of this paper is organized as follows: Related work provides a review on current solutions to FR situational awareness, including AR. System architecture describes the proposed solution's architecture, the structure of POIs, and hardware and communication channels used, while Tools includes a brief overview of the four tools collaborating in this solution. Operational use-case scenarios outlines some of the possible use-cases for shared AI POIs, and Field trial demonstration and evaluation presents both early feedback and plans for upcoming evaluation and piloting events. Finally, Conclusions and future work summarizes the paper and outlines future plans.

RELATED WORK

Situational awareness for Emergency Response

High level of SA facilitates efficient decision making and overall performance in dynamic systems as is a crisis situation. In emergency response situations, different responding agencies, with different roles are required to operate and collaborate in the same environment to pursue an overarching goal. For example in a collapsed building emergency, different types of FRs may be responsible for different mission objectives: firefighters to assess the damage, identify dangerous spots, locate and extract trapped victims; paramedics to attend to victims; and police to secure the area. In such complex situations, high level of Distributed Situation Awareness (DSA), accounting for "how whole systems perceive and maintain understanding in a collaborative complex system", is considered suitable for optimizing emergency response (O'Brien et al. 2020).

A variety of approaches on improving Situational Awareness for emergency response have been investigated and are available in the literature: Van de Walle et al. 2016 investigate how enriching raw incoming information and utilizing a central coordinator for appropriate information distribution among the team members improves situational awareness. The use of crowd sourcing and social media content is another common approach (Pogrebnyakov and Maldonado 2018, Watson and Rodrigues 2018, Basu et al. 2016). Many works utilize smart phones and tablets to provide SA tools focusing mainly in localization and mapping during crisis situations. Tashakkori et al. 2015 propose a spatial indoor/outdoor city model with embedded critical information to be used for orienting and navigating inside buildings during emergency situations. Berbakov, Pavkovic, et al. 2015 propose a smartphone-based indoor positioning system, for situational awareness during emergency situations, capable of providing information in environments without GNSS coverage. An Android application for collaborative mapping is suggested by Berbakov, Tripi, et al. 2017. In the studied case, emergency responders were able to collaborative create a map of the field and upload multimedia files in order to visually communicate the situation.

Augmented Reality for Situational awareness

Augmented Reality is defined as an intermediate state of the reality-virtuality continuum, referring predominantly to the augmentation of an otherwise real-world environment with virtual, computer graphic generated, objects (Milgram and Kishino 1994). AR is able to offer a perceptually enriched experience as real-world objects are enhanced by computer-generated information and is proven to be an effective approach to improve and assist several cognitive, operational, information-critical and SA related tasks. In an early work in the field, Sacks et al. 2013 has demonstrated a case of VR training in construction safety. D'Anniballe et al. 2020 showcased an application of AR simulation in air accident investigation. In that case, a real air-craft crash scene is recreated using AR, allowing the specialists to investigate and train using a low cost approach.

Figure 1. Concept example of an AR application for improving Distributed Situational Awareness.

In emergency management, AR has demonstrated a significant number of conceptual or market-ready applications in pre-emergency preparedness, emergency response and post-emergency recovery (Zhu and Li 2021) as AR is capable to facilitate SA and DSA; an example is presented in 1. In *pre-emergency preparedness*, Sebillo et al. 2016 used a, relevant to our approach, POI solution in 2D mapping to visualize geographic points in an AR interface for smartphones.In the same direction, Frøland et al. 2020 applied AR in live training to treat severe wound injuries after disasters. In *emergency response*, depending on the nature of the event and the case-specific conditions, there are a lot of heterogeneous tasks to be performed and objectives to be attained during a crisis event. In building evacuation cases, Ahn and Han 2012 introduced an evacuation method using AR into a smartphone. Using the application, evacuees were able to see the evacuation route as a rendered path overlaid on top of the building corridors on their smartphone displays. Sharma et al. 2020 explored a different approach for an AR-based, situational awareness improving, building evacuation application. The application goal is to help the users abandon the building fast and efficiently by presenting the fastest evacuation plan in a 3D-map visualization where the user's current position was displayed as a point and the evacuation route was indicated using arrows. In *post-emergency recovery*, AR applications are limited and focus mainly on damage assessment. Liu and Bai 2021 proposed a Building Information Modeling (BIM) based method in post-earthquake building retrofitting where operators could explore the building with detailed damage awareness in an AR environment.

SYSTEM ARCHITECTURE

Points of interest

A point of interest (POI) is defined as a specific physical position (point location) that someone may find useful or interesting. In general, it may correspond to the past, present, or future location of a person, event, device, or any other entity of interest. The term POI is widely used in cartography, especially in electronic variants including GIS, and GPS navigation software. As GPS-enabled devices, as well as software applications that use digital maps, become more available, the applications for POI are also expanding. POI data provides users information about a specific place, such as where it is located, what is its name or function, and in general what else is there to know about it.

A GPS point of interest, also known as geo-localized annotation, should at minimum specify the latitude and longitude of the POI, assuming a certain geodetic datum. It could also include other properties such as the name and/or description of the POI, and additional information such as altitude, specific POI category (or type), its status, etc. GPS applications typically use icons to represent different categories of POI on a map graphically.

Several POI types are defined, including: Switch, Valve, Risk, Victim, Exit and Equipment. These types are identified as main recognized information of interest at specific infrastructures where the tools are already demonstrated, and any additional POI types identified as useful could be easily included in this list. Some of these types could also have POI SubTypes. Examples are Water, Gas, and Electrical, which are sub-types of Switch or Valve POI types, while Electrical, Fail, Biological, Nuclear and Other are subtypes of the Risk POI type. For each of so far included types, a specific graphical symbol to represent it on the geographic map is defined, f.e. colored rectangle or triangle with specific icon and/or POI sub-type name.

