Collaboration On-the-field: Suggestions and Beyond

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ABSTRACT

In disaster scenarios, emergency operators/first responders need to collaborate in order to reach a common goal. The use of mobile devices and applications in these scenarios is very valuable as they can improve collaboration, coordination, and communication amongst team members. But there are also risks involved while using these mobile applications, e.g., decreasing of performance. Most of the tasks are highly critical and time demanding, e.g., saving minutes could result in saving people's life. Therefore, it is unacceptable to use systems that lack proper interaction principles. In this paper, we provide some suggestions, in the form of lessons learned and/or hints for possible future research activities, on how to effectively support on-the-field collaboration of emergency operators. Such suggestions are based on the authors' experience in a recently concluded successful research project on the use of mobile devices for supporting first responders.

Keywords

Mobile devices, geo-collaboration, task assignment, mobile networks, suggestions and research hints.

INTRODUCTION

Nowadays, mobile devices (e.g., smartphones, iPhones and iPads, tablets) are widely used by persons in their daily lives for personal information management (managing calendar, reading e-mails, business and/or private phone calls, accessing Google maps, etc.) and entertainment. The use of such devices in working/business environments is conversely still in its infancy, besides the cited personal information management. A few persons in a few organizations really work with their mobile devices, with some notable exceptions in the sectors of postal delivery, tickets managements on trains, etc.

An interesting area in which mobile devices could play a major role is in supporting emergency operators / first responders acting on-the-field. A recently concluded successful research project, namely WORKPAD (`http://www.dis.uniroma1.it/~workpad`), has deeply investigated the use of mobile devices for supporting emergency operators, through the provision of collaborative features, geo-collaboration and mobile internetworking. The aim of this (hopefully) inspiring paper is to identify and discuss, on the basis of the authors' experience, challenges, requirements and suggestions for the design and development of innovative software systems for supporting work of human operators in emergency/disaster scenarios. The solution of such points, in the near future, is a prerequisite for moving mobile computing from the current personal sphere to the business/organizational one, with specific focus on emergency operators. In particular, the support intended to be provided is about the coordination and automation of the processes to be carried out on-the-field by first responders.

The following of the paper is as it follows. After presenting the WORKPAD project, we provide the suggestions, by organizing into six main areas. Finally we conclude the paper.

THE WORKPAD PROJECT

Due to the recent increase of safety threats like environmental disasters or terrorist attacks, Crisis Response has become a relevant application field for the development of new information technologies. In this context, different teams belonging to different organizations need to collaborate in order to reach a common goal. The use of mobile devices and applications is valuable for the improvement of collaboration, coordination and communication among team(s) to achieve the desired goals. In emergency/disaster scenarios most of the tasks are highly critical and time demanding; for instance, the saving of minutes can result in saving people's lives. A system working in such a critical environment that lacks the basic interaction principles can be dangerous as it could increase the level of disaster or can make the efforts ineffective in such scenarios, by inhibiting government agencies and volunteer organizations to successfully communicate and act in a coordinated way.

The WORKPAD project achieved to provide a software architecture and a communication infrastructure that intends to improve the collaboration in emergency management by leveraging on the above principles. WORKPAD had a duration of 36 months; it started in September 2006 and ended in September 2009, by involving 8 different organizations, including the Civil Protection from a partner country as the main end user. WORKPAD focused on response and short-term recovery phases. The response phase is designed to provide emergency assistance for victims immediately after a disaster happening. Short-term recovery activities aim at returning vital life-support systems to a minimum operating standard. The approaches and technologies developed by the WORKPAD project have been radically different from the existing solutions and methodologies used in previous research projects about emergency management and there was a need for a certain amount of experimentation. Thus the solutions developed within the project needed to interactively be assessed with the users and the new ideas and concepts needed to be tested.

This section aims to give an high-level overview about the adopted methodology, the system architecture and the techniques used to design and to make the WORKPAD system more interactive and more efficient in emergency scenarios, according to the User-Centered Design (UCD) approach (Dix, Finlay, Abowd and Beale, 1997).

