Command & Control: Information Merging, Selective Visualization and Decision Support for Emergency Handling

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ABSTRACT

Emergency situations call for the timely collaboration and error free communication of first responder (FR) teams from their Command Posts (CP) and between themselves. First responder teams must form and adapt their plans and actions as a real-time critical situation unfolds. This paper presents an advanced Command Post application that manages a diversity of FR teams during an emergency. Data from biometric, fire and/or gas sensors in addition to received annotated videos from first responders on site, carrying personal digital assistants (PDAs), are simultaneously managed. The presented system provides properly configured access to and alert-dependent visualization of real time location, biometric, gas, fire and annotated video data from FRs in the field to allow for effective reaction and decision support from CP personnel. Additionally, the system forms an information management system for all necessary information to be quickly handy during emergency handling, such as FR information, critical infrastructure information, historical information, etc. This system has been validated through qualitative analysis in a field trial at the M30 tunnel in Madrid by participating end users.

Keywords

Command post, crisis management, first responder, information merging, visualization, decision support, formal communication, wearable sensors, video annotation, enhanced communication.

INTRODUCTION

When scanning the many disasters that struck Europe over the last decades, focusing on the Energy and transportation sectors, it can be seen that most of the devastating disasters to Critical Infrastructure (CI) sites are man-made (i.e. terror attacks) with the transportation sites to be more prone to terror attacks than the energy sites. Besides the heavy toll in human life and injuries, these disruptions of the public transportation have adverse effects on the traffic of people and goods in the whole country and maybe also in neighboring countries. Furthermore, physical phenomena such as earthquakes or physical disasters such as fires and gas leaks lead to equally devastating end results for human lives and properties as well as disruptions in the everyday operation and economy of a town or country. A timely and efficient response to such crisis situations leading to both the saving of human lives and property as well as to a quick restoration of service will minimize the disruptions to the traffic or other everyday city/country operation and minimize the collateral damage caused by such disruptions. The response and restoration of emergency situations call for the collaboration and coordination of different first responder teams, such as police, medical teams, fire fighter teams, etc. Each one of these teams is attributed with different responsibilities and task assignments when operating at the CI. However, collaboration

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and coordination among them is of vital importance for effective emergency handling. These teams need to act both in concert, supporting each other's' efforts, and individually, carrying out their own task assignments. In such emergency cases, the situations at hand are changing in real-time, thus immediate response and reaction is necessary for saving lives and protecting infrastructure. Therefore, the first responder teams, operating at the critical infrastructure, and the Command Post, that coordinates all actions on site, must form and adapt their plans and actions as the situation unfolds. A key enabler in crisis management applications is that of Command and Control (C2) applications. New technologies, both in hardware and software, provide opportunities to improve and extend information retrieval, visualization, decision support, and communication within the crisis management domain. C2 systems exist for many application domains ranging from military to emergency handling and disaster management.

This paper presents an advanced command & control application for effective emergency handling. The Command Post application constitutes an information integration and visualization medium of data arriving from diverse information sources, such as sensors, cameras, and PDAs used in CI sites. In more detail, the application collectively visualizes all information sent by FRs at the critical sites to the command & control application in an advanced and coherent manner for instant understanding of the emergency event, its location, people involved, etc. without the danger of lost information or misunderstandings, enabling at the same time immediate reaction and in the long run saving of human lives and/or human property. The Command Post application is composed of two major sub-systems. The first subsystem is the real-time information merging and visualization subsystem that during an actual emergency, processes and manages real-time received information from dispersed information sources and First Responders (FRs) at the critical site, performing selective visualization of the underlying information according to prioritized received or detected in data alerts and alarms. The second subsystem is the administrative one which allows operators to input fundamental data (i.e. maps of critical infrastructures, FR information, etc.) in its database, author/edit rich media templates that are used for enhanced visual communication with FRs on site, and retrieve past cases and history logs. In short, the proposed command & control application serves as an enhanced location-based situational awareness and decision support tool and a communication and alerting tool back to first responder teams.

RELATED WORK

This section describes a state-of-the-art study on innovative approaches and systems, (using mobile devices, deploying geographic information as well as situational awareness systems), that are also considered by the proposed C2 system in order to allow a comparative analysis and description of the innovative features.

