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Training Emergency Responders through Augmented Reality Mobile Interfaces

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Abstract
In the domain of emergency management, in addition to the constant technical skill-upgrade required by the nature of the humanitarian context, the importance of an appropriate training is widely recognized. In particular, giving responders information technology skills so that they are well prepared to address health, security and managerial concerns represents a key factor by which the goal of an efficient and effective humanitarian emergency response can be pursued. In this paper we propose the adoption of augmented reality mobile interfaces to enhance the training efficacy for on-site crisis preparedness activities. The system we propose originated from the idea to allow trainees to exploit Augmented Reality (AR) interaction and become quickly familiar with the mobile technology adopted today in emergency response activities.

Keywords - Emergency Management, Mobile Interfaces, AR-based Training Applications, Information Sharing, Situation Awareness.

1. Introduction

When an emergency has just occurred, the goal of organizations and agencies involved in the response phase is to reduce the number of victims and damages and restore quickly a safe situation.
Within this context, the usage of the Emergency Response Information Systems (ERIS) for the management of the activities to be performed is largely promoted by several agencies, along with the involvement of trained personnel for their immediate deployment.
Literature shows that the usage of Information Technology (IT) has undoubtedly improved the whole emergency management process by providing decision makers with profitable tools to support their activities (Petak 1985; Carver and Turoff 2007). In particular, the four phases of the emergency management process (preventing, preparing, responding and restoring) have significantly benefited from the adoption of integrated systems where procedures and standards are embedded within seamless infrastructures. Moreover, relying on efficient organizational structures and effective mechanisms for collaboration among operators represents a key factor when designing an emergency management system. In particular, the emergency preparedness and response phases include actions taken prior as well as during and after a disaster event in order to reduce human and property losses. Such actions can be performed only if an overall view of the evolving situation is available to those who make global strategic decisions from a Command and Control Center or Centro Operativo Comunale (COC), and to those who perform actions on the ground.
However, as argued by Jennex in (Jennex 2004), during a real situation where people are under stress, the use of emergency information systems is often hindered by the lack of familiarity with them. Unfamiliarity can notably impact the effective use of a new technology in crisis situations. Therefore, in addition to the constant technical skill-upgrade required by the nature of the humanitarian context, the importance of an appropriate training is widely recognized by all the actors playing a role in the emergency domain. In particular, giving

responders information technology skills to be well prepared to address health, security and managerial concerns represents a key factor by which state and local organizations and agencies can pursue the goal of an efficient and effective humanitarian emergency response. Moreover, as stated in (Ginige et al., 2014), enhancing the role of the on-site operators can improve the collaboration among responders, and provide all the actors with an increased situation awareness about the crisis evolution. Situation awareness and shared mental models is gained when information is gathered from multiple perspectives, acquired from the environment, or received by voice, or encoded in artifacts (Toups et al., 2011). In this paper we propose a solution to the general concern of training emergency responders so that they become familiar with the adopted mobile technology and hence benefit from the enhanced situation awareness. Our proposal combines the pervasiveness of mobile technology, its adoption for collaboration purposes with the intuitive interaction gained through augmented reality, and its capability to engage and motivate trainees, also thanks to the impactful visual cues provided by a visualization technique named Framy (Paolino et al., 2010). In particular, in this paper we propose an AR-based training system that, through two different interactive visualization modalities, MapMode and LiveMode, leads the trainee within a scenario enriched by a virtual content where data can be aggregated and associated with visual metaphors. MapMode corresponds to the classic two-dimensional map view, LiveMode instead exploits scenarios enriched by virtual contents. By performing a set of suggested activities the trainee acquires familiarity with the underlying technology both in terms of functionality and participation in the whole decision making. As a matter of fact, he is immediately informed about the effect of his interaction because the collaborative artifacts reflects the impact of his data both in an analytical and synthetic manner, thus improving the situation awareness.
The remainder of the paper is organized as follows. Section 2 presents some related research on training methodologies and techniques in the domain of emergency management. Section 3 recalls the technology, which underlies the AR-based training system. In Section 4 we explain how the proposed training system works, describing its adoption inside a realistic scenario of use during a training session. In Section 5 the system architecture is described. Some conclusions are finally drawn in Section 6.

