Health and rescue services management system during a crisis event

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The performance of rescuers and personnel handling major emergencies or crisis events can be significantly improved through continuous training and through technology support. The work done in order to create a system has been discussed which can support both resources and victims during a crisis or major emergency event. More specifically, the system supports real-time management of firefighter teams, rescue teams, health services, and victims during a major disaster. It can be deployed in an *ad hoc* manner in the disaster area, as a stand-alone infrastructure (using its own telecommunications and power). It mainly consists of a control station, which is installed in the area command centre, the firefighters units, the rescuers units, the ambulance vehicles units, and the telemedicine units that can be used in order to support victim handling at the casualties clearing station. The system has been tested and improved through continuous communication with experts and through professional exercises; the results and conclusions are presented.

1. Introduction: Recent crisis events and major emergencies have increased the need for more effective and accurate response procedures. Civilians involved in a crisis or major emergency event are becoming sensitive and demanding. First, responders such as firefighters and rescuers are the first groups that have to deal with such events, secure the area and enable immediate victim treatment and area evacuation in the case of a major emergency event.

Management of first responders during crises or disasters is the major field of interest of this Letter. A recent report from the World Health Organisation [1] states that during the decade 2001–2010, an average of 700 disasters (flood, earthquakes etc.) were reported on an annual basis. These disasters affected around 270 million people. Deaths reported exceeded 130,000. Typically, after a disaster, the area infrastructure (telecommunications, electricity, building etc.) collapses. Civilians might respond in a chaotic way after a major emergency event, which is why first responders such as firefighters and rescuers need to take control and react in an effective and systematic way. Several issues can also arise among the members of the rescue groups; these could be related to coordination, decision making, and team collaboration, among others. These are issues that can be improved through continuous training before an event [2, 3].

Along these lines and having in mind the evolution of modern technology (portable devices, easily installed *ad hoc* networks, small medical devices etc.), we had designed, created, and tested a system which can be used during a crisis event such as a major accident, a terrorist attack, a natural disaster etc.). The system was developed based on the main axes described in the literature for effective emergency management: (i) mitigation, to prevent or lessen the impact of disaster; (ii) preparedness, which includes training and action plans; (iii) response, search and rescue activities; and (iv) recovery, restoration of basic services [4–6].

Our goal was to have the system used and tested by first responders during professional exercises in order to ensure that the system fits the needs of first responders and has added value during a major crisis event.

2. Methodology: On the basis of user requirements, we had developed a system that can be integrated in the existing major

emergency/crisis response framework [6–9] and support the management of firefighter teams, rescue teams, and health services provision during an event. The work presented here is an extended version of the work presented in International Federation for Medical and Biological Engineering (IFMBE) Medicon 2016 conference [10].

One of the main issues after an event such as an earthquake, a fire, or a terrorist attack might be the destruction of infrastructure. To solve this problem, the system is based on its own power (small portable generator and battery operated devices) and wireless network that can be installed in an *ad hoc* manner. The system consists (see Fig. 1) of the part installed in the disaster area and the parts located at the central disaster control centre. At the disaster area the central station unit is located next to the chief of operations and collects all the information from the area (regarding first responders, victims, ambulance vehicles in the area).

All information is recorded and transferred to the control station (based on a Windows personal computer) in order to help the chief of operations on any decisions and resource handling (see Fig. 2). Additionally, the whole area image can be transferred to a Main Disaster Control Center, through satellite or third generation network communication, if available, thus giving an overview of the area.

The rest of the units are:

(a) *The rescuers' units:* These are portable android devices through which the position of the rescue team carrying the unit [based on global positioning system (GPS)] can be traced. Additionally, the rescuers can use these devices in order to send descriptions about the position of the victims and their status based on the simple triage and rapid treatment protocol (START) [11]. Cases are characterised and colour-coded as: deceased (black), immediate (red), delayed (yellow), or minor (green).

(b) *The firefighters' units:* These are portable android devices through which the position of the firefighter can be traced. The firefighters can also mark a hot zone.

(c) *Ambulance units:* These are android devices through which any ambulance entering the area can be marked as free or occupied (when it is ready to carry victims out of the area).

