Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 63 (2015) 392 – 399

Procedia Computer Science

The 5th International Conference on Current and Future Trends of Information and Communication Technologies in Healthcare (ICTH 2015)

Smart Augmented Fields for Emergency Operations

Pietro Brunetti*, Angelo Croatti*, Alessandro Ricci, Mirko Viroli

University of Bologna, Dept. of Computer Science and Engineering (DISI) – via Sacchi 3, Cesena, Italy

Abstract

The impressive development of wearable computing and augmented reality technologies which is occurring in recent years allows to devise ICT systems that can bring a disruptive innovation in how emergency medical operations take place. In this paper we describe first explorations in that direction, represented by a distributed collaborative system called SAFE (Smart Augmented Field for Emergency) for teams of rescuers and operators involved in a rescue mission. SAFE is based on the integration of wearable computing and augmented reality technologies with intelligent agents and multi-agent systems.

Peer-review under responsibility of the Program Chairs
Keywords: Healthcare, Emergency Management, Augmented Reality, Hands-free

1. Introduction

In the last decades, advances in mobile computing technologies have had a fundamental impact in devising IT systems supporting the daily work of people involved in healthcare. More recently, the developments in wearable computing and augmented reality technologies allow for conceiving a new generation of systems that can further reshape the way in which people work and collaborate. A main specific healthcare context where such technologies can bring a disruptive innovation is *emergency*. In this context, although latest technologies could allow human capabilities empowering through a seamless interaction with smart and complex systems, in the current state-of-the-art doesn't arise a leading solution for the large scale use (see Sections 2 and 5).

In this paper, we describe an ICT system for supporting the work of teams involved in emergency/rescue scenarios, based on the integration of wearable computing and augmented reality technologies along with intelligent agents and multi-agent systems. The system has been designed and developed upon a middleware called *augmented field* (AF). AF provides basic services and functionalities for building and running agent-based distributed online collaborative systems, exploiting different degrees for *augmentation*, to support the action and the coordination of a team of operators acting in some physical environment/field. Essentially, the AF-based system presented in this paper – referenced in the following as *Smart Augmented Field for Emergency* (SAFE) – exploits, among others, such services for:

* Corresponding author. Tel.: +39-0547-338888; ; fax: +39-0547-338890.
E-mail address: {p.brunetti | a.croatti}@unibo.it

Peer-review under responsibility of the Program Chairs
doi:10.1016/j.procs.2015.08.358

- improving the effectiveness of the action of individual rescuers engaged in the physical field where the rescue takes place;
- improving their interaction and coordination with others team members, that they may follow the mission from remote control rooms.

The remainder of the paper is organized as follows: first, section 2 provides a background on state-of-the-art technologies applied to emergency and rescue systems; then, section 3 describes the main concepts and architecture of AF; after that, the SAFE is described in 4, along with a first evaluation based on a prototype implementation. Related works (section 5) and concluding remarks (section 6), including a discussion of future works, complete the paper.

2. Healthcare Emergency Scenario

In case of disasters only a limited number of resources is available and an efficient coordination of rescuers' work/actions it's essential to achieve the best usage of all available resources. Medical first-aid treatments to involved people must be carried out rapidly and rescuers should have the capability to establish health status of each person and execute a primary medical treatment[1], if it's necessary. All rescue actions on a field are carried out as a set of collaboration and cooperation activities, involving one or more teams acting within a specific environment with a very dynamic (and potentially unpredictable) context[2]. In particular, teams act cooperatively, sharing information with the purpose to making each rescuer aware of the global state of all actions performed on the field. Every disaster area could have different features, most of them potentially critical: communication infrastructures are often damaged or overwhelmed and some sub-areas could be difficult to reach, for example. Moreover, not all rescuers have same skills and same duties (we can distinguish them between general-rescuers, nurse and medics) and, generally, a set of coordination mechanisms is needed to achieve a fruitful collaboration[3]. Healthcare emergency scenarios are not simple to manage. A way to improve and empower rescue actions may pass through the introduction, in these emergency contexts, of smart software systems that could help rescuers actions and improve teams coordination and collaboration.

