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DIFFERENT APPROACHES TO ICT-ENHANCED EMERGENCY MANAGEMENT

Lydia Kraus, *University of Belgrade, Institut Mihajlo Pupin, Volgina 15, Beograd,* lydia.kraus@pupin.rs
Valentina Janev, *University of Belgrade*, *Institut Mihajlo Pupin,Volgina 15, Beograd,* valentina.janev@pupin.rs
Sanja Vraneš, *University of Belgrade*, *Institut Mihajlo Pupin, Volgina 15, Beograd*, sanja.vranes@pupin.rs

Abstract – *In this article a survey of emergency management (EM) systems reinforced by Information and Communication Technologies (ICT) is given. Emergency management is the process of managing situations that expose people and infrastructure to damage and that are difficult to handle due to their complexity, size, number of stakeholders and emergency evolution unpredictability. This article aims at giving an overview of the emergency management domain and its technologies with respect to ICT research shown on examples from European projects.*

1. INTRODUCTION

Emergency management, disaster management and crisis management are often used interchangeably to refer to the management of exceptional situations. According to the extent of the emergency situation and the circumstances to which they refer either the one or the other, sometimes even two or all three of them are appropriate. But, what all of them have in common is the same inherent structure. In this paper, we will be referring to the domain of emergency management, but we will be using the same concept to denote the domains of disaster and crisis management as well.

The emergency management process consists of four main phases: prevention, preparedness, response and recovery. Emergency management itself is a complex field, with a lot of different active and passive stakeholders that need to perform different tasks in a short time. Having the right information, equipment and resources available is a prerequisite for successfully handling emergencies. However, emergency events are mostly difficult to monitor and to coordinate, as they usually occur randomly and/or simultaneously. As developments in the ICT field progressed, the area of ICT based emergency management systems evolved as well.

With numerous crises and emergencies taking place within the last years, such as natural hazards and terrorist attacks, the European Commission (EC) has identified the need to push the performance of research in this field [1]. Thus, within the Sixth and Seventh Framework Program (FP6 and FP7), many projects addressing the field of emergency/disaster/crisis management were/are undertaken. These projects use a variety of approaches to solve the different issues that have to be handled in emergency management, such as collaboration between stakeholders, provision of communication infrastructure, dealing with uncertain information and sharing of a common picture of the emergency situation.

This paper aims at giving an overview about the widespread domain of emergency management by classifying sub-domains, and by surveying the technological approaches used in FP6 and FP7 projects. In section 2, we define sub-domains of emergency management. In section 3, we give an overview of the different emergency management systems that were developed within FP6 and FP7, as well as their technological approaches. We draw the conclusion in section 4 by summarizing what functionalities all of these systems have in common, and by providing an overview about the most common approaches and technologies. We conclude the paper by discussing emerging trends and future developments in section 5.

2. SUB-DOMAINS OF EMERGENCY MANAGEMENT

In emergency management a lot of different processes have to be performed that need support from the technical side. To better structure the domain, we split it in several sub-domains that describe the different challenges in emergency management and how they can be approached.

Situational Awareness - During a stressful emergency situation, responders and involved people can suffer from a lack of objective situational awareness. Emergencies are usually large scale, distributed events that require many prompt decisions which need to be based on often incomplete, inconsistent or even contradictory information. The term “situational awareness” describes the un-biased assessment of what is happening around somebody. Common understanding (i.e. consensus building) between all stakeholders, especially among the responders, helps to handle the emergency more effectively. This common understanding is referred to as “shared situational awareness”. Problems that need to be solved within the situational awareness sub-domain include disparate semantic meaning of information, ensuring of data quality (precision and completeness) and influence of socio-cultural factors (different perceiving of information), as well as the sharing of information [2], [3].

Decision support - Decision support is meant to facilitate the decision makers providing relevant raw data as well as derived information (e.g. situational data) from the scene and even recommending feasible actions (or ranked alternatives) to emergency managers and other stakeholders. Evacuation route finders are an example application for decision support systems [4], [5].