Fig. 1 Overview of the crisis system (main components and their relevant communication way)

(d) *Emergency telemedicine units*: These are an improved version of the work published in [12] in the sense that they include additional features and use a new way of communication). The units can be used in the victims' evacuation stations in order to help in the evaluation of victims.

The communication is based on an instantly installed wireless fidelity networks (WiFi) using high-gain antenna for the access points. On the basis of our tests, our setup was sufficient to cover an area of 0.5 km. A bigger area would need a repeater to be deployed along the line of communication. An overview of the functional characteristics of the system are:

- Tracking of victims and their evaluation status based on the START protocol.
- General description of the victim including his/her age and sex and trauma description.
- Identifying the victim with a coloured card based on START and using a code (quick response (QR) or near field communication (NFC)) for matching.
- Tracking firefighters GPS mark in the area.
- Marking areas as hot zones in order to keep any unauthorised person out of these areas (this can be done by the firefighters).
- Tracking rescuers acting in the disaster area. Identifying their status (available or not).
- Monitoring of ambulance vehicles entering the area and their status (type, occupied or not).
- Presenting all information on the central station unit (see Fig. 2) and transferring all information to the disaster control centre.
- Real-time transmission of vital information (electrocardiogram 3-12 leads and parameters such as oxygen saturation (SpO2) etc.)

from selected victims in order to support the casualties' evaluation procedure.

Security issues: Security is an important element of our system as it ensures the correct operation of a critical infrastructure and its ability to remain available in the face of attacks. Continuing, we outline the basic security elements of our approach. To ensure that all information is recorded and transmitted in a way that ensures security of the system, we had thoroughly analysed any issues related to security as follows [13].

The infrastructure deployed during an emergency will be comprised of a series of users: namely, rescuers, ambulance personnel, firemen, doctors, and the administrator. They will all be using portable android devices, except from the administrator. Information from these devices is aggregated to a database server in the central control station, except from the telemedicine unit, which transmits bio-signals to the bio-signal server at the Main Disaster Control Center. Aspects that are considered in terms of security are authentication, authorisation, and data confidentiality and integrity [14].

As far as authentication is concerned, the identities of all entities in the system need to be verified. Verification is executed based on per user and/or per device. Doctors using the Doctor Mobile Unit are initially authenticated based on a per device basis. The ID of android devices is utilised to establish the uniqueness of a specific access. In addition, doctors are further authenticated themselves, so that they can then be authorised to access victim information. Rescuers, firemen, and ambulance personnel are not authenticated on a per user basis, but only on a per device basis. This is a form of indirect authentication, since prior to a deployment, rescuers, firemen, and ambulance personnel are assigned to specific

Fig. 2 Area monitoring screen as displayed in the control station

android devices. Authentication per user during an emergency would delay the response to the emergency and users need to send information as fast as possible for the purpose of expediting processing. A vulnerability to this relaxed authentication is that somebody can steal the device and submit false information, e.g. false assessment regarding a victim. However, this constitutes an unlikely scenario and it was decided to sacrifice security to a small extent, for increased functionality.

Origin of the submitted data is provided by the aforementioned authentication mechanisms, which ensure that a malicious entity cannot submit false reports by circumventing the data, altering it, and resending it, unless he has possession of the android device. However, this does not prevent a bypasser from sniffing on collected data and finding information regarding the incident. To prevent such an attack, confidentiality needs to be provided by deploying encryption among communication entities through the use of asymmetric cryptography. Android units can then encrypt information with the server's public key prior to transmission. It was decided to encrypt information transmitted between firemen and the control station, and between rescuers and the control station, so as not to disclose information regarding the perimeter that is being secured and casualties involved. However, for information such as the transmission of an ambulance status from the ambulance personnel, the focus was more on providing integrity checks, as the confidentiality of this information was not deemed critical. Furthermore, communication between the bio-signal server and the emergency telemedicine unit does not apply encryption since again the data do not directly disclose any confidential information for a specific individual and the focus is on best effort connectionless communication to expedite the delivery of information.