The Adopted Methodology to Design the System

In order to improve the collaboration between teams working in emergency scenarios the selection of interactive designing principles was very critical. Therefore, it was decided to employ User-Centered techniques from human-computer interaction (HCI) paradigms (Dix et al., 1997). User-Centered design relies on continuous interaction with end users to understand how organizations are arranged during disasters, what information is critical, and how teams exchange this information among themselves and with their operational centers. In the WORKPAD project, twofold (bottom-up and top-down) high-level approaches with various human-computer interaction techniques were selected for taking the requirements and for designing the system. A top-down approach was used to get information about the related works, investigating relevant legislation, recommendations and initiatives with respect to emergency management. Furthermore, other research projects have been examined regarding the requirements analysis methods adopted, the concrete outcomes and their validity for the WORKPAD project. On the other hand, a bottom-up approach was used to get requirements from the practical work carried out in the field. It has been also used the experience knowledge of users and technical persons working in the emergency or disaster scenarios to get more User-Centered focus. The potential users had a significant impact on the design and development process and were considered to be the most important drivers of innovation within the project. The users were actively involved in all stages of the system engineering process. In WORKPAD, the slightly adapted Scenario-based Requirements Analysis Method (SCRAM) (Sutcliffe, Maiden, Minocha and Manuel, 1998) has been used in order to get a realistic understanding of the user's problem context, to derive early requirements that have served as a basis for further UCD activities such as storyboards and hierarchical task analysis (HTA), to design the showcase, and later on to evaluate the WORKPAD approach. The purpose was not just the simplicity but to develop a working system with functionalities and capabilities with an adequate level of usability. A detailed description of each phase can be found in (Humayoun, Catarci, de Leoni, Marrella, Mecella, Bortenschlager and Steinmann, 2009).

The Overall Architecture

According to the initial user requirements collection (de Leoni, De Rosa, Marrella, Mecella, Poggi, Krek and Manti, 2007) we learned that the most suitable architecture is two-level: a first level is deployed on the spot and a second level involves the servers of the different rescue organizations. There are several front-end teams on the field, each composed by rescue operators and headed by a "leader operator", who coordinates the intervention of the other team members. Rescue operators are equipped with PDAs and their work is orchestrated by a Process Management System (PMS) which is hosted on the most powerful device which is typically the team leader's device. The PMS manages the execution of emergency-management processes by orchestrating the human operators with their software applications and some automatic services to access the external data sources and sensors. At the back-end side data sources from several servers are *automatically* integrated and the result is a single virtual data source that front-end devices can query, thus obtaining information aggregated from several sources. From an organizational perspective, back-end includes the control rooms/headquarters of the diverse organizations that have rescuers involved at front-end. These control rooms provide instructions and information to front-end teams to support their work. Collaboration strictly depends on the possibility that operators and their devices can communicate with each other. Communication is executed on top of mobile networks. Such mobile networks provide gateways to connect to back-end servers. Figure 1 shows the overall WORKPAD architecture.