2. Related work

Emergency management is a critical and continuously evolving research area, where each single step to improve either methods or tools make a significant contribution towards reducing human lives and resource losses. The awareness about this stimulates professionals and researchers from the crisis management field to devote much effort to define future research directions, whose results are in fact essential for drawing up an agenda by public institutions and Civil Defence agencies to identify sectors where investments could produce effective solutions. Geology, construction science, structural engineering, material science and technology are some examples of individual sectors where improvements can be made. The crisis management field could benefit from the advances in these sectors. Information Communication Technology (ICT) represents an across-the-board sector that would contribute to enhancement in all aspects of crisis management. Currently, ICT already supports several aspects of crisis management and it is paramount in some relevant phases. It is in fact possible to quickly learn about a crisis and undertake some activities whose promptness is fundamental. Further ICT advances are required anyway, which could enable teams of practitioners to quickly make the appropriate actions so as to further decrease losses both in terms of people and damages (Carver and Turoff, 2007). Towards that goal, several research directions have been identified, all sharing the observation that experiences of different actors and contributions from relevant domains represent the only means to achieve stable and reliable solutions for the crisis management (Petak, 1985).
The goal of this Section is to draw the state of play with respect to an aspect of crisis management, which is considered essential for the achievement of effective and efficient solutions, namely preparedness through appropriate training activities.
The re-creation of realistic environments where emergency response simulations can take place is considered paramount for effective training in emergency situations (Drabek, 2003). Jackson et al. (2004) underline the importance of training activities that rely on realistic operational or situational scenarios. They also highlight that by learning from the effects of simulation training, crisis management agencies may gain better acquaintance with respect to the preparation for actual event management. Such beliefs have greatly encouraged the use of Virtual Reality (VR) to simulate crisis management activities as a way to increase safety standards, while retaining efficiency and reducing training costs. Similar benefits have been long experienced in the general field of education and training, where the adoption of VR intelligent simulators, having knowledge of correct, or appropriate, responses to situations, allows the training system to guide the trainee,

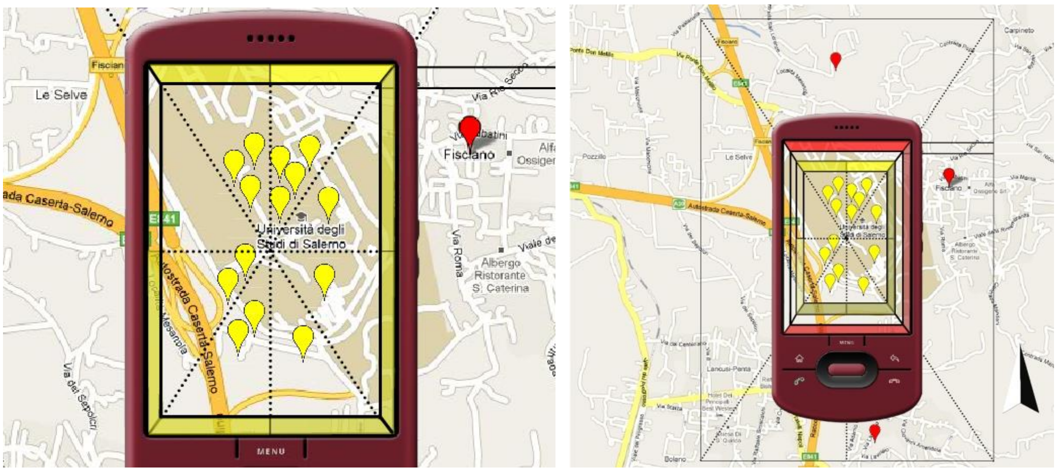
either to teach a correct procedure or to assist the user in making appropriate corrective action (Johnson et al., 1998). Compared to traditional training techniques, the trainee becomes an actor of the simulated scenario and improves his/her cognitive and spatial skills and understanding through practice.
Several systems have been proposed to assist emergency management teams during training activities within immersive environments. (Houtkamp and Bos, 2007). However, one issue with the adoption of 3D virtual environments is that their construction is hard and in most cases restricted to specific emergency situations.
Aedo *et al*. have suggest as a solution the design of emergency services training software tools for Emergency Planning, which are highly configurable, easy to use, and capable of reproducing different scenarios (Aedo, Bañuls, Canós, Díaz and Hiltz, 2010). With their simulation authoring system they emphasize the need to allow simulation designers to overcome problems related to the complexity of 3D virtual environments and to represent realistic situations and different action paths that can support the training processes. We fully embraced this thesis and decided to investigate the use of AR technology as a way to increase trainees' engagement and motivation. The system we propose originated from the idea to enhance the efficacy of existing training procedures allowing emergency responder trainees to exploit AR interaction and become quickly familiar with the mobile technology adopted today in response activities.