Mobile Devices and Crisis Management

The explosion in the use of mobile devices means that new innovative mobile applications can be created. A system that can be used for crisis management, in which information is conveyed to recipients using an iconic language and this information is shared to all PDAs within the network is described in (Rothkrantz, Datcu, Fitrianie, and Tatomir, 2005). Our system is similar to this as a visual language is used in the form of video annotations as opposed to icons – the proposed C2 system presents a more advanced solution by considering both images and videos and emergency related visual annotations. The use of agents running on PDAs which assist emergency workers during crisis situations has been researched focusing on ontologies as a communicate aid to share information such as sensor readings (Diggelen, Beun, Eijk and Werkhoven, 2009). The proposed C2 system innovates in that not only sensor readings but rich media is exchanged.

Geographic Information Systems

Crisis management involves being able to see where critical elements and resources are located and so is similar to the localization application but on a much larger scope (GPS, etc) . Geospatial technologies now allow the integration of multiple sources of information with geographic information systems allowing collaboration and cooperation during crisis scenarios (MacEachren, Cai, Michael, Sharma, and Fuhrmann , 2006). It has been proven that GIS reduces the need for oral communication volume and that commanding officers using GIS have more detailed, easily accessible information, and hence issue more direct commands than other officers (Johansson, Trnka, Granlund, and Götmar, 2010). The proposed C2 system innovates in that it utilizes a completely new localization system capable of functioning below ground as opposed to GPS (Amanatiadis, Chrysostomou, Koulouriotis, Gasteratos, 2010). The system makes use of wearable inertial sensors and RFID tags plus beacons for localization.

Situational Awareness Systems

Situational awareness systems aim to provide information about the environment as well as individuals themselves (Fall, Iannaccone, Kannan, Silveira, and Taft, 2010). Situational awareness map applications have been developed to allow users and citizens to send data to a central site for viewing. These applications make use of technologies such as the Google Maps API and are considered to be mash ups. Our application is a situational awareness map displaying real time data for multiple FRs as well as allowing FRs to access rich media information related to their surroundings.

PROPOSED COMMAND & CONTROL APPLICATION FOR EMERGENCY HANDLING

To our knowledge, based on the brief overview presented in the previous section, no other Command and Control system exists that merges and processes a variety of information sources from the critical site originating from different sensors, visualizes such information based on the conveyed alert type and deploys video annotation forth and back to FRs as a means of enhanced communication avoiding time-critical voice communication misunderstandings with Command post personnel. In short, the proposed Command and Control Application integrates a number of different yet essential applications for effective collaboration and communication among FRs and the CP and enhanced control of the situation by the CP. The specific Command & Control application advances the state of the art as it integrates and visualizes on a single visualization interface data from different information sources, as well as providing a communication and coordination medium for different First Responder Team members. To do this, it considers that FR team members, located at the CI site, may carry a variety of sensors and portable devices (PDAs) to enable them to deal with and resolve the critical situation more effectively with the improved support and guiding of the Command Post that is due to this equipment aware in real-time of all the happenings at hand, even those that FR teams may not be aware of (e.g. a gas leak not easily detectable that may lead to an explosion). Such equipment could be navigation sensors, gas and radioactivity sensors, fire sensors, vital signs sensors and PDAs for media rich visual communication among the Command Centre and FRs.

Furthermore, in order to handle emergency situations of high complexity, among the scenarios that are managed by the proposed Command & Control application, underground crisis cases are included (i.e. metro fires, tunnel explosions, etc), where no communication infrastructure is available. In such cases, an ad-hoc wireless network is setup and used by all sensors and applications to transmit and receive data to/from the Command & Control application. Such assumption introduces complexity to the design and implementation of the application, as the wireless network is of limited bandwidth capacity and the exchange of information should be optimized, in terms of message formats and data size for real-time operation, as is necessary.

Thus, the proposed C2 application comprises the centralized information merging and communication hub within a distributed integrated emergency handling system and infrastructure, as shown in Figure 1(a). The application itself runs on a web-server with a number of sub-components working together to achieve information fusion and visualization of incoming information and associated alerts, location-based situational awareness and decision support, bi-directional communication between the command post and the First Responders on site. Thresholds and filtering are utilized to only draw attention to data which is critical. Information that is arriving at the Command Post application from FRs on site is diverse: real-time location data of FRs, various gas and fire sensor readings, biometric sign readings for FRs, short rich media annotated videos with alerts on faced incidents that are captured using a ruggedized PDA device and a dedicated video annotation and visual communication application running on the PDA device, as shown in Figure 1(b). From a technical point of view, the C2 application constitutes a web application using among others the Adobe Flex technology.