Collaboration - During an emergency, responders from different organizations such as emergency medical services, fire fighting services, police and local/regional/state authorities have to collaborate. However, these organizations have different communication and coordination systems and organizational structures, providing obstacles in collaboration. The topics that are addressed in collaboration research include system interoperability, semantic interoperability, system integration and conflicts in autonomous coordination [6], [7], [8].

Communication – Crucial to the success of emergency management is the communication between stakeholders, i.e. communication on scene, from on-scene to off-scene and vice versa. In case of large scale emergencies it is likely for the communication infrastructure (mobile phone network, internet) to break down in the affected area. Also, responders are communicating via radio, but this also includes technological drawbacks as every response organization has to use its own radio channel which makes inter-organizational communication difficult [9]. The heads of each organization have to meet in person to communicate. An important issue addressed in this field is the provision of a reliable communication infrastructure.

Human behavior – Emergency events involve humans and their reactions and decisions which have extensive consequences on the development of the emergency situation. By analyzing and simulating human behavior, intelligent emergency management systems can help to predict the evolvement of a situation and thus can help to avoid more dangerous situations or to better manage these situations. Crowd management, for example, is a field in which prediction can be of high importance. Thereby, the behavior of crowds in panic situations is an important issue in emergency research [10].

Training – Emergency management procedures are defined in emergency plans adopted by different organizations. To be prepared for an emergency case, stakeholders that respond to an emergency (different organizations), as well as emergency managers and personnel of sites that are likely to experience an emergency (e.g. airports, metro station, large public buildings, etc.), are required to perform emergency trainings. As real-life emergency trainings are costly and difficult to organize, software systems for emergency training offer advantages. They allow, for example, the play of real-time scenarios simulating emergency events and demanding interaction from the trainee. Training systems can be built upon different approaches such as scenario [11] or game-based (see CRISIS project).

Simulation - Simulation can be applied in emergency training systems, but it can be applied in real-time emergency management systems for situation prediction as well. Subject to simulation can be, for instance, evacuation, crowd behavior, fire and heat spread. An overview of evacuation simulation environments is given in [12].

3. ANALYSIS OF APPROACHES IN EUROPEAN PROJECTS

In this section we will analyze the approaches taken in emergency management systems of selected EU projects. Therefore, we categorized the projects according to the sub-domains defined in section 2. An overview of the projects and their related sub-domains is given in Table 1.

All of the referred projects are mainly addressing the field of emergency preparedness (e.g. TR and SIM sub domain) and emergency response (SA, DS, COLL, COM, HB and SIM sub domain). The first part of the considered projects deals with multi-sensor fusion and human behavior analysis (all projects that combine SA, DS and HB). PROMETHEUS (Prediction and interpretation of human behavior based on probabilistic structures and heterogeneous sensors) is focused on interpreting data in order to predict human behavior. The approaches used to achieve this objective are human behavior modeling and multi-sensor fusion techniques, e.g. video and audio processing, processing of proximity measures etc. and Bayesian networks (https://www.informationsystems.foi.se/~prometheus-fp7).

Table 1. *Overview of European projects and related sub domains.*

Project Name	SA	DS	COL	COM	HB	TR	SIM
PROMETHEUS*	X	X	-	-	X	-	-
VANAHEIM*	X	X	-	-	X	-	X
HERMES‡	X	X	-	-	X	-	X
SAVE ME*	X	X	-	X	X	X	X
INDIGO*	X	X	X	X	-	X	X
IDIRA*	X	X	X	X	-	-	X
COPE*	X	X	X	X	-	-	X
BRIDGE*	X	X	X	X	-	X	X
ESS*	X	X	X	X	-	-	X
EMILI*	X	X	-	-	-	X	X
MOSAIC*	X	X	-	-	X	-	X
WORKPAD†	X	X	X	X	-	-	X
SECRICOM*	-	-	X	X	-	-	-
TASS*	X	-	-	-	-	-	-
PANDORA*	-	-	-	-	X	X	X
CRISIS*	X	X	-	-	-	X	X

* FP7, †FP6, ‡ national funded projects

SA – Situational Awareness, DS – Decision Support, COLL – Collaboration, COM – Communication, HB – Human Behavior, TR – Training, SIM – Simulation