Besides type and subtype, each POI has GPS coordinates, specified with Longitude and Latitude. There is also a Floor, which is used for indoor POIs, to identify the specific floor in the building where POI is recognized (e.g., -1, 0, 1, 2. . .). POI could also contain other information such as POI Header and POI Info, and other relevant metadata identifying origin of creation, such as: ID (identifier of the POI, UUID), User ID (identifier of the project logged-in user who added the POI), Time (timestamp when POI is created), Team ID (identifier of the team executing the mission on the field), and Device ID (identifier of the device used).

Hardware

HoloLens 2 (Figure 2, top) is an mixed and augmented reality headset blending holograms with the user's world and mapping its surroundings to remember where interactive content is placed. It is an optical see-through device allowing the user to see its environment naturally. It can display 2D and 3D augmentations that overlay the real world, thus both virtual and real objects appear to belong to the same environment offering a real Mixed-Reality experience. The HoloLens features an inertial measurement unit (IMU), four visible light cameras (two on each side , for the head tracking), and a depth camera, which allow it to map the environment. Over time, the HoloLens builds up a spatial map of the environment that it has seen and updates the map as the environment changes or as the user moves around. Moreover, Hololens 2 support users hand tracking; it is able to recognized the hand of the users and the specific hand gestures performed by the user. In addition, the HoloLens has built-in Wi-Fi and Bluetooth connectivity capability.

The HoloLens 2 is nowadays often used for training or education in various domains such as medical, healthcare, industrial and manufacturing, allowing it to move from a static 2D content to appealing 3D holographic scenarios. It is also a very interesting tool for marketing and design allowing an immersive mixed reality experience with 3D environments rendered over the real world. The HoloLens even moves to productive environment with the release of industrial edition validated for clean rooms[2] or field production and maintenance with a hardhat-integrated version.[3]

UAV integration has focused on DJI drones supported by the DJI Mobile SDK[4]. Initial development and testing were performed on the DJI Mavic 2 Enterprise Dual (Figure 2, bottom) and the DJI Mavic Mini. A companion Android application based using the SDK provided the interface between the UAVs and the other components.

Figure 2. Top: The Microsoft HoloLens 2, used to create and visualize AR POIs, track the position of the FR wearer, control UAVs with hand gestures, and display the UAV's camera video feed in context with the environment.
Bottom: the DJI Mavic 2 Enterprise Dual, used to test gesture control, extended vision in AR, and mapping.

Communications

Inter-tool communication was implemented through Apache Kafka[5], a message broker supporting both binary and JSON formats and incurring minimal latency. Kafka's contents are organized into topics, with POIs being exchanged through a dedicated topic accessed by the four cooperating tools. Messages are structured in a JSON format which include POI type, GPS coordinates, floor level, the IDs of the POI itself and the tool that generated it, as well as any additional info. A dedicated JSON field notes if the message pertains to POI creation or deletion.

In order to share POIs, all tools must be connected to the Internet. The COP maintains a constant landline connection, while mobile devices such as the HoloLens, connect either by Wi-Fi to a local network granting Internet access, or directly to the Internet through 4G or 5G (through tethering to a SIM-bearing device, in the HoloLens's case). In case of use in areas with no Internet access, all tool-specific services, as well as the COP and Kafka, can be deployed on a local network.

Inter-tool synergy

This simple but effective architecture allows different tools to create POIs easily and share them with each other simply by posting a message to Kafka. POIs can be created beforehand, using background information already known before a mission, or on the fly, with POIs being created and deleted as the mission progresses, risks re discovered and mitigated, victims found and rescued. Share POIs can be a valuable tool both at the C2 level, for monitoring and tactical planning, and the individual FR level, for expanded situational awareness and keeping track of multiple POIs.

As sharing is based on short JSON messages, it is easily compatible with all devices and consumes negligible bandwidth, as each message is less than 1 KB in size. The next section presents the four tools that are currently collaborating and sharing POIs between them. However, the presented architecture is easily expandable to include additional tools, such as mobile navigation apps, wearable (smart watch) apps for both warning and tagging, UxV autonomous navigation by POI, citizen localized distress signaling through external POI generation, and more.

[2] https://www.microsoft.com/en-us/d/hololens-2-industrial-edition/8mqn5pzp01x5?activetab=pivot:overviewtab
[3] https://fieldtech.trimble.com/en/products/mixed-reality/trimble-xr10-with-hololens-2
[4] https://developer.dji.com/mobile-sdk/
[5] https://kafka.apache.org

TOOLS

The presented solution encompasses four interconnected and collaborating tools developed in the context the FASTER project, aiming at increasing the safety and efficiency of FRs. The four tools access a shared pool of POIs and include the capability to create, view and/or manage them. In addition, each tool offers a range of other functionalities relevant to disaster response. This section briefly presents each of the contributing tools, describing their capabilities while focusing on their interaction with the POIs.

Common Operational Picture

The FASTER Common Operational Picture (COP) is a web-based application for improving situational awareness while handling the disaster scene's critical situation. The COP collects, normalizes, and visualizes all the data arrived from heterogeneous sources (e.g. environmental and biometric sensors, UAVs, UGVs, mobile devices, AR devices, social media analysis, weather station positions and measures, etc.), to create an overall situational picture in a single dashboard. The COP is operative with or without an Internet connection and is provided, with different privileges, to both the incident commanders operating at the control centre (C2) and the team leaders or FRs operating on the field, to give them a clear perception of the disaster scene. Leveraging on the inputs coming from project components, the COP provides a detailed picture of a current situation, even updated in real-time, in the area affected by the hazard, preserving FR safety and mitigating the consequences of a disaster more efficiently. By using the Geographic Information System (GIS) and in collaboration with other modules, the COP provides the current positions of all engaged subjects (e.g., FRs, UxVs, dogs with animal wearables, AR users), the distance between them, data about their physical state, activity status, and any other collected data. Each item on the map is presented using descriptive visual elements (e.g., color, icon, animation), making it easier to understand their type and activity. A new critical area with all specific details can be defined on the map by the commander and visualized by all users. Processing and visualizing data collected from UxVs (e.g., UAVs and UGVs) such as images and videos, gives a detailed overview of the consequences of the disaster, and a better starting point for quality mission planning. Moreover, it is possible to create a new mission using COP, to assign it to the specific team member, edit particular mission details, change its status, inspect all created missions, etc.