In more detail, the C2 application for emergency handling is composed of two major sub-systems:

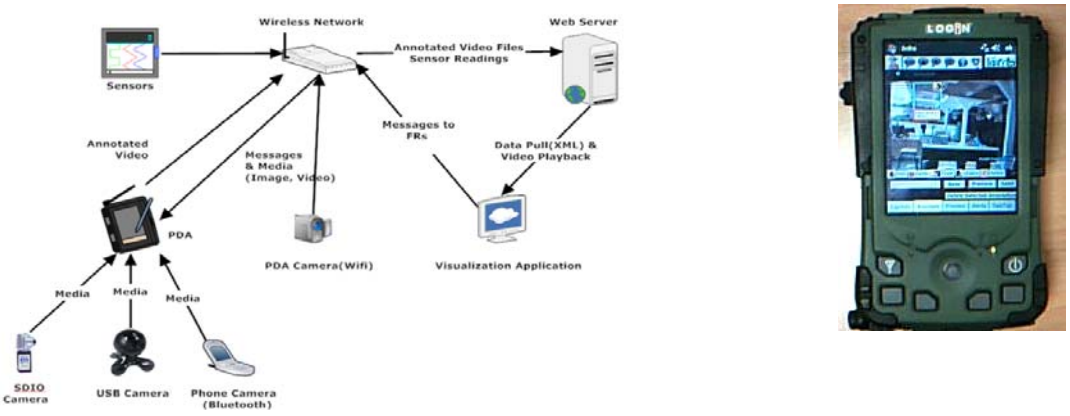
a) the real-time information merging and visualization subsystem which handles the merging and processing of received data from other sensor and video-based applications and their optimal visualization in real-time and presents the interaction medium with the CP personnel during the handling of a critical situation with FR teams dispersed on site. This subsystem manages the receiving, handling and responding to the input and alert messages received by FRs, and

b) the administrative subsystem, which manages the adding, editing, storing, removing and archiving of data vital for the operation of the Command Post application, at any time and not necessarily during an emergency situation. It assists the optimal configuration and operation of the real-time subsystem.

In the sub-sections that follow, these are presented in more detail.

Real-time Information Merging and Visualization Subsystem

As already mentioned, the Command Post Real-time Information Merging and Visualization subsystem provides the functionality that the Command Post needs in order to optimally manage all interactions with FRs and control the reaction to events at critical sites during an emergency. The main categories of the processes included are: a) receiving, parsing and where necessary processing data of various forms from different information sources, b) visualizing the received data in the most appropriate form for facilitating instant and correct understanding of the situation and fast response and c) responding in the most optimum way to the alerts and data received by FR(s), allowing rich media content creation and transmission. The communication between various devices and information sources occurs utilizing an ad-hoc WiFi network, as it is assumed that existing communication channels may cease to operate or there might be cases that emergencies happen underground, where no communication infrastructure exists. The sequence of operations that the real-time subsystem performs as well as the various tools and services it provides to CP personnel is described in the sequel. The Initialization of the Command & Control application is related to the selection and loading of the map or maps of the CI site. The application assumes that all these maps are available and stored in the application database – this has been previously performed using the administrative sub-system at normal operation, as it will be described later. It should be mentioned that these maps are country, region, type (i.e. cultural place, transportation system, energy site, etc.) and location specific. At the initialization phase following the selection of the CI map, the application tries to receive data from any First Responders already located at the site. Figure 2 depicts the map selection process and initialization of the application along with the visualized map data.



(a) (b)

Figure 1: (a) Overall system and (b) PDA running communication and video annotation software

After loading the CI map the Command & Control application is waiting for the FRs on site to connect and start sending data, as already mentioned. These are:

- Location data are sent through indoor navigation sensors and are used for visually placing the FR on the CI's map as an icon further representing the FR team he/she belongs to. The data is provided through the system in Amanatiadis et. al (2010).
- Gas and Radioactivity data sent through sensors: these data, when received are used for monitoring the area around FRs and the values of these data are always monitored in order to issue any necessary alerts that the FR may not be aware of and it may endanger his/her life.
- Biometric data sent through the vital signs sensors: these data, when received are used for monitoring the physical well-being of FRs and the values of these data are always monitored in order to issue any necessary alerts, again for cases that the FR may not be aware of (e.g. fainting). Data include blood oxygen level, total hemoglobin level, and pulse rate. The hemoglobin content is measured by the system in Timm et al (2010).
- Fire data sent through the thermal imaging cameras: these data, when received are used for monitoring the area around the place where the thermal imaging cameras have been placed. At this point it should be mentioned that the thermal imaging cameras are placed once and left to the CI site until the emergency is over – they are not carried by FRs.
- Media (image, text, video or a combination of these) data sent through the video annotation application which runs on the PDA that each FR carries: these data, when received, always issue an alert that prompts the Command Post end user to open the corresponding file, process the data and proceed with the necessary actions and responses that need to take place.