The FP7 project VANAHEIM (Video/Audio Networked surveillance system enhAncement through Human-cEntered adaptIve Monitoring) is based on video and audio processing of data from the surveillance system combined with human behavior research in order to perform real-time monitoring of people and crowd behavior modeling (http://www.vanaheim-project.eu/). Both projects focus on indoor environments. The German project HERMES applies for the same purpose technologies such as image processing, image analysis algorithms and faster-than-real-time simulations (http://www2.fz-juelich.de/jsc/appliedmath/ped/projects/hermes). Another category of systems are multi-functional EM systems (all projects that address at least 5 sub-domains). SAVE ME (System and Actions for VEhicles and transportation hubs to support Disaster Mitigation and Evacuation) belongs to this category. It is focused on public transport and critical infrastructures. The system uses sensor networks, real-time/closed-loop simulations, modeling, intelligent agents and ontology engineering and human behavior analysis. A telecommunication infrastructure is provided, too (http://www.save-me.eu/). INDIGO (Innovative Training & Decision Support for Emergency operations) provides a multi-function EM system covering 6 of 7 sub-domains. Approaches include tools for 2D/3D map interaction, system interoperability tools to enable integration of different technologies/ standards (e.g. GPS, UMTS, TETRA, CAD), and it offers simulation modules for training and decision support (http://indigo.diginext.fr/EN/index.html). According to the CORDIS website (http://cordis.europa.eu) IDIRA (Interoperability of data and procedures in large-scale multinational disaster response actions) is focused on interoperable communication, information and response in order to create a command and control structure by unifying existing ideas and technologies for the purpose of crisis management (http://www.idira.eu). As the project started recently, no information about the technologies could be found yet. COPE (Common operational picture exploitation) followed a user-driven approach to develop an improved emergency management system (http://cope.vtt.fi/). The developed system is based on already available technologies. However, through the user-centered design approach they are combined in a novel, more useful way for the end users (emergency responders, emergency coordinator, etc.). Main parts of the project were system integration and technology mapping (sensors, communication, command and control) according to end-user requirements [1]. BRIDGE (Bridging resources and agencies in large-scale emergency management) investigates run-time intra- and inter-agency collaboration, ad-hoc network infrastructures, middleware for system and network interoperability, agent-based simulations, adaptive, multi-modal user interfaces and other areas (http://www.bridgeproject.eu). ESS (Emergency Support System) is based on data fusion, for example, from a sensor infrastructure which is set up in real-time on-scene. ESS provides an independent communication infrastructure, and a portal (DFMS, data fusion mediation system) for information processing and fusion which is ubiquitously accessible by the stakeholders (http://www.ess-project.eu). EMILI (Emergency Management in Large Infrastructure), the project in which the authors of this paper have taken part, uses data gathering from on-site installed systems (SCADA systems) and semantic technologies (complex event processing (CEP), ECA rules, ontologies) for data processing and interpretation. It offers a rule-based simulation environment for training and real-time simulations (SITE) (www.emili-project.eu). MOSAIC (Multi-Modal Situation Assessment and Analytics Platform) is based upon data fusion from different sources (multi-media sensors, sources and databases) and advanced analytics using post-processing, as well as pre-processing algorithms through intelligent hardware (e.g. smart cameras) and semantic technologies (ontologies) (http://mosaic-fp7.eu). FP6 WORKPAD (Adaptive peer-to-peer software infrastructure for Supporting Collaborative Work of Human Operators in Emergency Disaster Scenarios) used user-centred design approaches which lead to a two level architecture with a back-end peer-to-peer (P2P) part and front-end peer-to-peer parts (http://www.dis.uniroma1.it/~workpad/index.html). Thereby, the back-end P2P provides data, services, knowledge and content integration, and the front-end P2P services to users. SECRICOM (Seamless communication for crisis management) is focused on secure data transmission for emergency management providing a communication infrastructure and a communication control center to enable network interoperability based on secure wireless communication and secure agent communication. Also, a focus was put on the development of new hardware (secure docking module, SoC) (http://www.secricom.eu/). TASS (Total Airport Security System) is dealing with airport security focusing on situation awareness for different stakeholders of an airport. Approaches include multi-source data fusion (passenger, airport, airline, etc.), data processing, as well as an information portal and WEB based applications for analysis and view (http://www.tass-project.eu). PANDORA (Advanced training environment for crisis scenarios) is focused on simulation and training combined with human behavior. It is based upon a knowledge engineering approach, using rule based, event network planning for loop scenario simulation with real-time sensor input from the trainees and integration in a multi-media environment (http://www.pandoraproject.eu/). CRISIS (Critical Incident management training System using an Interactive Simulation environment) is a distributed, scalable, collaborative interactive simulation environment for training of emergency managers. It is investigating interactive game paradigm in emergency management, user interaction with the game and psychological aspects (http://idc.mdx.ac.uk/projects/crisis/).