In our approach, it was important to deploy cryptographic algorithms only where necessary in an effort to maximise the devices battery life by reducing processing as much as possible. On the basis of our tests, the battery life spans to 1–2 days of usage and varies by an insignificant amount compared the typical usage scenario. As an alternative we also have backup devices that could ensure seamless operation during emergencies, since we expect that devices will be charged through an electricity generator whenever needed.

Data submitted is also time-stamped and geo-stamped. Sending a timestamp along with data provides liveness for a specific

transaction and also prevents replay attacks. Sending geo-location information along with data allows the control station to pinpoint the location of a casualty. However, this geo-fencing also provides the additional benefit of blocking any false reports that could originate outside the designated area set by firemen. More specifically, a person with malicious intentions would need to use a Rescuer's Unit, within the secured perimeter; otherwise, these reports would be marked as malicious and deleted. One could argue that a malicious user could hack a device and spoof his geographical coordinates, but this scenario is far-fetched and thus not considered.

During an emergency multiple areas may be impacted and thus multiple control stations could be deployed. All these control stations report to the Main Disaster Control Center. We assume that the required infrastructure is deployed to securely handle the received data and the communication between the different control units. Discussion regarding the inner workings of this infrastructure is beyond the scope of this Letter. Every control centre has a database server, which captures the data regarding the emergency. Access to information in the database system is handled by assigning different levels of access to each user in the system (see Table 1). The five different types of users are: (i) the administrator, (ii) firemen, (iii) ambulance personnel, (iv) rescuers, and (v) doctors.

The administrator is responsible for overseeing that the network operations are being carried out effectively and the system is always available. He registers all types of users, except from victims who are registered by the rescuers, and has access to all the logs generated by the system. He can also add information pertaining to the emergency scenario. The ambulance personnel can alter the status of an ambulance based on the emergency schedule. The status of the ambulance could be 'on Call', 'Available', or 'In Service'. Firemen can add location information to geo-fence a specific area during an emergency. Rescuers can read information regarding the emergency, add records of a new victim, and submit bio-signals. Doctors can only read and append to victims' records. Logging is used throughout the entire system to keep track of the rescue operation. Every instance of the database has a log file associated with it. Log files include the victim_log, the ambulance_log, the incident_log, and logs capturing the activity of users such as the doctor_log, the rescuer_log, and the firemen_log. The administrator may look

Table 1 Role-based access control to database entities of the system

Roles of participants in the crisis management unit					
Database entities	Administrator	Firemen	Ambulance personnel	Rescuers	Doctors
user	R/W(A, D, M)	—	—	—	—
ambulance	R/W(A, D, M)	—	R/W(M) ^c	—	—
victim	—	—	—	R/W(A)	R/W(Ap)
emergency	R/W(A, M)	R/W(Ap) ^a	—	R/W(A)	R ^b
biomedical signals	—	—	—	W(A)	R
logs	R	—	—	—	—

R = read, W = write, — = no permission.
W(A = add, D = delete, M = Modify, Ap = append).
Note: Modify implies append, unless append is stated instead.
^aFor adding geo-fencing data.
^bFor emergency event tied to victim.
^cModify the status of the ambulance (available, on Call, In Service).

at the logs to investigate any malicious or erroneous behaviour of the users in the system. In addition to account-ability, it can be used to assess the effectiveness of an operation and suggest improvements.

Even though the system was created following a user requirements analysis procedure, feedback from different target groups and users will continuously help in improving the system and achieving the initial goals in the best possible way. Feedback is typically sought in authentic or simulated conditions of the actual use of the system. This is described in the following section.

3. System evolution and testing through professional exercises:

The system was initially designed in collaboration with the rescue teams of the ambulance services department of the Cyprus Ministry of Health and the Cyprus Emergency and Prehospital Association. Further development to include features such as monitoring of firefighters has been added after using the system at a professional exercise as described below.