State of the Art. Several software systems applied to healthcare emergency management were proposed in last decades. As reported in[1] and[4], most of them are related to automatize triage procedure. In most cases, each rescuer have a smart device which is able to guide the rescuer to perform his actions on victims. With the smart device, rescuer can evaluate patient's health status and, in some cases, communicate in some way (and under some restrictions) with the mission coordination centre. This current approach is an evolution of the previous basic approach, principally based on paper sheets, and the focus is about reducing (1) each procedure duration and (2) the amount of skills that rescuers have to obtain to perform their actions in an emergency. In some existing software systems for emergency management, there is also the concept of mission coordinate centre (also defined as operative centre, central unit, . . .), that can receive data and information sent from operators for monitoring and persistent storage purposes.

Remarks on current approaches. Software system that are currently used in emergency scenarios are mostly focused on single rescuer/operator and not on teams: a first remark about this approaches is related to the lack of system design for cooperative work support. Only the mission coordination centre, if exist, is aware about the global state of ongoing actions. Rescuers are only aware about their own actions and they are not helped by the system to cooperate with others operators, for example to send each other (implicit or explicit) messages or to have a real-time summary of both the global state of the mission and the actions performed by others.

Another important thing that is not been considered in current approaches is the hands-free requirement. For each operator should be possible to interact with the software system without using his hands, because hands should be used to perform medical assessment to patients. Considering this requirement, the interaction between operator and systems should pass through different supports rather than commons mobile devices, like smart-phones or tablets: for example, introducing glasses for augmented reality. Furthermore, the lack of focus on the hands-free systems and techniques has reduced the intuitiveness in using those systems; in fact, they often fail into an overall reduction of human mistakes accidentally done during a critical emergency scenario.

3. The Augmented Field Idea and Middleware

AF integrates ideas from different fields: in particular augmented/mixed reality, multi-agent systems and smart environments/ambient intelligence. From a conceptual point of view, an AF can be conceived as a digital/virtual layer running on top of some physical environment (such as some part of a city, or a building, a room), *augmenting* it with a dynamic set of situated information and computational resources. These augmented elements can be then perceived by operators equipped with suitable devices, such as smart-glasses or AR helmets. For *situated*, here we meant that such augmented entities are anchored either to some specific location or object in the physical environment.

The augmented entities are not necessarily *just* information items or *points-of-interest* (like in the case of classical mobile augmented reality applications), but full-fledged computational objects, encapsulating a computational state and behavior. That is: an AF application is a distributed system whose computational components (or a part of them) are spatially located somewhere, on the physical field which is augmented by the application.

The AF middleware provides a set of core functionalities that can be exploited by specific applications running on top of it, in which augmented entities are created, manipulated. The control part of these AF applications is meant to be distributed and decentralized across dynamic set of *agents*, which are the autonomous software entities living in AF, running on operator devices as well as on hosts on which the AF middleware is running.

3.1. AF Functionalities and Conceptual Model

Generally speaking, AF functionalities are targeted to ease the development and execution of real-time collaborative applications supporting teams engaged in some mission, taking place on the physical environment. These functionalities can be summarized in:

- *Capability empowering* – extending and integrating the set of perceptions and functions of operators that are participating to the mission – on the field and on proper control rooms – so as to improve reactivity and make their decision making process more effective.
- *Context awareness and sharing* – supporting the continuous and principled sharing of the contextual data/information collected by operators acting on the field by means of sensors so that they can be fruitfully exploited by who needs them.
- *Implicit communication and coordination* – providing the functionalities for team coordination through forms of implicit communication based on spatial traces and messages placed on the field.
- *Mission tracking, monitoring & analysis* – allowing the collection of continuous streams of data and events coming from the augmented field (including both physical and logical events), so as to: (1) keep track of the real-time state of the mission, (2) enable a real-time automated analysis of such streams in order recognize critical situations and (3) record the mission, allowing for post-mission replay for analysis purposes.

Main elements of the AF model are shown in the UML diagram in Fig. 1. Thinking about AF as an OS/platform, then each application running on top of it is characterized by a *mission* involving a *team* of *operators* acting on some *physical field*. Operators can have different roles (operator participation is per-role based) and they can join a mission by specifying their role inside: in a sense, operators are like the users of the applications. A mission, with a start and an end, occurs on some physical field – defined by some coordinates. On top of it a digital field is created – adopting a local system of reference to identify spatially the location of objects (physical, digital) inside. As long as the mission is carried on, its status is tracked by the AF middleware.