COP POI interface

Among all various kinds of COP functionalities of which some main are mentioned, COP also provides an easy-to-use interface for interacting with geo-localized annotations, i.e., POIs, of different POI types (e.g., risk, victim, exit, switch, etc.). This interface includes: new POI creation; inspecting all created POIs shown in the global POIs list (with view details of each); focusing geographical map at the spot of particular POI selected from the list; and deletion of POI (one which is considered as not relevant to be shown any more).

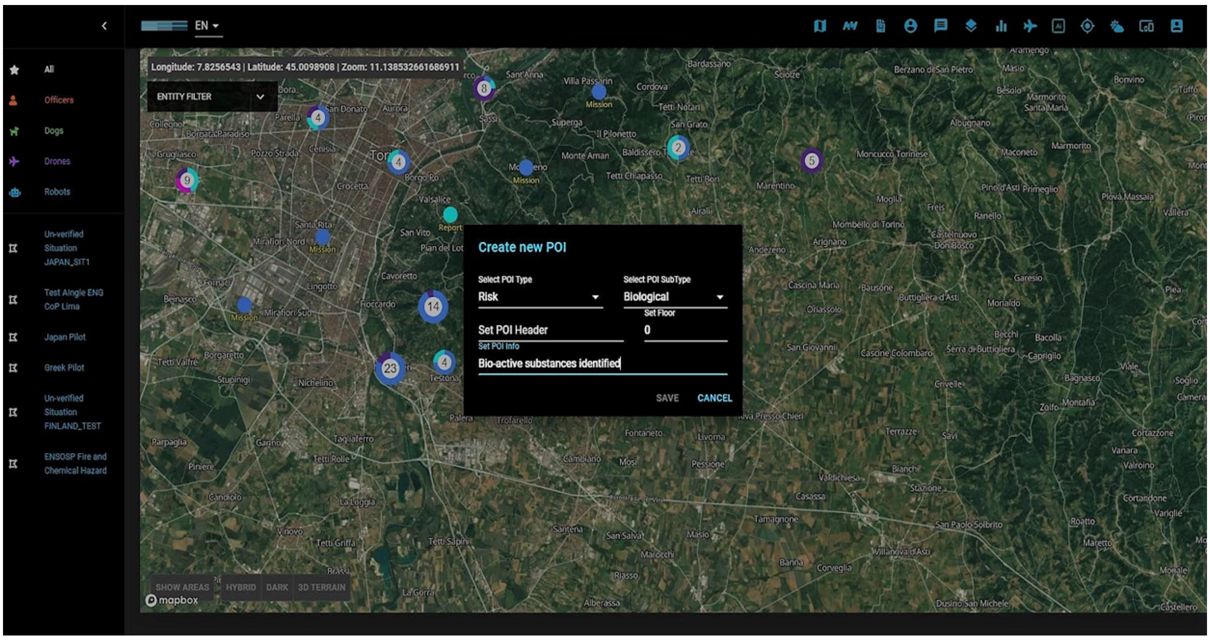

Figure 3. The FASTER COP interface, showing the POI creation dialogue.

Figure 4. Inspection of POIs in the FASTER COP.

POI creation

The COP user (commander in Control Centre) is able to create new POI on whatever geographic location on the map very easily. After a successful login, the first thing that the user will see is the interactive map which takes the most significant part of the COP's User Interface. The map is supported with clustered visualization capabilities and provides the place where all the data containing any geo-localized information is visualized. Just by a single (right) mouse click, at any selected location on the map, a simple panel for creating a new POI is opened to the user (as shown in Figure 3). Using this panel, the user can select POI Type from the list of all available, select its SubType if it is relevant, set POI Header and Info, choose a floor level, and click on save. After this, notification "POI created successfully" is immediately shown to the COP user, and it is also shared with the other POI-sharing tools.

POIs inspection

All POIs are shared between the collaborating tools and are visible on the map, using descriptive visual elements at appropriate locations. As an interactive map is usually focused on the place of the current emergency situation, that is the place where the user has a detailed view of all POIs which are relevant to that particular situation, as shown with red polygoon and various POIs inside of it, in Figure 4. Moreover, every newly generated POI is immediately added into a global list, shown at black panel at the right side of picture in Figure 4. Besides POIs related to a particular critical situation, which are already visible on the current focus of the map, this list contains all POIs belonging to other disaster situations, in different geographic areas, and therefore not visible on the dashboard at the moment. For this reason, there is a green visual circled symbol next to each POI in the list, which facilitates immediate navigation of the user to different geographic areas on the map, with automatic focus on location of the chosen POI. There is also a red garbage bin icon for POI deletion, where on click POI disappears both from the list and from the map, as well as down arrow icon, where on click all the details of selected POI are shown. In order to not overload users with multiple POI icons on the map while they are inspecting another critical issue, a blue toggle at the top of the global POI list, allows POI visualization to be turned ON or OFF.

Situational awareness AR app

First Responders are assisted in their tasks by an AR application offering targeted situational awareness and real-time collaborative capabilities enabling FR to contextually access information previously inaccessible. The AR system displays immediate threat information, mission information and its current location information to the user on an on-demand minimap. The minimap is also enriched with additional information, such as team members, victims, and POIs. Special attention has been paid to keeping the Field of View (FoV) of the user clear and displaying information primarily on-demand or on a specific area of the FoV.