Professional exercise 1 – earthquake simulation: The system was initially tested at an exercise simulating the scenario of an earthquake with several victims. An overview of the exercise area is shown in Fig. 3. The scenario was deployed in the premises of the Cyprus Special Fire Rescue Unit (EMAK). There were several victims trapped under building ruins and in buildings under fire. This was in an area of about 1000 m². The professional exercise took place in March 2014 and had a duration of ~2 h. Firefighters and health care rescuers were involved. Firefighters were the first to enter the area (marked as a hot zone) and secure it before allowing entrance to health care personnel groups. Users received short training for system use before the exercise. When the exercise was completed, a briefing and discussion took place. During this session, we had the chance to discuss several issues with potential users and get their initial feedback verbally.

Through this exercise we were able to identify additional needs that included: (a) the need of monitoring the firefighters as well as the medical rescue teams thus showing a complete image of

Fig. 3 Overview of the exercise area showing the area with the victims, the emergency system area control station and the casualties clearing station

the area to the local control centre information; (b) the need for hot zone marking; this should be done by the firefighters which are the first group of people entering a disaster area; (c) the introduction of telemedicine support at the casualties clearing station; this will help when locally handling the victims; and (d) the improvement of the area network coverage.

Professional exercise 2 – terrorist attack: This exercise followed professional exercise 1. After the system was further improved, and tested in a second exercise which was simulating a terrorist attack. It was conducted by the Cyprus Emergency and Prehospital Association in November 2015. The goal of this scenario was to use the system during the initial logging and evaluation of all victims with actual users and receive their feedback in a systematic way.

The scenario was supposed to take place at a holiday camp where several people were shot or wounded by terrorists in an area of about 1000 m². The rescuers had to enter the camp, identify, and evaluate the victims and evacuate the area. This was done in collaboration with the police and civil defence. The area of the professional exercise is described in Fig. 4. About 32 rescuers worked in groups of approximately eight people. The duration of the professional exercise was ~2 h. The first step of the professional exercise was a short training session on the use of the system. Immediately after the completion of the professional exercise, a briefing session took place. The goal of the briefing session was the identification of mistakes and issues that could be improved in the system. Additionally, participants were asked to individually complete an evaluation questionnaire about the electronic system.

Instrument: As this was the first systematic evaluation of the system, pursued with the dual goal of (a) examining participants' perceived value of the system and (b) soliciting their feedback on

specific functionality of the system for its improvement, creating a custom-made instrument was deemed necessary.

The evaluation questionnaire, which was the main data collection instrument of the study, consisted of: (a) four questions for basic demographic information (participants' gender, age, profession, and years of professional experience), (b) 17 statements on a five-point Likert scale, on which participants were asked to select an answer ranging from completely disagree (1) to completely agree (5), and one open-ended question prompting participants to identify ways in which the system can be improved from a technical and functional perspective.

The main part of the instrument focused on the evaluation of two dimensions: perceived value of the system (10/17 questions) and perceived usability of the system (7/17 questions).

Participants: Participants were 32 people (16 male and 16 female) with an average age of 32.47 [strongly disagree (SD)= 8.39]. More than half of participants (62.5%, 20/32) were nurses, while approximately one in five (21.9%, 7/32) were nursing students. The rest (15.6%, 5/32) included various professions such as military personnel, doctors, and computer scientists. Participants had an average number of 10 years of experience ($M = 9.9$, $SD = 7.59$).

Data analysis: Data was input in the Statistical Package of the Social Sciences (SPSS22.0). Three questions that referred to the usability of the system which and were negatively phrased (see Table 4, where these questions are marked with an asterisk) were reversed prior to analysing the data. The composite score for the two dimensions that were examined (value and usability) as well as the composite score of participants' overall evaluation of the system based on all 17 items were computed. Basic descriptive

Fig. 4 Overview of the exercise area showing the area with the victims, the emergency system area control station, and the casualties clearing station

Table 2 Descriptive statistics of system's overall evaluation score and system's perceived value and usability

Descriptive statistics					
	N	Minimum	Maximum	Mean	Standard deviation
composite score	32	3.18	4.76	3.8860	0.40971
value	32	3.50	5.00	4.3750	0.48260
usability	32	2.17	4.33	3.2396	0.47318
valid N (listwise)	32	—	—	—	—

statistics were run and correlation analyses using the Pearson's coefficient were conducted by setting an alpha level of 0.01.