For each mission, some *devices* can be deployed on the field to help human/team action. Examples can be sensor networks or tags useful to creating the coupling between the physical and the digital layer. For each field device, a device driver must be installed in the AF to enable its use. The *control room* is a special/predefined distributed applications that allows for real-time tracking of the mission, as well as for controlling.

3.2. AF Design/Programming Abstractions

An AF application is a distributed system composed by an dynamic set of agents that are logically situated into the AF environment, conceived as a distributed shared workplace and composed by a dynamic set of resources that can be

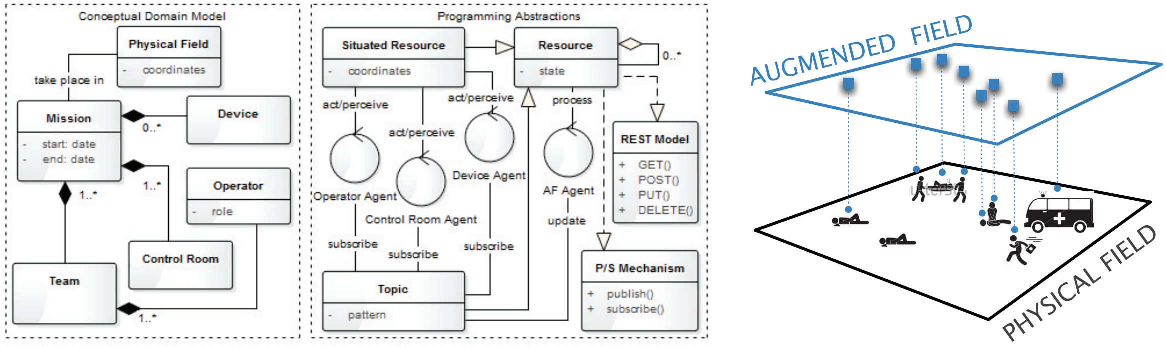

Fig. 1. AF conceptual domain model (left) and a logical representation for the Augmented Field (right).

perceived and accessed by agents. The notion of *resource* is used here to represent any passive computational entity that can be useful to support agent activities. Among others, the most important kind of resource is given by *situated* ones, representing the *augmented entities* of AF. These resources refer to a specific location in the physical environment, "anchored" either to some specific geographical coordinates or to some physical object/marker. In particular, REST[5] has been adopted as reference model and architecture to conceive their design and overall organization, extended with a first-class support for a publish-subscribe interaction style. The conceptual resource tree is organized as follow: each node is a resource identifier, with mission ID as the root node; resource properties are also mapped in node elements, like sub-resources in a hierarchical way, and are observable by Agents.

Agents represent autonomous software entities situated in the AF environment, (running on devices worn by operators or on distributed host computers) responsible of carrying on some tasks by (1) creating/observing/manipulating the resources that are part of the shared AF environment and (2) directly communicating with other agents by means of asynchronous message passing. Agents can act upon resources in a REST-style way, so by means of predefined interaction primitives such as PUT and POST. Viceversa, they can perceive the current observable state of a resource either by pro-actively performing GET like action (pull style), or by *subscribing* a resource (push style). In the latter case, after subscribing a resource, the agent will receive the stream of observable events generated by changes to the state of the resource, eventually filtered according to filters/rules specified by the agent upon the subscription. Like in Event-Driven Architectures and P/S systems, agents can create subscriptions to perceive events not only from a specific resources, but any event occurring in the AF satisfying some conditions. This is uniformly modeled by predefined built-in resources, called *topics*, that are instantiated specifying the patterns and predicates useful to identify the events that can be made observable through the topic. Topics can include conditions (filters) related to the spatial setting of the resource (e.g. a specific value of all coupled devices inside a defined field area).

3.3. The AF middleware: an Architectural Overview

The role of the AF middleware is to provide the adequate abstraction (as a "glue") in order to allow the necessary smart interoperability functions among system entities. Part of this middleware is distributed as a set of APIs that allow applications to interact with the underlying middleware communication layer by means of two modules, an *event receiver* and a *resource manager*. Moreover, such interactions between SAFE applications and the AF middleware is mediated by an upper domain specific API level that encapsulate the behavioral patterns useful to define entities application logic. API also contributes to the communication level failures management, providing autonomous features to detect and restore possible lacks of connectivity through an *heartbeat-like mechanism*. This functionality enables entities to be aware of the (1) connectivity state of the ecosystem and (2) time-related accuracy of its belief base.