3. Background

In this section we briefly recall the technology, which underlies the AR-based training system we present. In particular, we describe the information visualization technique Framy, the AR mobile interface Link2U and the spreadsheet-mediated collaborative system developed for emergency management.

3.1. Framy

Framy was explicitly conceived to enhance geographic information visualization on small-sized displays through qualitative synthesis of both the on- and off-screen space (Paolino et al., 2008), (Paolino et al., 2010). By displaying semi-transparent colored frames along the border of the device screen, users are provided with clues about the object and phenomena distribution. Each frame is partitioned and colored with a saturation index, whose intensity is proportional to the result of an aggregate function which summarizes one of the properties of the objects and phenomena located in the corresponding map sector either inside or outside the screen. The higher the result, the greater the intensity.
Figure 1(a) illustrates a mobile device embedding Framy. The frame is partitioned into 8 yellow colored portions. The intensity of each portion is proportional to the number of Points of Interest (POIs) located around the map focus.



1(a) 1(b)

Fig. 1. (a) An example of (on/off-)screen subdivision accomplished by Framy. (b) A snapshot of Framy where two frames are visualized

In case information associated with different kinds of objects and phenomena is contemporary requested, nested frames may be visualized along the borders, each one corresponding to a different aggregate with a different color, as shown in Figure 1(b).

The goal of the present work has been to embed Framy into applications meant to support on-site responders and decision makers working on field in critical situations. As a matter of fact, they need to identify more convenient solutions which may not be directly seen from elsewhere, and evaluate constraints not detectable from remote sensors. Thus, the availability of a qualitative overview is relevant to this aim and the Framy capability of summarizing properties, even not visible, is a fundamental requirement for the achievement of informed and reliable decision making.

3.2. *Link2U*

Link2U is an integrated solution for mobile devices which combines the potential of augmented reality with the ability to “communicate” of the social network (De Chiara et al., 2010). In particular, it was conceived to meet mobile users’ requirements of continuously acquiring information about the surrounding environment, essential for their activities. A member of a Link2U group (SNU: Social Network User) can invoke several functionalities and advanced services where mobility comes into, such as services that support navigation and location based services (LBS).
Figure 2(a) shows the MapMode visualization modality that corresponds to the classic two-dimensional map view, where paths and geographic objects of interest are drawn on the map. In Figure 2(b) the LiveMode visualization modality is instead shown that exploits the augmented reality both to improve users’ sensory perception about objects located inside the camera visual field, and to provide visual clues of those located beyond that can be visualized as aggregated data. Moreover, in order to avoid confusion due to SNUs crush on the screen, a grouping metaphor could be used, which consists of two alternative approaches. The former extends the Framy visualization technique by visualizing an arc on the bottom of the screen. It represents the portion of the world bounded by the camera visual field, divided according to the corresponding sectors and colored according to the number of the captured SNUs. The latter approach is meant to map the Areas of SNU Aggregation (ASA) where SNUs are used to gather. Such places are represented by icons when the SNU number / ASA surface ratio is bigger than a threshold value. The presence of those icons evoke the presence of a set of SNUs as shown by the associated label.

Fig. 2. (a) MapMode visualization of POIs and users' position. (b) LiveMode representation of a user's position

The goal of the present research is to embed both the two visualization modalities and the grouping metaphors in order to enhance the expressiveness of the whole interaction and visualization technique. As a matter of fact, starting from an overview of the surrounding world, captured through MapMode and then LiveMode, visual clues can help users generalize or detail the content of a given space. In particular, the grouping metaphors can be useful both in case of a region of interest not directly visible through the camera, and in case of SNUs falling within the camera view. Moreover, the integration of AR-based functionality can enhance users' awareness about a situation and provide them with an improved user experience.