4. Results: Overall, as can be seen from Table 2 the system's evaluation results were positive, as the average value of the composite score of all 17 items was ~4 out of 5. ($M=3.89/5$, $SD=0.41$). Participants clearly saw the potential value of the system ($M=4.38/5$, $SD=0.48$), while a lower score was reported as far as the usability of the system is concerned ($M=3.24/5$, $SD=0.47$). A potential explanation for the relatively lower scores of the evaluation of the usability of the system might be the limited time that was available for participants to familiarise themselves with the use of the system prior to the professional exercise and

the evaluation of the system. Detailed results of all 17 individual items are presented in Tables 3 and 4. Individual items marked with an asterisk are the ones that were negatively phrased. Results are presented focusing on the net per cent agreeing (NPA), which responds to the percentage of participants that agreed or strongly agreed with each statement.

If we focus on the items evaluating the participants' *perceived value of the system* (Table 2), almost all of participants (NPA = 97%, 31/32) agreed that the continuous identification of the geographical position of rescue teams by the centre, and the knowledge of the availability of rescue teams by the centre at any given time (NPA = 97%, 31/32) are both useful features of the system. Moreover, two additional features of the system that were found to be useful included the knowledge by the centre of (a) the availability of ambulances at any given time, a statement with which more than 90% of participants agreed [NPA = 93.8%, (30/32)] and (b) the exact geographical position of ambulances (NPA = 90.7%, 29/32).

The value of the system for the improvement of the coordination of the members of the rescue teams was also seen by the majority of participants [NPA = 68.8%, (22/32)]. The same finding was observed for the improvement of the communication among the members of the rescue teams (NPA = 81.3%, 26/32) and the collaboration among rescue teams and the firemen or policemen (NPA = 81.3%, 26/32).

A second step of the analysis included the examination of correlations among participants' professional experience, measured in

Table 3 Frequencies and descriptive statistics of 17 items of evaluation questionnaire. Part A: perceived value of the system

Dimensions examined		Frequencies ^a						Descriptive statistics ^a	
		N	SD, %	D, %	N, %	A, %	SA, %	M	SD
A. Perceived value of the system (ten questions)									
1	<i>the continuous geographical identification of rescuer groups is useful</i>	32	0	0	3.1	6.3	90.6	4.87	0.42
2	<i>a useful feature of the system is that it provides the centre with the capability to know at any given time which rescuer groups available/not</i>	32	0	0	3.1	15.6	81.3	4.78	0.49
3	<i>a useful feature of the system is that it provides the centre with the capability to know at any given time which ambulances available/not</i>	32	0	0	6.3	6.3	87.5	4.81	0.54
4	<i>a useful feature of the system is that it provides the centre with the capability to know the exact geographical position of ambulances</i>	32	0	3.1	6.3	18.8	71.9	4.59	0.76
5	<i>the electronic system can improve the way we work in case of mass destructions</i>	32	0	0	34.4	31.3	34.4	4	0.84
6	<i>the electronic system can improve the coordination of rescuers groups</i>	32	0	0	31.3	37.5	31.3	4	0.8
7	<i>the electronic system can help in the faster identification of the victims that have already been evaluated</i>	32	0	0	25	37.5	37.5	4.13	0.79
8	<i>the electronic system can improve the communication among members of the rescuers' groups (firemen, rescuers)</i>	32	0	0	18.8	31.3	50	4.3	0.78
9	<i>the electronic system can improve the collaboration among members of the rescuers' groups (firemen, rescuers)</i>	32	0	0	18.8	40.6	40.6	4.22	0.75
10	<i>I would recommend the electronic system to my colleagues</i>	32	0	0	31.3	34.4	34.4	4.03	0.82

^aSA=strongly agree, A=agree, N=neither agree nor disagree, D=disagree, SD=strongly disagree, M=mean, and SD=standard deviation.