AF middleware (depicted in the lower part of Fig. 2) keeps a *shared space* containing domain specific data (e.g. mission information, tag data streams, . . .), resources and rules in particular. Entities can interact with this data space through a specific interface that enables I/O operations, in order to obtain and update the stored global environment representation. Specific reactive and proactive components (AF Agents) observe, perceive and act upon such data to generate all system events. Then, they are dispatched to all interested system entities by a dedicated *routing compo-*

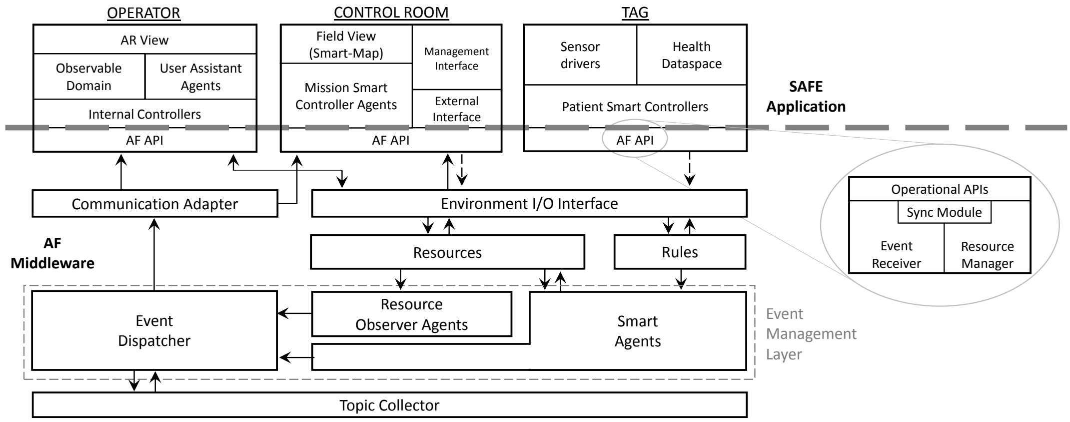

Fig. 2. AF middleware and SAFE logical architecture.

nent, through a *communication adapter*. Finally, an *event collector* component maintains event related information as soon as they are available, organizing them into dynamic topics to better support the continuous information flow.

4. SAFE: Smart Augmented Field for Emergency

In this section we introduce architectural details about a feasible design approach for distributed software systems, based on the idea of augmented field as previously explained. Using this design approach, we also propose a first prototype that realizes a concrete software application to evaluate the SAFE idea.

Emergency scenarios supported by the most recent and cutting-edge technologies should lead to contexts in which rescuers (operators) are equipped with suitable smart mobile/wearable devices able to host and support a software system with the aim to improve rescuers capabilities and the impact of their actions on patients' life. Moreover, rescue protocols could be more effective introducing wearable devices (tag) to support patients identification and monitoring of their health status. Finally, the whole mission set of information is shared between operators and a control room by means of a communication and cooperation infrastructure. In order to interact with entities, tracking all events and supervising the entire ongoing mission, a control room is defined as a central control unit.

4.1. A picture of notable scenarios

In order to achieve the best outcome (e.g. save lives, giving first aid, . . .) actions and operations performed by rescuers – arranged in order to carry out a rescue mission on the field – must be as much effective and accurate as possible. In other words it is important (1) to assign the right health severity code to patients, (2) keep monitored their health status if necessary and (3) exploit cooperation and information sharing about the overall environment to decide where and how to act.

In SAFE idea, each rescuer's action (e.g. patients identification and first medical treatments such as triage) is assisted by smart agents that take advantage of context data, stored in a shared information space provided by the AF middleware. These user assistant agents are able to use such information – rescuer location, patient vital sign's real-time measurement, environment state and others – to guide and to make easier rescuer tasks completion through an augmented reality based interface that, in fact, represents the main way to interact with the support software application. As a part of the SAFE concept, we have taken into account the importance of the free-hands principle in order to introduce an innovative approach to the input issue in contexts where the interaction based on touch-screen devices may adversely affect mission efficiency and efficacy. So, each rescuer is equipped with a mobile AR-oriented device (e.g. AR-Glasses like Epson Moverio BT-200 or, better, DAQRI Smart Helmet) that allows the system to bring up all messages and information coupled to the rescuer's current real field of view. These messages could be either related to a specific system entities or associated to a more general field point of interest (POI). The latter case represent another way to enrich environment with augmented located and useful information.