3.3. *Interactive Spreadsheet-Based Collaboration*

The work described in (Ginige et al., 2014) represents a solution to some relevant requirements distilled during one of the earthquake simulation events that the Italy Civil Defence Agency periodically organizes in seismic territories. Basically, it was highlighted that reliable and timely information sharing among members of distributed teams of disaster responders is paramount for the success of the overall response process. As a

result, a spreadsheet-mediated collaborative system was proposed that combines the advantages of mobile devices with the high potentials of spreadsheets for supporting operators acting on a wide geographic area and requiring advanced tools for geodata collection and management. Figures 3 show how quantitative and qualitative aspects of a situation can be displayed and shared on the same device. In particular, Figure 3(a) shows a spreadsheet shared among on-site operators about census information of a gathering area. In Figure 3(b) the same information is summarized and visualized through the Framy visualization technique.
A further significant aspect is that in order to build a collaborative system prototype, a participatory design methodology has been adopted, in which representative users and stakeholders were involved since the initial phases of problem analysis and requirements specification and throughout the whole design/evaluation process. This approach guaranteed the full adherence of the resulting system with the expected results.

Fig. 3. (a) the spreadsheet-based information and (b) the Framy view of it

As for the present research, the goal is to use that system also as a means to allow users of more complex systems to acquire familiarity with the underlying technology. Indeed, thanks to the approach followed in the design phase, many relevant requirements still hold for complex systems. Then, they can be satisfied by simply extending the prototype functionality, provided a similar underlying principle.
In the next section we explain how the proposed training system works, describing its adoption inside a realistic scenario of use during a training session.

4. Improving trainee's experience through Augmented Reality

Our research work evolved from the field of earthquake management in Italian high-risk areas. In (Ginige et al., 2014) we described a contextual inquiry conducted in collaboration with the Civil Defence Agency of the town of Montemiletto, in the South of Italy. We observed the emergency management activities carried out during one of the simulation events which take place every six months and were able to develop the spreadsheet-mediated collaborative system mentioned in the Background section. As a result of the contextual inquiry, we were able to understand the importance of the training activities carried out through periodic simulations. We realized that the development of an emergency plan ends with a validation phase aiming at facing possible exceptions caused by both human factors and temporary objective impediments, such as a work in progress on a road network. During that phase targeted training activities are scheduled which may contribute to tune the involved parameters (residents, personnel and tools) of the underlying protocol, by taking into account both general requirements set by national regulations and local availability and supply. Final results consist of modifications and instructions to be integrated within the initial intervention model.
In the present section we depict a scenario illustrating how the system works when it is used for training sessions addressed to the emergency responders. Basically, two main categories of actors are considered, the designer of the simulation scenarios and the system stakeholders. The first category comprises people involved in the design of the simulation tasks with a deep experience in the field of the emergency management and in the conception of related evolving scenarios, for training purposes. The system stakeholder category includes