The minimap

The AR application allows the visualization of a 2D map as a hologram, displayed static in the environment and placed at a comfortable distance from the FR, as shown in Figure 5. It displays map data of the area where the user is, coming from OpenStreetMap [6]. So, regardless of their location, users always have a background map available. On top of the map, the user position is indicated with a blue arrow and the user identifier. The tip of the arrow gives the user's orientation. As the user's direction changes, the map rotates to reflect the user's new orientation. Complementary to the user's current position, other FRs locations are indicated (with a green dot and the FR identifier) along with the shared POIs (displayed as icons on top of the map). Finally, when a blueprint of the building is available, the indoor layer is also depicted.

Figure 5. The minimap, as displayed in AR in the HoloLens 2. The blue arrow in the center shows the location and facing of the user. The green circle shows another team member, while nearby POIs are also displayed.

Holograms of the POIs

The AR application takes advantage of the HoloLens's capabilities to display holograms of the POIs (Figure 6) in the nearby environment of the user, thus providing them with a hands-free visualization of hazard, victims, or other important information contextualised within the real world.

As the POIs are geo-referenced, we have researched and developed means to match geographical coordinates to the HoloLens space. To do this, we used a QR Code embedding coordinates (latitude and longitude) and placed it, aligned to the geographical north, at the corresponding position in the real world. Once scanned, we retrieve the coordinates of the QR Code and place the shared POIs holograms accordingly in the environment. This mechanism not only matches the position of objects in the virtual space to a common reference system (WGS84), but it also allows the position and orientation of the user wearing the HoloLens to be tracked. In addition to the geographical position, we have also encoded into the QR code a number indicating the floor where it is placed, allowing the minimap to automatically switch the indoor blueprint and display to the user the layer of the current floor.

Figure 6. First-person view of AR POIs: the green triangle in the center indicates the location of a victim, while the red and white triangle on the left and further back shows an electrical risk.

Finally, the application also provides the FR user with the capability to create and share a POI directly from the field using dedicated voice commands or holographic buttons that pop-up, on-demand, next to their hand, as shown in Figure 7. In addition to the type of POI, the geographical position and its floor are automatically forwarded to the rest of the tools.

UAV control app

Part of the synergy of tools we developed for facilitating emergency and rescue operations, is an additional AR application for controlling UAVs using hand gestures and voice commands. The rationale behind this approach is that quite often during emergency operations FRs need to carry various tools and equipment and being able to control the UAVs without the need of a specialized controller and by using only one hand or even voice commands would by useful.

Gesture control

The user of the HoloLens 2 AR app is able to control the drone of choice using one hand (default is the right hand) and performing intuitive palm gestures that simulate the drone movement. Making the hand into a fist corresponds

[6] https://www.openstreetmap.org/

Figure 7. POI creation from the situational awareness AR app. Left: a menu presents different types of POIs as AR buttons, allowing the user to select one. Right: the POI is added and displayed in front of the user's position.

to braking and stopping, while having the palm open and the fingers extended and tilting to the front instructs the drone to move forward. In the same manner, an extended palm rotating to the right instructs the drone to turn right. When the user's hands are occupied performing another task the drone stays in place and waits for the next commands. Additionally, the user can use voice commands to perform high level tasks, e.g. drone landing/takeoff. In a similar approach, using the other hand, by default the left hand, and by performing similar palm gestures the user can control the UAV's camera viewing direction and view the video feed inside the HoloLens 2 display. Additional features include a "Periscope" mode, where the drones viewing direction follows the user's viewing direction, for example when the users rotates her head to look 10° North, the UAV turns to the exact same direction. This mode allows for a quick and intuitive inspection of the surrounding environment, a feature very useful in search operations.

Extended vision

An additional feature of the UAV control app is the incorporation of extended vision modules. 2 main tools comprise the extended vision functionality: drone tracking and contextualized video feed. In *drone tracking*, after an initial calibration process, a virtual drone object is overlaid on top of the real UAV position. This way, the UAV pilot, and app user, can have a rough estimation of the UAV's location and heading direction when flying even if it is not in her field of view (e.g when it is hidden behind constructions or if it is far away). Using *contextualized video feed*, the app user is able to see video feedback from the UAV camera displayed in the AR app. Video feedback can either be displayed on a large virtual panel filling her field of view or on a smaller panel placed on top of the virtual drone (and consequently the real UAV) position and viewing direction. This *contextualized* video feed visualization provides an easily perceivable way to the user to understand what the UAV "sees" and in which direction during flying time. Additionally, the user has the ability to choose between different video modes, RGB, infrared and a hybrid mode, its one suitable for different type of search missions.

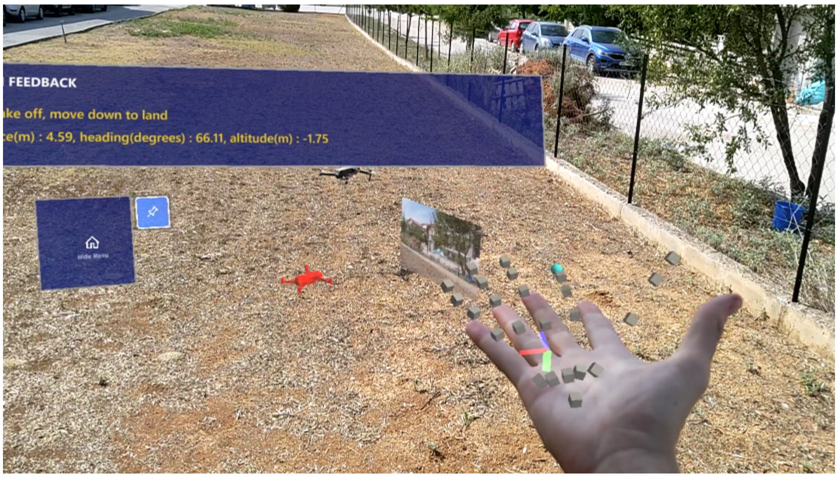

Figure 8. A capture from a UAV control application. The hand joints displacement error visible in the figure is due to the caption camera position. The AR user can see the virtual joints overlaid on the exact position of the actual joints.