On the rescue field, when a rescuer finds out a victim involved in some way into disaster he/she has to identify and evaluate patient health status in order to perform first aid treatments. At the identification time, in SAFE concept, a mobile (wearable) active device (tag) is associated to each patient. It's composed by (1) a memory unit dedicated to the real-time storage of patient health status and (2) a smart sensor management layer, in which some software agents continuously sense patient's vital signs and update local state. Data flow arising from the tag, are elaborated by rescuer's smart assistant agents helping to perform actions in the shortest time and hopefully with the best outcome within mission goals. Two communication approaches are supported by tags. The first is related to the interaction between tag itself and the overall system as a way to sharing state and sensor data; the second, instead, concern the direct communication (P2P) to a specific reachable operator in patient's proximity range.

As a member of an heterogeneous rescue team, each operator can exploit cooperation and interaction capabilities supported as building-blocks functionality of the AF middleware which plays an essential role to achieve the best result for the ongoing mission. In the SAFE idea, the inner cooperation is reinforced by a third SAFE entity – named Control Room – that act as a central control and management node is introduced to give a further point of view, the mission overall perspective. The most important goal to achieve is related to the remote real-time monitoring and support of the mission story-line, that includes both actions carried out by each rescuer and the patient's tag data flow. A smart visualization and interaction functionality is a fundamental part in the characterization of every control room application, as the most convenient way to increase human component capabilities. The control room is organized into a three-phases cycle described as follow. The first phase includes the mission configuration and initialization, the definition of role/goals for rescuers and, possibly, a first environment setup. In the rescue scenario this phase should be performed as quickly as possible, thus the control room software agents could help to define an initial configuration for the mission which is based both on preliminary disaster related information and on the rescuers' profiles (capabilities and roles). The second one, instead, is related to the management of the current mission. In this phase it's possible to obtain a complete overview of the entities involved in the mission through an interactive geographical map that enable a kind of environmental view. The most relevant feature of this map is related to the real-time tracking of locations and states related to each entity (both rescuers and victims) involved or discovered. The control room staff, using the map, can also (1) directly interact with one or more operators at the same time (by sending and receiving implicit or explicit messages), (2) receive from the mission field many implicit feedback (e.g. alarms/warnings) based on a set of rules specified either at configuration moment or dynamically during the mission and/or (3) act onto the field introducing augmented information perceivable by operators (e.g. assigning a degree of criticality to a specific geographical area within field's boundaries). Finally, the third phase – post-mission evaluation phase – concerns both the summary of all meaningful events generated during the mission and the use of data analytic techniques to improve data quality and increase the entire know-how useful to next missions.

4.2. Application level entities: features description

In our vision, every domain-specific application that dealing in some way with the cooperative rescue in emergency scenarios should be designed as an instance of SAFE applications, as presented in the previous section. In the healthcare rescue related case study, aforementioned three main parts (operator, control room and tag, depicted in Figure 2) represent all fundamental elements and so they should be considered as SAFE first class entities linked each others through the more general AF middleware in order to define the whole system architecture.

Every entity use API provided by the AF middleware as a medium to interact each others. The operator entity uses an internal observable domain, partially bound to the AR-view elements, to store local (context-related) information. User assistant agents may use and manipulate these information to properly guide rescuer in the real field, enabling the perception and the interaction in the entire augmented field. Tags are composed of an internal dataspace designate to maintain real-time patient vital signs values continuously collected by sensor drivers and managed by some specific smart controllers. The design of tags doesn't include an embedded specific view because we assume that related information may directly shown onto other system entities' view component. At last, the control room offers two main ways to interact with the application: a smart geo-map and a management interface. The first is designed to provide a more useful and dynamic field view while the second one is introduced as a generic I/O command interface. Control room is also conceived as a strategic management node; through the external interface component it is possible to