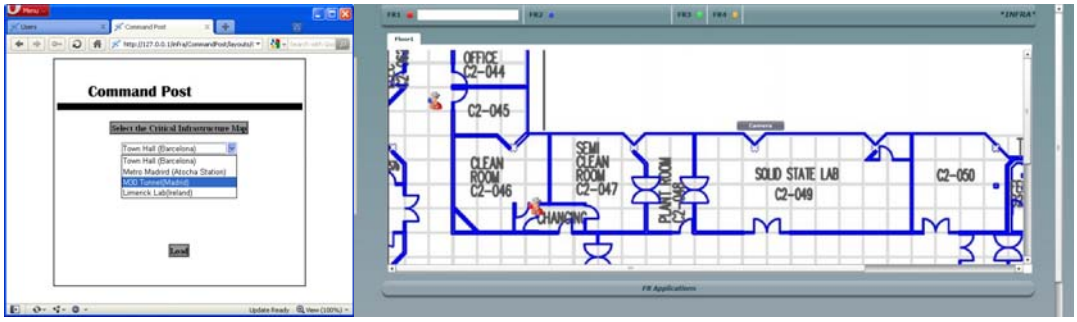
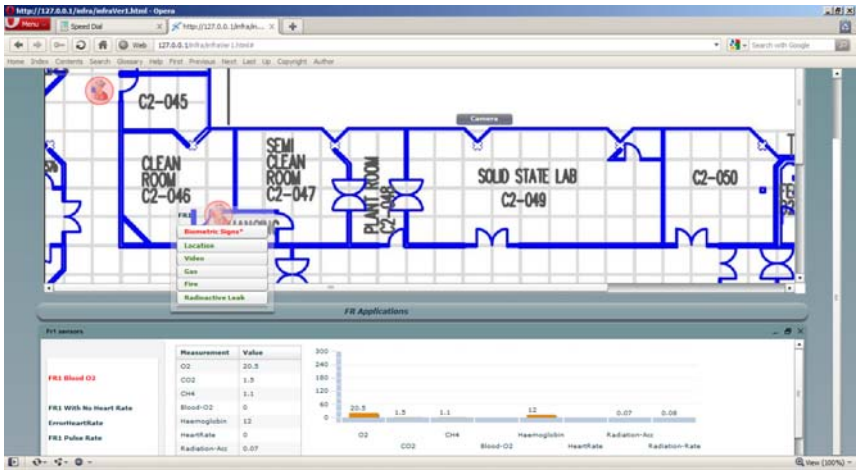


Figure 2: C2 Application Real-time Subsystem: CI Map Selection and Loading, retrieving FR information on site

Figure 3 depicts the Command Post application when data from FRs at the critical site have been read in real-time and constant manner and properly visualized for the benefit of the CP personnel. For minimizing the information burst at the Command Post application, which might complicate the monitoring, control and response of the Command Post users, the Command Post application selectively displays received information of each FR only when alerts are received according to the alert priority. Thus, until an alert is received by one or more of the participating FRs the Command Post only visualizes the FRs position and movement in the critical infrastructure as shown in Figure 2. However, at all times the Command Post user can view information for the data sent from FR's sensors simply by clicking on the interactive icon of the respective FR on the map. When doing so, the list of sensor readings and other information is displayed, as shown in Figure 3(right), highlighted in green color if everything is under control and if all received data are within safety boundaries. When an alert is received by the C2 application from one of the transmitting information sources per FR, then the FR icon on the map is circled by a semi-transparent red circle as shown in Figure 3, for a case of a biometric alert for the specific FR – his /her Blood O2 has fallen below his/her individual threshold for such measurement indicating that he/she may not be in good physical condition. By selecting the red text alert option from the list of received information for this FR, a chart of the specific session readings opens up for the CP personnel to look closely into the respective information and react accordingly.



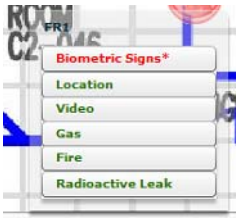


Figure 3: Command Post Application Real-time subsystem: real-time information gathering, data visualization for location-based situational awareness and decision support, and biometric signs alert.