Figure 8 shows gesture control and extended vision in first-person-view, including the capture of the user's right hand, the red virtual object tracking the drone's position, the video feed displayed in AR, and a navigation feedback panel.

POI creation

When the user spots a hazard, a victim, or other object of interest through the drone's camera feed, she can add a POI through the UAV control app using a dedicated virtual button available in the app's menu or by performing a predefined voice command. The POI is added to the location corresponding to the center of the UAV's camera.

UAV interface and communications

The UAV control app communicates with the drone through a UAV interface Android application, running on a smartphone connected to the remote controller. The Android application handles all communication between the UAV and Kafka as well as the direct video link between the UAV and the HoloLens. Navigation and camera control commands are received by the UAV interface app through Kafka, parsed, and forwarded to the drone. It also provides the necessary functionalities to support the mapping tool (presented in UAV mapping and AI annotation tool). The connection pipeline is the following: the AR app sends the navigation commands to a pre-configured Kafka broker and the Android app receives the commands messages and commands the drone using the dedicated controller's air transmission system. The app includes a fallback safety toggle that allows a user to disable gesture control and assume manual control of the drone using the remote controller.

UAV mapping and AI annotation tool

The UAV mapping and AI annotation tool is a suite of collaborating modules aiming at using UAVs to obtain a high-resolution, multi-modal, up-to-date, annotated map of an area of interest. The tool directs one or more drones to scan a selected area, taking overlapping photos at appropriate waypoints. The photos are combined into an orthomosaic map, on which a group of AI algorithms detect objects of interest, including buildings, vehicles, risks, landscape features, and victims. UAV mapping supports different modalities, including 2D and 3D maps, thermal maps for drones equipped with such cameras, and a fast mode that sacrifices a a very small amount of clarity to speed up the mission by not pausing flight while taking photographs.

The tool involves four cooperating modules:

1. The COP, presented in Common Operational Picture
2. The flight path calculation system
3. The UAV interface Android app, also presented in UAV control app
4. The map generation module
5. The AI annotation group of algorithms

Integration with the COP

The tool's front end is integrated into the COP, allowing a user to mark the desired area, set mission parameters such as altitude and overlap, and select one or more drones to execute the mission. When all mission parameters are set, users receive feedback regarding the feasibility of the mission and, in case of a negative assessment, advise as to how to change parameters to improve the mission's performance; e.g., if the selected area is so large that it would take the UAVs too much time to scan, the user would be warned and prompted to increase the altitude, so that the area can be covered with fewer photographs. Figure 9 shows both mission creation and the results of mapping and AI annotation on the COP.

Flight path calculation

After a mission is created, a number of waypoints are defined at which geo-tagged photographs will be taken by the drones. Waypoint locations are automatically calculated considering the altitude of the mission and the field of view of the drones' cameras, to cover the whole area with the desired amount of overlap between adjacent photos. Multiple drones split the area between them, reducing the time required for a mission and allowing the mapping of larger areas.

UAV interface app

Drones participating in mapping missions have their remote controllers connected to Android smartphones running the UAV interface app, also presented in UAV control app. The Android application receives the mission parameters through Kafka and generates a corresponding mission for the drone connected to it. After mission completion, the app collects all photos taken during the mission and forwards them to the map generation system, again through Kakfa.

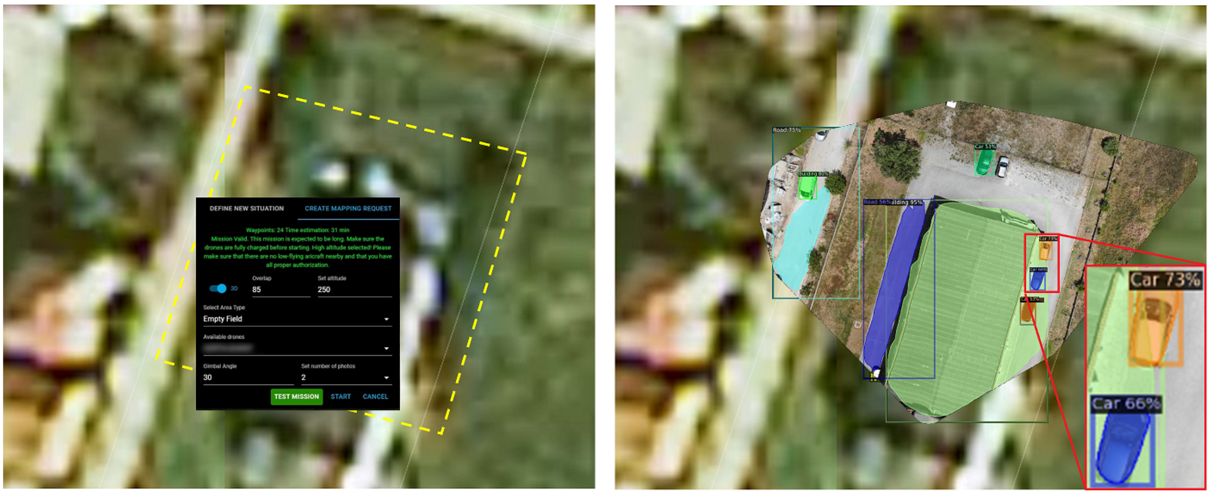

Figure 9. Mapping and AI annotation. On the left: marking an area for mapping on the COP, setting the mission parameters, and receiving feedback regarding feasibility (in green). On the right: the results of mapping as a layer on the COP map, including AI annotations (zoomed detailed shown in lower right corner).