4. CONCLUDING REMARKS

We investigated different approaches used in European projects for emergency and crisis management systems. By dividing the domain in sub-domains, we made a classification of the main challenges for these systems. When comparing the projects, it is obvious that most of them follow a similar functional approach. EM systems need to be built on an ICT infrastructure, whereas the focus can be on different points, such as communication, collaboration, integration or sensors. ICT infrastructures enable the gathering of data, sharing and exchange of data, its fusion and interpretation. When data is gathered, fused and adjusted to an interchangeable format, it is ready for further intelligent processing. This enables the development of situation awareness and decision support applications. For advanced situation awareness and decision support, a real-time simulation of potential situation evolution is of enormous significance. Simulations are often a fundament of training applications as well. Fig. 1 gives an overview of EM system functionalities.

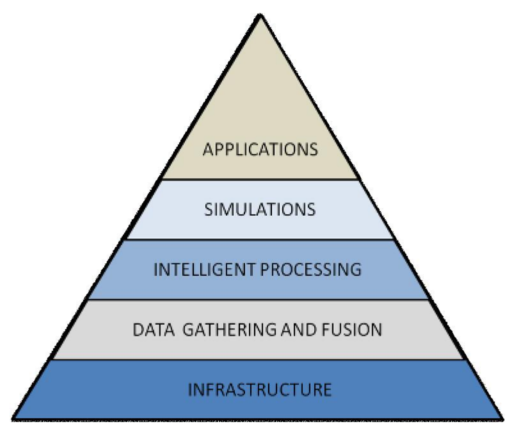

Fig. 1. *EM system functionalities*

By comparing the selected projects we identified the following main approaches and technologies used in the field of emergency management systems:

- Image Processing
- Probabilistic approaches
- Audio processing
- Human behavior modeling
- Computer Vision
- Semantic technologies
- Sensor Networks
- Software agents
- Interoperability/ Integration
- Advanced/Interactive User Interfaces
- Simulation
- Network infrastructure

- Data fusion technologies
- Databases
- WEB technologies

As emergency management is a broad field with a lot of sub-domains, the approaches and technologies used are numerous as well. In each project, several approaches and technologies were combined to address the objectives of the project.

5. EMERGING TRENDS AND NEEDED FUTURE DEVELOPMENTS

Emergency management systems include many technologies and approaches as shown in section 4. We believe that all these areas offer a great innovation potential. Thereby, we give 5 examples of emerging trends that we consider useful for future developments.

Intelligent hardware – As hardware is getting cheaper and processing capabilities are getting more powerful, intelligent hardware offers a possibility to speed up data processing and improve the robustness of the system, which thus does not fail when its core processing unit fails.

Standardization – So far EM standards in several fields are missing: common ontologies and/or terminologies as well as technical standards [1], [6]. We believe that by defining standards, system reusability, interoperability and integration can be improved.

Social networks – Social networks offer a high potential for citizen participation and alerting in case of large-scale emergencies. However, to the best authors' knowledge, their use in emergency management is not yet addressed in European projects at this point in time.

New semantic technologies – New semantic technologies such as linked data, linked open data and RDF offer new means to easily link data for improved situational awareness. An example for this is given in [13] where linked data (in RDF) is applied to manage real-time data which is important for fire fighters to improve their situational awareness.

User-centered design/Usability – To avoid the development of systems that are innovative but not useful to emergency practitioners we believe that user-centered design is crucial for the development of EM systems. This includes, for instance, end-user involvement by design and cyclic analysis through use cases, scenarios and persona. In [1] the need of "demand-side initiatives" is stated as well.

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