At this point it should be mentioned that for the Media type alerts (video alerts) the visualization supported by the application is different from other sensor based alerts. More specifically, media alerts can be images and videos, either annotated with visual and text elements or not. Annotated videos, created by the video annotation application at the FR PDA, are composed of the short captured video file, an XML metadata file listing the types of conveyed alerts and a Synchronized Multimedia Integration Language (SMIL) file of the combined scene presentation (video and visual and text overlaid elements) conveying the alert message better, as shown in Figure 4. The rich media SMIL package is transferred in ZIP format to the C2 application where it is unpackaged and played back to a dedicated SMIL Player (Ambulant). Upon the receipt of a media alert, the Command Post user, by clicking on the interactive red colored alert of the transmitting FR, opens up Ambulant and views the transmitted visual alert for further processing and reaction to it, as shown in Figure 4 it is noted at this point that by reading the metadata with the alerts info sent by the video annotation application, the C2 application is able to display a representative to the alert type icon near the FR icon that has transmitted it, thus allowing CP personnel to judge the criticality of the alert and be able to decide what to manage first in case of multiple simultaneous alerts.

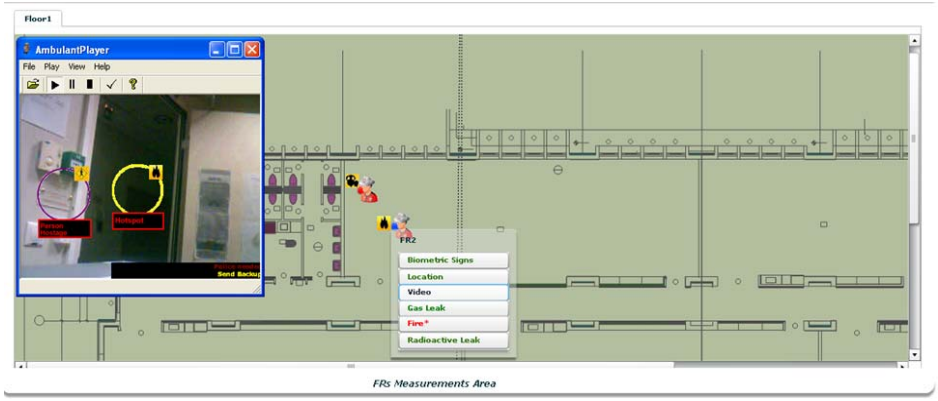


Figure 4: Received Annotated Video conveying a Fire Alert

In order to facilitate the communication among the Command & Control application and FRs operating at the CI site, a formally defined set of alert icons for each different emergency case as well as of rich media templates per emergency case and FR team (these are composed of visual and textual elements describing an alert or highlighting a critical area, overlaid on top of captured video, as shown in Figure 4) has been devised with the assistance of end users and stakeholders. Such alert icons and rich media templates, used in visual communications by the video annotation and C2 applications, facilitate the immediate and correct understanding of the crisis situation and create a commonly understood and formal framework upon which the communication and exchange of information is realized – it resembles the definition of a visual emergency language. An indicative list of the formal list of alert icons per main emergency case and the specific emergency sub-cases it may represent, that can be received at the Command Post, is shown in Table 1.

Alert Icon	Description	Specific Emergency Case
	This alert sign is used when a fire related alert is received.	Hotspot
		Escaped Fire
		Fire Hazard
	This alert sign is used when a gas related alert is received.	Gas Leakage
	This alert sign is used when a radioactivity alert is received.	Radioactivity Leakage
		Biological Spill
	This alert sign is used when a body temperature alert is received.	
	This alert sign is used when a heartbeat alert is received.	
	This alert sign is used when a media rich alert, such as annotated images and videos or even text messages is received.	
	Flooding	Bridge about to collapse
		Car carried away
	Earthquake	Building about to collapse
	Terrorist Attack	Bomb
		Hostages
		Shooting
	Medical Emergency	Entrapped (Injured) Person
		Injured Person
		Drowning Person
		Unconscious Person
		Dead Person
		Burnt Person
	Person in Danger	Enclaved Person
		Taken Hostage

Table 1: Alert Icons used by the Main and Sub-cases of a list of Emergencies, as received at the Command Post Application

Figure 5: Backward Communication with FR

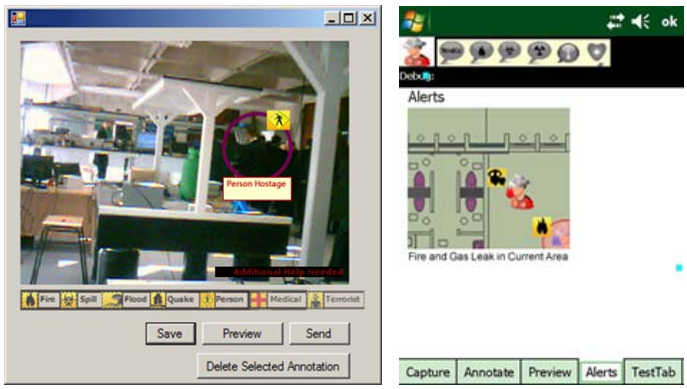


Figure 6: Media Annotation at C2 Application and an example of a Media message composed at the C2 application and transmitted to affected FRs