Map generation module

The map generation module is based on OpenDroneMap[7], which receives the geo-tagged photos taken by the drones, identifies and matches features present in multiple photos due to the overlap, and constructs a point cloud, from which it creates a textured 3D mesh. A top-down snapshot of this in the orthomosaic map, used by the AI algorithms to detect and mark objects, including POIs. The module also creates map tiles compatible with digital map platforms, such as the COP, allowing the results to be easily integrated as toggle-able layers.

AI annotation algorithms

The orthomosaic map is scanned by three AI algorithms, each looking for different features relevant to disaster response:

- Faster R-CNN (Ren et al. 2016) scans for prone human figures (victims).
- ResNet 50 (He et al. 2016) scans for disasters.
- Panoptic FPN (Kirillov et al. 2019) scans for a range of other features, including, buildings and other infrastructure, vehicles, environment features, and more.

As the orthmosaic map used as input is geo-tagged (i.e. the GPS coordinates of each corner is known, and hence the coordinates of any pixel on it can be inferred by bilinear interpolation), the coordinates of detected features are also known. Hence, they can be used to generate POIs, as appropriate per mission type. Victims will always generate a POI, and other features, such as fires or vehicles, can be configured to generate POIs when these are relevant to the mission.

OPERATIONAL USE-CASE SCENARIOS

Shared AR POIs in a disaster response mission can have multiple uses, including the marking of static, previously know POIs, the discovering and sharing of additional POIs during the course of the mission, and the use of POIs to orchestrate automated vital supply drops by UAVs. This section presents these use-cases.

Known, static POIs

Known, static POIs can include entry/exit points, the location of fixed equipment like fire extinguishers, electricity, water, or gas switchs or valves, and static hazards such as falls (e.g. a shaft). Such POIs can be included in the shared pool long before a mission or the incident that triggers it. Static POIs in public buildings could, for example,

[7]https://github.com/OpenDroneMap/ODM

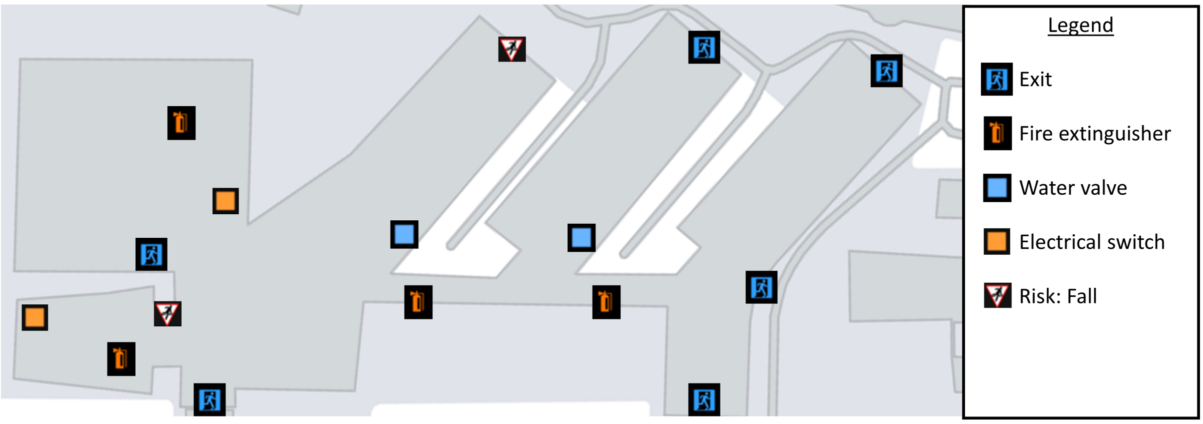

Figure 10. An example of static, known POIs in a public building. The POIs mark entry/exit points, fire extinguishers, water valves, electrical switches, and fall risks.

be noted and updated during regular inspections every few months. In a near-future, more digitally integrated society, private properties could publish their own static POIs as part of the building plans.

Figure 10 shows an example of known, static POIs in a public building. The POIs mark 6 entry/exit points, the location of 4 fire extinguishers, 2 water valves, 2 electrical switches, and 2 possible falling hazards. Equipped with this information from the beginning of a mission, FRs can navigate more safely and accurately, locate important equipment that will help them, and take additional care near marked hazards.

Dynamic or discovered POIs

Other POIs are not previously known, and will be discovered during the course of a mission. These can include the direct and indirect effects of the incident that prompted the response mission: fires, hazards related to electricity or gas, injured or trapped victims in need of evacuation and/or medical assistance and more.

Figure 11 shows examples of such POIs discovered in the course of a mission. On the lower left, an FR tags a damaged electrical board as an electricity risk. On the top left, a drone spots and tags an injured person on the roof (through the mapping tool or the UAV gesture control and extended vision app). Near the middle, two FRs discover a blazing fire. Using that tag, firefighters can move in to put it out, other specialties can avoid it, and nearby FRs, guided by the fire extinguisher POIs, can bring such equipment to the scene. Meanwhile, left of the center, a single FR discovers multiple victims and tags them all, so that the C2 can direct enough paramedics to help or evacuate them.

Figure 11. An example of POIs discovered during the course of a mission. It includes a fire, an electrical risk, and multiple victims, including one spotted by a drone on the roof in the upper left.

UAV supply delivery

Apart from visual cues used by humans for situational awareness, POIs can also be accessible to drones and used as autonomous navigation waypoints. A specialized type of POI can be used to request a supply drop at a specified point. For example, if an FR discovers a victim in need of urgent medical attention, they can tag their location with the supply drop POI and have a drone navigate to them automatically, carrying the needed supplies. This may be done in either a wholly unsupervised way, where a UAV pre-loaded with a specific type of supply appropriate to the mission flies to the POI on request; or, in a semi-supervised way, where the FR requesting the supply drop first communicates their exact need to the C2 or the drone operator, who attach the requested supplies before sending the drone to fly autonomously to the POI. Naturally, the applicability of this feature and the level of automation are highly dependent on the mission parameters

FIELD TRIAL DEMONSTRATION AND EVALUATION

Field trial description

As the AR POIs and the tools involved are part of the FASTER project, they are participating in a series of demonstration and evaluation "pilot" exercises. Two major such events took place in October and November 2021, in Greece and France respectively. Both events involved FR-designed search-and-rescue scenarios, in the context of which the presented tools were used. Besides demonstrations, these events presented local FRs with the opportunity of a hands-on experience with the tools.