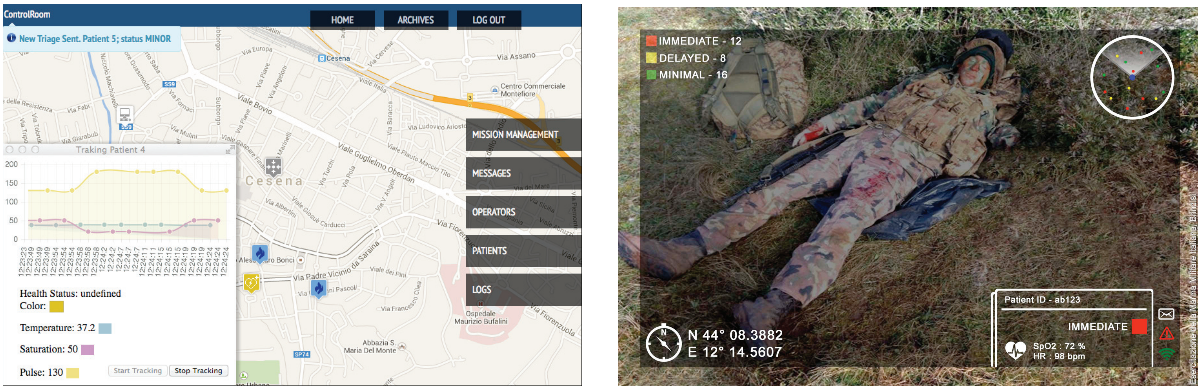

Fig. 3. Prototypes of (a) Control Room Field View and (b) Operator AR View. Note that the operator AR-View it's superimposed on a simulated field to show a possible example of how each rescuer, through AR-Glasses, can interact with the system and perceiving augmented field information.

extends its functionality with the injection of newest third-part functionalities (e.g. information exchange to evacuate victims from the critical area and move them to hospitals).

4.3. Prototype

Based on the idea of SAFE explained before, a prototype has been developed to validate and evaluate the introduction of a kind of smart augmentation into rescue scenarios and emergency management in healthcare. The architecture proposed for the AF middleware has been converted into a first implementation attempt using mainstream technologies. We have also realized an instance of SAFE – based on the previous explained case study – developing a set of application, both for operators and for the control room, that are able to take advantage of a first released version of APIs library and so interact with our middleware.

In our prototype each operator is equipped with an Android based wearable device – *Epson Moverio BT-200* smart glasses – used to obtain an innovative *see-through* view (see Fig. 3, right) that is characterized by the superimposing of a minimal (unobtrusive but useful) set of information from the augmented field over the perceived physical world and explicitly related to the operator's context. In the current evolutionary state of the prototype, we're using a dedicated controller such as a smartphone (connected to glasses through an ad-hoc Bluetooth protocol) to give inputs to the application mapped as a set of limited gestures. Anyway, in the near future we are ready to introduce a different feasible input support which it replaces smartphone with a complete hands-free solution. For the tag application, some experiments has been carried out exploiting the integration of the Arduino microcontroller with the *eHeath v.2 sensor platform*. The control-room client application is available as an intrinsic distributed system exploiting standard web technologies such as Javascript and HTML5 to easily develop seamless smart interaction functionality over a dynamic geo-map (see Fig. 3, left). That application is able to receive and elaborate warning alarms (related to specific rules) and explicitly interact with operators through the underlying middleware. The proposed implementation of the AF middleware use a RESTful service abstraction to model, store and retrieve information (resources and rules). The *RabbitMQ* Message Oriented Middleware (MOM) is used to inject event delivery and routing functionality in the AF middleware implementation whereas smart entities (agents) of the middleware has been modeled using Java.

5. Related Works

Some attempts to inject ICT in emergency processes to support rescue scenario are proposed in [4] and [1]. Furthermore, in [6] is proposed the *UbiMedic* agent-based framework usable into rescue contexts to implement and deploy services for monitoring information about injured people. In [7] is proposed the idea of a mobile triage tag that makes victims information available to the central unit as soon as possible. In this case, the information flow is managed by mobile agent technology without require any specific network infrastructure. In [8], is evaluate a possible integration for the introduction of Augmented reality technologies as a tool to support collaboration among rescue services and to improve cooperation between actors from different organizations/teams. In [2] is proposed the *CoMa* approach for a collaborative map that exploit the spatial context of a group's members as a means to visualize and provide collaboration functionality. Finally, in [9] the *WORKPAD* adaptive P2P infrastructure is proposed to support collaborative work of human operators in emergency/disaster scenarios.