Upon the receipt and processing of an alert message that appears on the Command Post application map the Command Post may respond with three different types of messages, as shown in Figure 5:

- *Ready Messages*: these are predefined text messages at the C2 application, to speed up the reaction and response of CP personnel – an initial list of those has been defined with the assistance of end users. They are stored in the system database and are associated with a specific alert type and a specific FR team. For example, upon the receipt of a fire alert if the user selects the ready messages a list of fire related messages will appear. From this list the user can select the message that needs to be sent. Furthermore, a ready message can contain different information according to the FR team.
- *Text Messages*: these are free text messages that allow the Command Post end user to respond as deemed most appropriate the emergency at hand when predefined text messages do not suffice.
- *Media Messages*: this type of messages includes media messages that can be sent to FRs, which include not only text but also media info such as images, graphics or even video. This type provides the Command Post with the ability for rich visual communication with FRs that issued the respective alert as well as with other FRs that might be affected by the indicated emergency and need to be fully aware of the situation. For that purpose, a media annotator has been added to the C2 application, shown in Figure 6. The same figure showcases an example of a media message as composed at the C2 application of a fire and gas leak alert in a specific area transmitted to affected FRs.

Administrative Subsystem

This section presents the administrative subsystem of the Command & Control application, which includes the necessary tools and processes for adding, editing, storing, removing and archiving data vital for the correct and timely operation of the C2 application during an emergency. The administrative subsystem allows the following main administrative processes, as shown in **Figure** 7:

- *Maps & Locations Administration*
  Responsible for a list of maps of various CI locations that have been analyzed and from which readings have been taken for the localization application. An example is shown in **Figure** 7.
- *Command Post Users' Administration*
  The command post users administration panel allows the editing of CP users and their roles/rights to initiate processes within the Command Post Application and Administration Page.
- *First Responders' Administration*

The First Responders Administration page will allow the addition and modification of first responders information including the editing of their personal details, what department they are from, who is in charge of them, personal vital sign thresholds, and other related information. Additionally the FR administration allows the editing of thresholds related to biometric readings.

- *Templates Administration*
  The templates administration page is responsible for the creation and editing of the rich media annotation templates and alert icons for the communication of the C2 application and the video annotation application. A sample screenshot of the C2 template editor tool is shown in **Figure** 8 - the addition of an Electrical Fire annotation with square shape, red border, electrical fire text label and 3 ready text messages, as a sub-case of the fire emergency, is displayed. New or modified templates are stored in the C2 application database, categorized according to the emergency case and FR team they address, to be later used, during emergency handling.
- *System Log File*
  The system log file presents a list of all the alerts and prior communication that has taken place during a crisis situation. This information is therefore available after an emergency, stored within the C2 database for analysis and review.

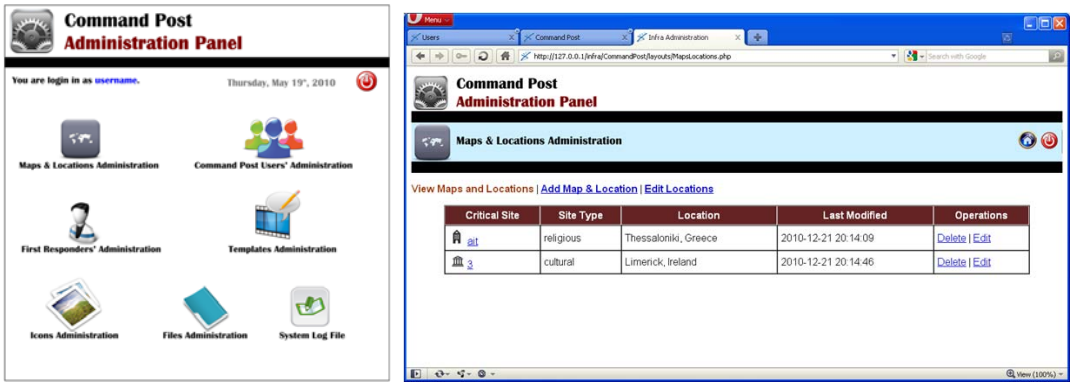


Figure 7: Command Post Admin. Subsystem: Main Admin. Panel and CI Maps and Locations Administration