Table 4 Frequencies and descriptive statistics of 17 items of evaluation questionnaire. Part B: usability

Usability (seven questions)		N	SD, %	D, %	N, %	A, %	SA, %	M	SD
1	<i>it was easy for me to evaluate the condition of a victim through the electronic system</i>	32	0	3.1	50	31.3	15.6	3.59	0.79
2	<i>it was easy to familiarise myself with the use of the system</i>	32	0	3.1	46.9	31.3	18.8	3.65	0.83
3	<i>I had difficulty in understanding how the electronic system works^a</i>	32	18.8	12.5	50	15.6	3.1	2.72	1.05
4	<i>the electronic system delays our actions^a</i>	32	6.3	9.4	59.4	15.6	9.4	3.13	0.94
5	<i>I would be faster in rescuing victims if I did NOT use the electronic system</i>	32	3.1	9.4	53.1	18.8	15.6	3.34	0.97
6	<i>all the information about the evaluation of each victim that I provided in the electronic system is necessary for rescuing victims</i>	32	0	0	43.8	37.5	18.8	3.75	0.76
7	<i>information needs to be added to the electronic system for evaluating victims</i>	32	0	6.3	46.9	37.5	9.4	3.5	0.76

^aSA = strongly agree, A = agree, N = neither agree nor disagree, D = disagree, SD = strongly disagree, M = mean, SD = standard deviation.

number of years, with their perceptions of the value of the system. What was found was a statistically significant, moderate, positive correlation ($p < 0.01$) between participants' professional experience and their perceptions of the overall evaluation of the system ($r = 0.59$) and between participants' professional experience the value of the system ($r = 0.65$). This means that the higher the participants' professional experience, the higher their perceptions for the overall evaluation and value of the system.

The same finding was not observed for the *usability* of the system, as this was not correlated at a statistically significant level with participants' experience. The usability evaluation of the system showed that 40.3% (10/32) of participants had some difficulty understanding how the electronic system works (Table 4). However, half of them (50%, 16/32) were uncertain on whether they would agree or disagree with this statement and were therefore hesitant to take a stance. The same finding, a high percentage of participants exceeding 50% of them choosing to neither agree nor disagree with statements concerning usability, was observed for a few other questions as well. For example, six out of ten responders (59.4%, 19/32) were uncertain about whether the use of the system would delay their responses during an emergency. An analysis of the open-ended question of the instrument, which was answered by 10 out of the 32 participants and referred to suggestions for the improvement of the system revealed the following suggestions: (a) further training on the use of the system should be organised to increase participants' familiarity with the system ($n = 2/10$), (b) a more user-friendly and simpler interface should be designed that will be accessed from a small and portable device, e.g. a smart-phone rather than a tablet ($n = 2/10$), (c) the system should be connected with the protocol used by the Emergency Department and colour tags (e.g. in the form of bracelets) should be used for easier identification of the victims ($n = 1/10$), (d) the system should provide safer, faster, and more valid information ($n = 1/10$).

Another interesting suggestion, also revealing some hesitation to use the system, referred to the need to have specialised personnel of the rescue teams be in charge of the use of the system rather than nurses, as the use of the system for the latter might be time-consuming ($n = 1/10$). The last suggestion involved the immediate notification of all relevant emergency services at the same time by the system ($n = 1/10$). This is a component of the system that has not yet been developed.

5. Conclusion: Concluding we had created and tested a system which can be used during major emergencies/crisis events. This system enables better management of the first responders, health services, and victims located in the area of the event. Furthermore, it incorporates information security elements and provides user authentication and privacy.

Testing the system in professional exercises simulating major emergency cases had shown that it could be a valuable tool to better train the users to handle an emergency. Additionally, the results from system usage could help in improving existing frameworks for major emergencies/crisis management.

The evaluation results after using it in circumstances simulating an earthquake and a terrorist attack were positive and promising. A statistically significant correlation based on age/experience and

answer scores indicates that, as we expected, the more experienced and older professional nurses can more easily appreciate the value of the system compared with young and relatively inexperienced nursing students. Overall, the personnel reacted in a very positive way and it was very well received.

Our future plans are to further test the system through professional exercises and continue system improvements and personnel training in order to have a finely tuned framework that could be utilised during emergencies.

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