people from the emergency response team, who have to learn both the system functionality and the protocols for the emergency management.
In order to support the first category the system has been conceived so that a simulation designer (i.e., an emergency trainer) can configure a number of events related to an emergency situation. The aim is to provide emergency trainers with a usable tool by which as many realistic situations as possible could be simulated. In this sense, an important characteristic of the system is its capability to describe evolutionary events. In fact, in most cases, real events do not limit their effect to only one moment but evolve over time as a sequence of successive sub-events which recovery teams should manage. For that reason, data input by simulation designers have both a spatial and a temporal component which allow to uniquely identify an event in terms of space and time.
In the following scenario, designers have simulated an earthquake situation where the first shake causes most damages to buildings and to people while a second successive one damages only some roads and produces a few displaced persons. The trainees should be able to manage the first situation as well its successive evolution.
In agreement with the emergency plan of the Civil Defence Agency, the territory is divided into zones on the basis of the population density and the number of buildings. Each zone includes residents belonging to a set of contained or overlapped roads. A zone is classified as a gathering area if it contains a wide open space where people can converge and wait for assistance. If such a zone can also be reached through a large accessible road, it becomes an area for gathering reinforcements. Finally, a zone is transformed into a sheltering area if some facilities are also available, such as power and water connections.
The simulation scenario takes place in Battipaglia (Salerno), a city in the South of Italy (Geographic coordinates 40.617°N 14.983°E). The land surface is 56 km^2, residents are 50,485 and the density of population is 8.9 resident/km^2. Basic information about the simulated situation is initially shared among participants, as follows. The territory is divided into 4 gathering area (GA1, …, GA4) and 3 shelters (S1, S2, S3). Each GA is associated with three local responders, namely the Medical Doctor (MD), the Environment and Territory Expert (ET) and the Public Employee (PE), while a Decision Maker (DM) is located in the COC. DM, supported by MD, PE and ET, has to make decisions on how to distribute evacuees across the shelters on the basis of the information and suggestions received by the ETs located in each GA. The decision is made taking into account the number of people to evacuate, information about their family composition, the number of vacancies at each shelter and the status of the roads.
For the sake of simplicity and without loss of generality, we decided to restrict the description to only one GA, since similar activities are expected to take place in all GAs.
At time t0, the city has been struck by a 5.7 Richter earthquake. The situation trainees are facing includes some people to evacuate, the status of some roads to evaluate as well as the condition of some buildings, after the first earthquake has occurred. Figure 4(a) shows the initial configuration, the green line identifies the gathering area (GA1) while the cyan area indicates the associated shelter. Red polygons highlight seven crashed buildings. Some of them are also associated with a red cross which identifies places where people have died or are injured (black and blue numbers, respectively). The configuration map contains also the coordinates where roads are interrupted and traffic must be redirected, a no-entry signal is used to illustrate those interruptions.
At time t1, a new 4.1 earthquake strikes the city and two other buildings are damaged. In particular, two people from the lower building and one from the upper are injured. In Figure 4(b) the black rectangles on the map show the zones impacted by the second earthquake.

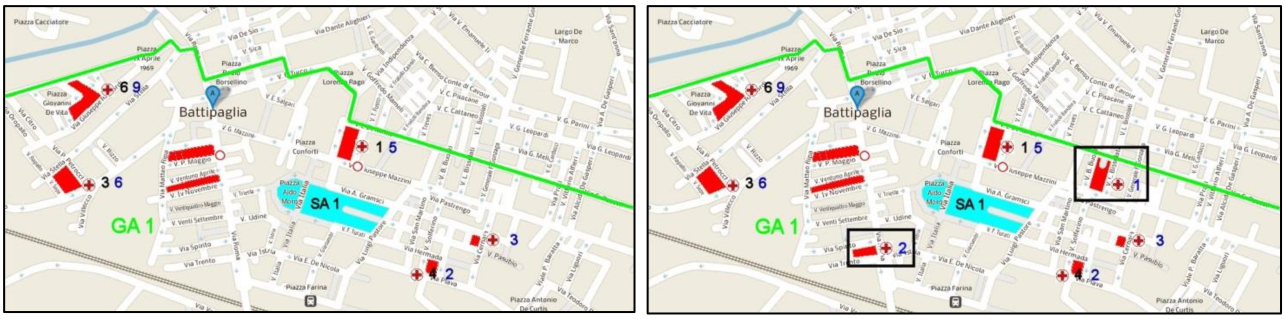


Figure 4. (a) the configuration map at t0 time, and (b) at t1 time.

The configured map is deployed by on-site responders/trainees to start the simulation phase, through the usage of a tablet in see-through modality.
Figure 5 shows an example of a see-through image appearing to the trainee. Basically, in order to understand whether a building is damaged, the trainee should reach it and verify its current status. To make the status of a damaged building immediately evident, in the LiveMode modality it appears surrounded by a red line filled by a semitransparent red color. Moreover, information concerning the building and the associated GA is visualized on the left side. On the top, *Building info* summaries the current situation about people living in the building, e.g., 4 families, 15 persons, the number of the currently recorded ones, the number of missing people, and finally, their health status, e.g., sane, injured or deceased. In this way, the trainee has an immediate view of the situation and can perform the appropriate operations. On the bottom, there is a general description of the gathering area he is managing. This can help him have a complete view of the emergency management plan execution.

Fig. 5. The building as it appears to the trainee when its status is changed to crashed.