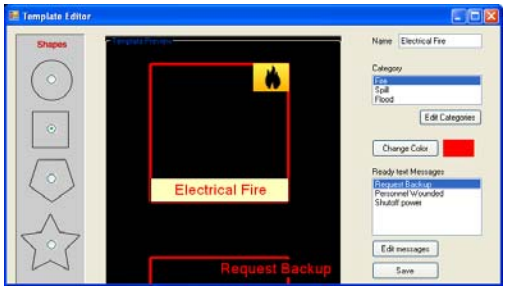


Figure 8: Command Post Administration Subsystem: Template Editor Tool

C2 SYSTEM EVALUATION

While incrementally implementing the system, the latter was evaluated at a number of occasions either via internal lab testing or in actual field trials. The complete C2 system has been evaluated qualitatively during a recent final field trial at the M30 tunnel in Madrid, Spain in January 2011.The test sequence involved testing of both the real-time (annotated video receipt and alerts from FRs, FR vital sign information and alerts, FR locations real-time visualization, thermal imaging data receipt and alerts) and administrative (user/CI data management, history log sub-systems, template administration, etc.). Users were stationed in the M30 emergency tunnel as well as in the Command Center during tests. The developed C2 system was deployed and tested successfully - the sending of a 721 KB annotated video from an FR to the Command post took 11 seconds. Figure 9 displays the deployed hardware and network infrastructure, assuming a wireless client in the tunnel connected to the wireless INFRA Nodes (access points, two of them positioned within a 1 km distance, the one connected with the M30 tunnel Ethernet network).

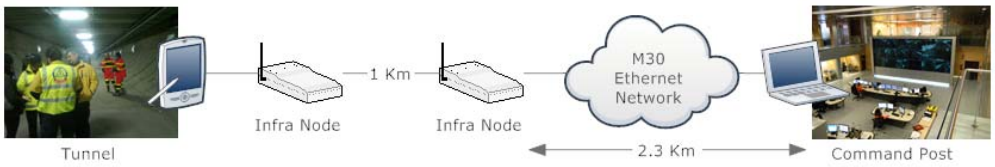


Figure 9: Madrid M30 Command Post and Emergency Tunnel

Upon completion of the Field trial, to which 19 guest end users from 7 EU states (Cyprus, Greece, Germany, Israel, Italy, Spain, UK) and various organizations (Airports, Fire depts., Medics, etc.) participated and experienced the demonstrated system among the other application, both at the Command Post site and in the M30 tunnel, they were requested to respond to a dedicated questionnaire for the qualitative evaluation of the C2 system and the innovative INFRA applications. The results of the C2 system evaluation are presented in Table 2 below where the abbreviations stand for A: Agree, U: Uncertainty, D: Disagree.

Description	**Degree of Conformity**		
INFRA C2 system has at some time stopped unexpectedly	A: 0%	U: 10%	D: 90%
Learning to operate INFRA C2 system initially is very easy	A: 85%	U: 0%	D: 15%
If INFRA C2 system stops, it is not easy to restart it	A: 0%	U: 25%	D: 75%
Working with INFRA C2 system is satisfying	A: 80%	U: 10%	D: 10%
The way that the system information is presented is clear and understandable	A: 85%	U : 0%	D: 15%
INFRA C2 system seems to disrupt the way I normally like to arrange my work	A: 20%	U: 60%	D: 20%
Tasks can be performed in a straightforward manner using INFRA C2 system	A: 65%	U: 25%	D: 10%
I would like to use INFRA C2 system every day	A: 70%	U: 20%	: 10%
Using INFRA C2 system is frustrating	A: 0%	U: 15%	D: 85%
The speed of exchange of info with INFRA C2 system is fast enough	A: 80%	U: 10%	D: 10%
User needs have been fully taken into consideration	A: 65%	U: 20%	D: 15%
The organization of the menus of information lists seems quite logical	A: 80%	U: 10%	D: 10%
Information exchanged with INFRA C2 is too much and it is difficult to handle all the data	A: 0%	U: 20%	D: 80%
Information exchanged with INFRA C2 helps to perform tasks	A: 90%	U: 10%	D: 10%
There is info not considered in INFRA C2 to be exchanged but desirable	A: 33%	U: 33%	D: 33%

Table 2: End User Qualitative Survey Responses

Overall the C2 system was rated with 60% of the questions receiving 80% or more of positive responses from participating FR representatives. End users could not respond exactly to the question of whether the system would change/disrupt the way things are currently done as well as if there are types of readings/sensors not being considered, as they have not actually deployed the system in line with the ones they are already using. There were positive responses with respect to the system's usability, usefulness, and satisfaction.