6. Conclusion

In this paper we have presented the idea of a distributed collaborative system called SAFE, Smart Augmented Field for Emergency. The goal of this system is related to empower rescue missions on emergency scenarios providing an innovative tool based on the idea of the augmented field. SAFE is composed by two main parts: (1) the more general, mission-oriented AF middleware, proposed as a kind of OS/platform and (2) the domain-specific applications to augment involved entities (rescuers, victims, control and coordination unit). The aforementioned proposed solution is primarily intended as a first design experiment, in order to find a unified system model (a set of common elements and patterns) that characterize these type of systems. We have also proposed an innovative architecture based on the integration of different mainstream technologies applied to the healthcare context, rescue scenarios in particular.

Discussion. The development of a first prototype for SAFE has allowed us an evaluation about the middleware's real effectiveness and limitations. After a careful analysis of the state of the art and some discussions with some domain experts, we are led to think that the proposed middleware encapsulate all main concepts of contexts in which the focus is about a smart cooperative work of teams on specific fields and areas. The AF middleware is not only conceived to be applied into healthcare context. In fact, we have proposed it as a general framework to design and develop *augmented fields*. Clearly, the healthcare context, the emergency and rescue in particular, represent actually the main case study where our idea can be applied and improved.

Future Work. In the next research agenda, many points are listed to be considered for future extensions to SAFE and for refinements to the *augmented field*'s idea. For example, the introduction of a completely hands-free support for each rescuer, using an innovative wearable device like *Myo gesture control armband*, from Thalmic Labs. Also, the introduction of a full-fledged agents paradigms could positively enhance future system refactoring reducing the programming abstraction gap from the current prototype toward a completely smart and autonomous system for rescue. Finally, we have to considering the distribution and scale issue and the integration of different degrees of Mixed/Augmented Reality as next-future challenges.

References

1. Mercadal, E., Robles, S., Martí, R., Sreenan, C.J., Borrell, J.. Double multiagent architecture for dynamic triage of victims in emergency scenarios. *Progress in Artificial Intelligence* 2012;**1**(2):183–191.
2. Meyer, E.M., Wichmann, D., Büsch, H., Boll, S.. Supporting mobile collaboration in spatially distributed workgroups with digital interactive maps. *Mobile Networks and Applications* 2012;**17**(3):365–375.
3. Pipek, V., Liu, S.B., Kerne, A.. Crisis informatics and collaboration: A brief introduction. *Comput Supported Coop Work* 2014;**23**(4-6).
4. Gao, T., Hauenstein, L.K., Alm, A., Crawford, D., Sims, C.K., Husain, A., et al. Vital signs monitoring and patient tracking over a wireless network. *Johns Hopkins APL Technical Digest* 2006;**27**(1).
5. Fielding, R.T.. *Architectural Styles and the Design of Network-based Software Architectures*. Ph.D. thesis; 2000.
6. Mola, F.D., Cabri, G., Muratori, N., Quitadamo, R., Zambonelli, F.. The ubimedic framework to support medical emergencies by ubiquitous computing. *ITSSA* 2006;**1**(2):15–26.
7. Martí, R., Robles, S., Martín-Campillo, A., Cucurull, J.. Providing early resource allocation during emergencies: The mobile triage tag. *J Netw Comput Appl* 2009;**32**(6):1167–1182.
8. Nilsson, S., Johansson, B., Jönsson, A.. Cross-organizational collaboration supported by augmented reality. *IEEE Transactions on Visualization and Computer Graphics* 2010;**17**(10):1380–1392.
9. Mecella, M., Angelaccio, M., Krek, A., Catarci, T., Buttarazzi, B., Dustdar, S., et al. Workpad: an adaptive peer-to-peer software infrastructure for supporting collaborative work of human operatoes in emergency/disaster scenarios. In: *In Proceedings of the 2006 International Symposium on Collaborative Technologies and Systems, IEEE Computer Society*. 2006, p. 173–180.