Once the trainee has reached the building, he has to perform the actions expected by the protocol. Each action is simulated on site and then it actually results in an interaction with the underlying system, such as notifying the building status and updating any number about the Building info. In particular, when the trainee recognizes the current problem he needs to verify both the status of the building and the condition of people living there (as shown on the top-left side by the training software). In this case, the trainee can interact with the other software components, namely Framy and the collaborative spreadsheet. Framy allows him to identify the building on the map through the MapMode view. Then, he has to update the new status, as shown in Figure 6(a). Moreover, he has to add information about the current status of residents starting from data shown in the AR-based LiveMode view. In this example, four families live in the building, 13/15 persons have been recorded, 2 of them are injured while other 2 are missing. Figure 6(b) illustrates the spreadsheet with which the trainee can interact in order to list residents and update their status.
Once he has completed the survey, his modifications immediately appear in the AR-based LiveMode view and the area surrounding the building is set to green, as shown in Figure 6(c).
The usage of the AR-enriched LiveMode view along with the collaborative spreadsheet and Framy allows the trainee to immediately provide the COC with information about the current crisis evolution. Moreover, he is timely made aware of the contribution he has produced within the task thanks to the prompt update displayed on the screen. This aspect is fundamental to gain a more collaborative involvement by trainees during the training session because it generates a greater situation awareness and stimulates confidence in the new technology.

Figure 6. (a) the Framy interface for updating the building status, (b) the spreadsheet for people status insertion, (c) the new AR-based view.

5. System architecture

Users of the proposed system belong to two main actor categories: the designer of the simulation scenarios and the system stakeholders. In this sense, the client-server architecture on which the system is based reflects the dichotomy of the actor categories: experts-server vs trainees-clients. In particular, this architecture may be decomposed in several components. As shown in Figure 7, some components, such as SIRIO, are provided by third-party and are necessary for preserving experts' knowledge and handling the current emergency management processes. In particular, the server side consists of three modules fully interoperable with SIRIO. The first one is addressed to the global management of the system, it integrates SIRIO with the other modules in a single environment and distributes data among parts. The information sharing is managed by the Information Sharing Module (ISM) while the training management is delegated to the Training Management Module (TMM). Basically, the ISM module captures the information generated by the SIRIO module in order to share it with clients and, vice versa, it receives information by the clients and forwards it to SIRIO to be computed. The TMM module works as a client even though it is located on the server side, it is necessary to build scenarios for the trainees. It embeds a GIS and allows to describe the evolution of the emergency in a real-time mode. In fact, the changes applied to the emergency map are automatically sent to the ISM and then to the clients. When they receive those updates, they manage them by using the VR module located on the client side.