Figure 12. The results of UAV mapping displayed on the COP. Zooming in, the COP operator can identify a victim laying on the ground and generate a corresponding POI.

The pilot in Greece was organized by the Hellenic Rescue Team of Attica (HRTA)[8], an NGO consisting mostly of volunteers. Ten volunteers from HRTA, including both men and women, took part in the exercise and evaluated the FASTER tools. In addition, small FR delegations of FASTER partners from France and Portugal participated actively in the pilot and the evaluation of the tools.

The pilot inf France was hosted by the École Nationale Supérieure des Officiers de Sapeurs-Pompiers (ENSOSP)[9], the French National Fire Officers Academy. It saw the active participation of 20 male firefighters, the largest FASTER pilot until that time in terms of participants.

Both exercises focused mostly on the use of each tool independently, rather than in collaboration. Early evaluation by the FRs was positive: the AR situational awareness

Figure 13. A first responder tagging a "victim" with an AR POI during the exercise in France.

[8]https://eodathens.gr/
[9]https://www.ensosp.fr/french-national-fire-officers-academy

app and the UAV mapping
tool proved very easy to learn and to use. The UAV control app provided a more intuitive way to control drones using hand gestures, easy even for users with no prior drone piloting experience. The COP acted as the focal point of everything, providing an overview of the mission's progress.

AR annotations were placed before the mission's start using the COP, marking static POIs such as exits and vertical shafts. At mission start, the UAV mapping missions were executed to perform a wide-area scan and show the state of the current situation. Once the mapping results became available on the COP , additional POIs were added based on those (Figure 12 shows the detection of a victim during the exercise in Greece). Following that, FRs equipped with the HoloLens performed a more detailed search inside and around buildings in the mission area, marking additional POIs where victims or simulated risks were detected (Figure 13). At the same time, the drone operator directed the drone to scan the roofs and other inaccessible locations, searching for additional victims.

The full synergy between all four POI tools will be further tested and evaluated in upcoming planned piloting events in Spain, Finland and Italy, featuring different scenarios and receiving feedback from FRs from different countries.

Feedback and impact

Feedback from participating FRs has been positive. The FASTER COP has a similar layout with other common operational picture tools commonly used by FR organizations. Participants praised the ease of creating POIs or requesting a mapping mission from connected UAVs. The two HoloLens applications (situational awareness and UAV control) required some practice, especially by the majority of participants, who had no prior experience with holographic displays.

Both user feedback and the observations of the technical teams, during the pilots, prompted the improvement of the tools and the inclusion of additional features:

Good connectivity proved to be a major concern during all tests. In particular, an unstable local area network in Greece caused frequent disconnections, while the thick walls of the fire-resistant ENSOSP training buildings in France meant that Wi-Fi coverage could not reach the inner rooms. Hence, future pilots were planned with more robust networking, using a Wi-Fi network on a band with no other networks, and using repeaters to reach inner rooms, when necessary.

During the exercises, the UAV interface Android app often exhibited crashes, usually during the uploading of photos after a mapping mission. This was in part due to some drones using a smartphone connected to the remote controller as their controlling device, while others used the smart DJI controller, which incorporates an Android device into the remote itself. However, the smart controller runs an older version of Android and is quite limited in terms of memory. Such crashed proved particularly disappointing in multi-drone mapping missions, as a crash in a single controller would render the whole mission invalid. This prompted a closer look into memory management and optimization, resulting in a reduction of required memory by about 70%. In addition, the app was modified to enable recovery even after a crash. Progress is now noted in a file local to the Android system, and a restart of the app after a crash allows users to resume uploading the results of a previous mission.

In terms of usability, the two-step calibration required for the correct tracking of a drone in AR proved too complex for inexperienced users, who expressed their frustration with it. After the pilots, the calibration process was completely redesigned to read a QR code, pasted either on the drone itself or on its landing pad). This improvement automates the calibration process completely, and requires a single step to calibrate both position and orientation.

Finally FRs using the situational awareness HoloLens app expressed a wish for visible feedback following the creation of a POI. Another request regarded confirmation/cancellation (ok/cancel) buttons for some actions like quitting the app or sending a distress signal. Both of these were implemented in the latest version of the app.

CONCLUSIONS AND FUTURE WORK

In this work, we have presented a unified solution for enhancing FR situational awareness by visualizing important information in AR. The core concept is shared POIs, which mark the location of hazards, victims, relevant equipment, exits, or other objects of relevance. POI visualization in AR can improve situational awareness in an intuitive way, without increasing an FR's cognitive load. By accessing a common pool of shared POIs, each team member's situational awareness expands, and both intra-team communication and communication with the C2 becomes clearer and more effective, using POIs as reference.

The solution encompasses four interconnected and collaborating tools, each covering a different set of FR needs during a mission: C2 coordination, localization and collaboration between multiple team members, and the inclusion of drones for scanning wide areas or inaccessible locations. It features a simple, JSON-based architecture that allows for the easy integration of additional tools in the future.

The tools comprising the solution have been demonstrated and tested by local FRs in two major piloting events. FR evaluation has been positive, and the technical and usability feedback, including minor setbacks, have proved useful in planning future improvements. Such setbacks include limitations of the HoloLens, whose spatial mapping can lose its tracking in conditions of low light or very uniform textures.