FURTHER WORK

Future works includes studies in the usability and also functionality of the system based on received end user comments. Measurements of network performance as well as quantitative evaluation of the system performance will be pursued to provide proof for the real-time aspect of communication and reaction to transmitted alerts, as well as effective visualization of the received information. Additionally, the use of multimodal interfaces integrating natural gestures for the interaction with the C2 application would be interesting as studies have been presented respectively on how GIS usability with such interaction patterns is improved (Krahnstoever, Schapira, Kettebekov, & Sharma, 2002). Interfaces combining speech and gesture commands (MacEachren et. Al, 2006) as well as pen interfaces for crisis management utilizing interactive maps (Willems & Vuurpijl, 2007) would be other types of interesting future work. The use of ontologies for sensor data communication and visual annotations will also be investigated following the paradigm of Diggelen et al. (2009).

CONCLUSIONS

We have presented a novel C2 application for enhanced near real-time situational awareness and media-rich commonly agreed visual communication between first responder (FR) teams and their Command Post (CP) during the management of an emergency and for effective administration of all necessary information and resources (FR personnel, critical infrastructure information, visual communication templates, etc.) during normal operation. Real-time location information and biometric sensor readings of FRs as well as rich media annotated video data highlighting emergencies on site transmitted by FRs with the use of Personal Digital Assistant devices are merged at the Command Post application and, according to the alert priority they may convey, are selectively visualized to CP personnel to allow for further immediate correct reaction, effective decision support and command dispatch from the latter. The proposed C2 application innovates from other proposed in the literature such systems in that it integrates effectively at the data and visualization level indoor navigation, biometric, gas and fire sensor applications, annotated video communication and thermal imaging, to allow for enhanced alert transmission and situational awareness. Real-life field trials have taken place in the M30 tunnel in Madrid, Spain, with the participation of a significant number of end-users to test and qualitatively evaluate the C2 system among other. The evaluation results revealed the added value and usefulness of the C2 application to potential stakeholders.

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REFERENCES

1. Amanatiadis, A.A., Chrysostomou, D., Koulouriotis, D. and Gasteratos, A. (2010) A Fuzzy Multi-Sensor Architecture for Indoor Navigation, *Proceedings of the IEEE International Conference on Imaging Systems and Techniques*, Thessaloniki, Greece.
2. Diggelen, J.V., Beun, R.J., Eijk, R.M. and Werkhoven, P. (2009) Intelligent Assistants in Crisis Management: from PDA to TDA, *Proceedings of the 21st Benelux Conference on Artificial Intelligence Eindhoven*, The Netherlands.
3. Fall, K., Iannaccone, G., Kannan, J., Silveira, F. and Taft, N. (2010) A Disruption-Tolerant Architecture for Secure and Efficient Disaster Response Communications, *Proceedings of the 7th International Conference on Information Systems for Crisis Response and Management*, Seattle, USA.
4. Johansson, B.J.E., Trnka, J., Granlund, R., and Götmar, A. (2010) The Effect of a Geographical Information System on Performance and Communication of a Command and Control Organization, *International Journal of Human-Computer Interaction*, 26 228-246.
5. Krahnstoever, N., Schapira, E., Kettebekov, S. and Sharma, R. (2002) Multimodal Human-Computer Interaction for Crisis Management Systems, *Proceedings of the Sixth IEEE Workshop on Applications of Computer Vision*, Washington, DC, USA.
6. MacEachren, A.M., Cai, G., Michael, M.D., Sharma, R. and Fuhrmann S. (2006) GeoCollaborative crisis management: designing technologies to meet real-world needs, *Proceedings of the International Conference on Digital Government Research*, San Diego, California, USA.
7. Rothkrantz, L. J. M., Datcu, D., Fitrianie, S. and Tatomir, B. (2005) Personal Mobile Support for Crisis Management Using Ad-Hoc Networks, *Proceedings of the 11th International Conference on Human Computer Interaction*, Las Vegas, Nevada, USA.
8. Timm, U., Leen, G., Lewis, E., McGrath, D., Kraitl, J. and Ewald H. (2010) Non-invasive optical real-time measurement of total hemoglobin content, *Procedia Engineering*, 5, 488-491.
9. Willems, D., Vuurpijil, L. (2007) Designing Interactive Maps for Crisis Management, *Proceedings of Intelligent Human Computer Systems for Crisis Response and Management*, Delft, the Netherlands.