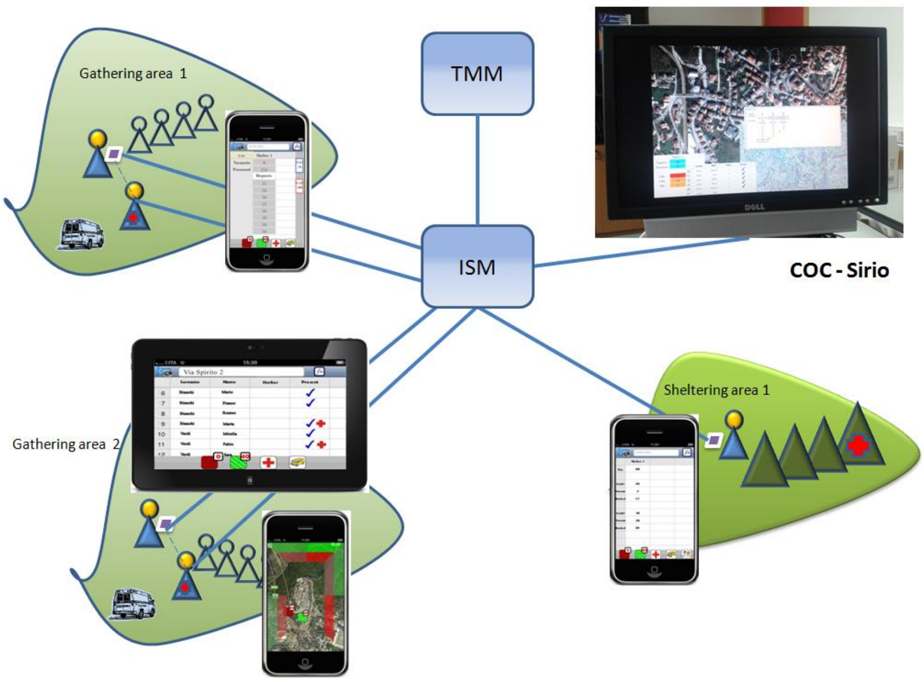


Fig. 7. The use of the collaborative system during a simulation session

As previously stated, in order to contribute to the designers' activities we developed a GIS module (TMM) where it is possible to set a number of events for featuring emergencies, such as the position of evacuees, the status of some roads and the condition of some buildings. An important characteristic of this system must be the ability to describe evolving events made up of successive sub-events. As an example, when designing an earthquake simulation the designer might plan an event where the first strike causes most of damages to buildings and injured while the successive strikes damage only some roads and produce a few displaced persons. Consequently, the trainees have to manage both the first situation and its successive evolutions, by taking into account that decisions and actions taken in the first phase have an impact on the subsequent ones. In order to satisfy this requirement, the system embeds a temporal GIS where data consists of a spatial and a time component.

On the client side, the main components are Framy, the shared spreadsheet and the AR module. As for Framy, a fundamental requirement is that the trainee should be able to comprehend changes also in terms of temporal crisis evolution. Thus, colored frames are used to represent comparative views of the same zone. This capability is important from a training point of view to acquire a complete browsing experience useful to improve responders' familiarity with new technologies. Details about the aggregate values associated to each sector, such as the number of POIs, the POI names or their distances from specified locations, may be required by tapping on the corresponding sector. The prototype featuring the present version of Framy has been developed by using Google API for the Android platform. It represents a framework specifically conceived for geographic mapping visualization and allows users both to download maps from Google Maps and to manage many typical GIS operations usually required from navigation devices. Moreover, based on tactile input and non-speech sound output as alternative interaction modalities, the prototype also offers a more appropriate interaction for users who experience difficulties due to specific environmental conditions (Paolino et al., 2009).

The AR module exploits Link2U. Here, trainees can exploit both mobile devices and laptops, which are commonly provided with an integrated camera for video-image capture, a Global Position System (GPS) device to detect the position, a compass and motion sensors to detect user's point of view. In an AR-enhanced LiveMode view, visual metaphors are superimposed on the image captured by the camera phone where phenomena and objects of interest are visualized.

Finally, as explained in Section 3, the collaborative work is based on the shared spreadsheets, where the communication between the central application SIRIO and the mobile application exploits web services based on Apache Axis 2 and Apache Tomcat. Further details on the underlying collaborative system can be found in (Ginige et al., 2014).

6. Conclusions

Starting from a productive field trail acquired in the domain of the emergency response, in this paper we propose an innovative approach to address the general concern of training emergency responders, which integrates some recent results from the field of information visualization, spatial data management and human-computer interaction. In particular, by taking part to simulation events we were able to elicit users' requirements and recognize that a constant skill-upgrade and an appropriate technological training represent two key factors for pursuing an efficient and effective humanitarian emergency response.

This paper shows how an advanced visualization technique embedding visual summary metaphors could be integrated with AR functions in order to support responders in acquiring familiarity with new technologies and thus be well prepared to face health, security and managerial concerns.

The goal of the system is to make the trainee confident with specific functionality by reproducing sequences of activities to follow in agreement with the protocol established by the Civil Defence Agency. In particular, the system provides the trainee with a scenario where an emergency situation is simulated. Through the interaction with a mobile device, the trainee is requested to perform some specific tasks that might result difficult to perform during a real situation where people are under stress. Such scenarios can be customized according to the skills of each trainee, thus bridging the gap between a specific technology feature and the responder who is going to use it.

An initial analysis of some demonstrator training sessions has confirmed that the AR functionality supports trainees when building their personal mobile experience with new technologies. They benefit from a low cost "ubiquitous learning" made available to all thanks to the pervasiveness of the necessary hardware. Moreover, the involvement of professionals and volunteers in designing personalized training sessions reveals to be important in order to obtain a higher level of matching between a virtual content and a real emergency situation.

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