Hence, although the presented solution is complete, all component tools are constantly undergoing improvements to robustness and usability. Piloting events planned for early 2022 will give FRs the opportunity to test and evaluate improved versions, and highlight the full collaboration of shared POIs in dedicated scenarios.

Future plans regarding the shared POIs include:

- an additional POI type to indicate rooms already searched and clear.
- automatic generation of breadcrumb POIs to assist FRs in retracing their path or allow teammates to follow their exact route.
- support for deleting POIs using the situational awareness AR app, indicating that a risk has been mitigated or a victim safely evacuated.
- implementation of autonomous or semi-autonomous UAV supply delivery upon the generation of special POI types.

Besides the POI-related improvements mentioned above, other improvements to the comprising tools are already in development:

- detection of HoloLens's spatial mapping tracking loss and generation of an appropriate AR warning prompting the user to re-localize using a nearby QR code.
- improved and faster UAV-HoloLens calibration utilizing QR code tags adhered to the drones.
- improvements in the AI algorithms, as well as the preprocessing of the orthomosaic map input, for more accurate detection of objects, and hence POIs.

ACKNOWLEDGMENTS

This research has been supported by the European Commission funded program FASTER, under H2020 Grant Agreement 833507. The authors would like to thank the Hellenic Rescue Team Attica (HRTA - Greece) and the École Nationale Supérieure des Officiers de Sapeurs-Pompiers (ENSOSP - France) for testing the proposed system and providing valuable feedback.

REFERENCES

Ahn, J. and Han, R. (2012). "An indoor augmented-reality evacuation system for the Smartphone using personalized Pedometry". In: *Human-Centric Computing and Information Sciences* 2.1, pp. 1–23.

Basu, M., Bandyopadhyay, S., and Ghosh, S. (2016). "Post Disaster Situation Awareness and Decision Support Through Interactive Crowdsourcing". In: *Procedia Engineering* 159, pp. 167–173.

Berbakov, L., Pavkovic, B., and Vrane, S. (2015). "Smart Indoor Positioning System for Situation Awareness in Emergency Situations". In: *2015 26th International Workshop on Database and Expert Systems Applications (DEXA)*, pp. 139–143.

Berbakov, L., Tripi, F. N., Abad, A. C., Gómez, J. V., and Pavković, B. (2017). "Android application for collaborative mapping in emergency situations". In: *2017 25th Telecommunication Forum (TELFOR)*, pp. 1–4.

D'Anniballe, A., Silva, J., Marzocca, P., and Ceruti, A. (2020). "The role of augmented reality in air accident investigation and practitioner training". In: *Reliability Engineering & System Safety* 204, p. 107149.

Endsley, M. R. (1995). "Toward a Theory of Situation Awareness in Dynamic Systems". In: *Human Factors* 37.1, pp. 32–64.

Frøland, T. H., Heldal, I., Ersvær, E., and Sjøholt, G. (2020). "State-of-the-art and Future Directions for Using Augmented Reality Head Mounted Displays for First Aid Live Training". In: *2020 International Conference on e-Health and Bioengineering (EHB)*. IEEE, pp. 1–6.

He, K., Zhang, X., Ren, S., and Sun, J. (June 2016). "Deep Residual Learning for Image Recognition". In: *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*.

Kirillov, A., Girshick, R. B., He, K., and Dollár, P. (2019). "Panoptic Feature Pyramid Networks". In: *2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, pp. 6392–6401.

Liu, Z. and Bai, W. (2021). "Building Information Modeling Methods for Post-Earthquake Retrofitting Visualization of Buildings Using Augmented Reality". In: *Applied Sciences* 11.12, p. 5739.

Milgram, P. and Kishino, F. (1994). "A taxonomy of mixed reality visual displays". In: *IEICE TRANSACTIONS on Information and Systems* 77.12, pp. 1321–1329.

O'Brien, A., Read, G. J., and Salmon, P. M. (2020). "Situation Awareness in multi-agency emergency response: Models, methods and applications". In: *International Journal of Disaster Risk Reduction* 48, p. 101634.

Pogrebnyakov, N. and Maldonado, E. (2018). "Didn't roger that: Social media message complexity and situational awareness of emergency responders". In: *International Journal of Information Management* 40, pp. 166–174.

Ren, S., He, K., Girshick, R., and Sun, J. (2016). *Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks*. arXiv: 1506.01497 [cs.CV].

Sacks, R., Perlman, A., and Barak, R. (2013). "Construction safety training using immersive virtual reality". In: *Construction Management and Economics* 31.9, pp. 1005–1017.

Sebillo, M., Vitiello, G., Paolino, L., and Ginige, A. (2016). "Training emergency responders through augmented reality mobile interfaces". In: *Multimedia Tools and Applications* 75.16, pp. 9609–9622.

Sharma, S., Stigall, J., and Bodempudi, S. T. (2020). "Situational awareness-based Augmented Reality Instructional (ARI) module for building evacuation". In: *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. IEEE, pp. 70–78.

Tashakkori, H., Rajabifard, A., Kalantari, M., and Aleksandrov, M. (2015). "Indoor incident situation awareness using a 3D indoor/outdoor spatial city model". In: *2015 2nd International Conference on Information and Communication Technologies for Disaster Management (ICT-DM)*, pp. 240–245.

Van de Walle, B., Brugghemans, B., and Comes, T. (2016). "Improving situation awareness in crisis response teams: An experimental analysis of enriched information and centralized coordination". In: *International Journal of Human-Computer Studies* 95, pp. 66–79.

Watson, H. and Rodrigues, R. (2018). "Bringing Privacy into the Fold: Considerations for the Use of Social Media in Crisis Management". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 89–98.

Zhu, Y. and Li, N. (2021). "Virtual and augmented reality technologies for emergency management in the built environments: A state-of-the-art review". In: *Journal of Safety Science and Resilience* 2.1, pp. 1–10.