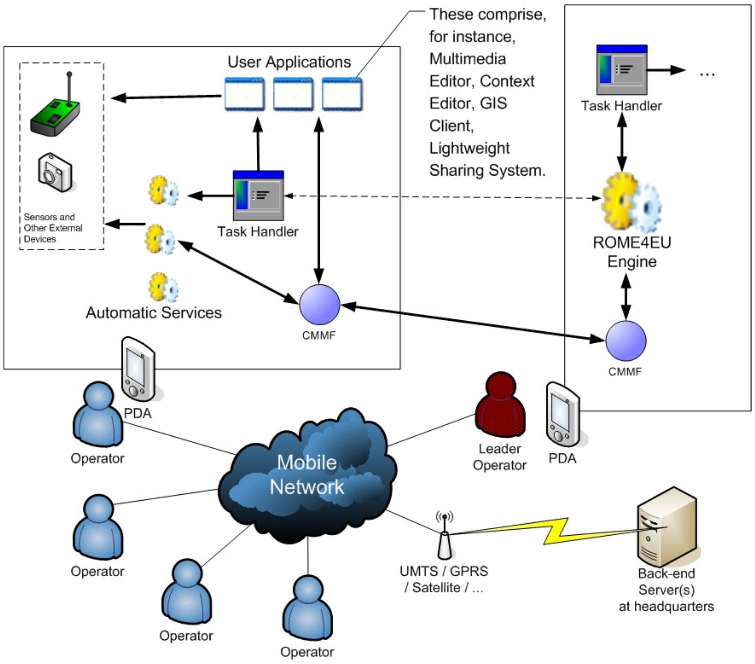

Figure 1. The WORKPAD Architecture

The figure refers to one single (front-end) team with different operators who are coordinated in an emergency. A PMS (de Leoni and Mecella, 2010) is at the heart of the system. The engine performs task assignments on the basis of some preconditions over the process status. Preconditions can range from the completion of tasks to variables which have a value in a certain interval and to the availability of certain members skilled with specific capabilities (e.g., equipped with cameras or specific external sensors). When a given task has been assigned to a specific operator, the engine interacts with the Task Handler, a client application deployed on each device. The Task Handler is informed about each assignment made to the respective operator. The communication between the Engine and the Task Handler relies on a Web service middleware. Each message is exchanged by a one-way invocation of a Web service end point. Once the Task Handler receives notification of a certain task assignment to respective users, it displays the name of the task together with relevant information. At any time users can decide to start a task by accepting the offer. In fact, Task Handler does not execute process tasks: tasks are executed with the support of external applications. The Task Handler only takes care of mediating the interaction between users and the engine and starts the applications that support users in the execution of tasks. For instance, the task “Build a medical tent” can be supported by the GIS-based application which shows the area, the terrain conditions and differences in altitude, as well as buildings and other objects of an area. This supports the operator in identifying the best location where to build a tent. Some tasks may be automatic, i.e., no human intervention is needed to carry them out. This kind of tasks is executed automatically by some special services running on a certain device. For instance, there exist some automatic services that retrieve environmental data from sensors and store them in a so-called Context Monitoring and Management System (CMMF). There are different kinds of sensors, such as the ones retrieving environmental data (e.g., humidity, temperature, precipitation) or others obtaining the state of devices (e.g., the battery level, the GPS position). The team leader’s PDA is able to retrieve such environmental data from sensors installed on the other devices. Almost all modern PDAs are equipped with GPS hardware and, hence, it is feasible to assume that every PDA is able to retrieve its own position. The information harvested by sensors is exploited to monitor possible and unexpected changes in the environment that, if not managed, can prevent processes from being completed successfully. This can result in the enactment of remedial actions, which can range from a reassignment of certain tasks to a full restructuring of the process.

In the WORKPAD project we have developed the following applications to support the execution of emergency management tasks:

- The *Context Editor* component allows users to enter additional contextual information that the sensors could not capture automatically. Context Editor stores all inserted data in the CMMF and retrieves them from the same component.
- The *Multimedia Editor* allows users to take and modify pictures.

- A *GIS Client* (as the one proposed by Bortenschlager, Goell, Haid, Rieser and Steinmann, 2008) allows users to have a graphical overview (e.g., a map) of the affected area and to retrieve relevant information about point of interests displayed in the map. The position of every team member is visualized to get a quick insight into the area where members are operating. All the information is stored in a back-end GIS server and cached locally in each team member's device.
- The *Lightweight Sharing System* enables to share pictures, questionnaires and other files among all operators.

The Evaluation and Validation Plan

The whole WORKPAD system was completely deployed in a realistic setting in accordance with the architecture previously described. The objective of creating a validation and evaluation plan was to carry out an effective assessment of the project outcomes. This was necessary for evaluating and validating the project activities and corresponding results from several distinct perspectives such as individual technological components, as well as the entire system being developed in the project. For the evaluation activities in WORKPAD we mainly used qualitative usability evaluation methods like feature inspection, observation of users while they perform different tasks, cooperative evaluation and questionnaires which told us details about the user satisfaction. Each evaluation step enabled an improvement of the prototype. Finally, the system was tested during a simulation of an earthquake that was supposed to occur in the small village of Pentidattilo (located in Calabria, Italy). During the showcase, we aimed to gain feedback from people with diverse cultural background. In this way, we could improve the effectiveness and efficiency by leveraging on comments from a wider range of users, thus obtaining a final system that mediates different needs. (Catarci, de Leoni, Marrella, Mecella, Bortenschlager and Steinmann, 2010) gives more details on a showcase storyboard and illustrates the interaction among the WORKPAD components.

SUGGESTIONS AND BEYOND

On the basis of the WORKPAD project experience, both on the positive and negative achieved outcomes, we gained some interesting insights which we aim to present here in the form of suggestions for inspiring future research activities and/or lessons learned to be taken into account when developing mobile systems supporting first responders. We divide them into two broader classes:

- The first one concerns grasping the users' mental attentions onto the system as little as possible because pervasive processes are really challenging and stressing for them.
- The latter class of issues is merely technological and deals with reducing the resource consumptions.

Process Design and Task Hierarchy

During an initial planning stage, first responders define an *Emergency Response Plan (ERP)*, specifying the set of activities and procedures that have to be performed on the field. ERPs are characterized for being as complex as typical business processes and can therefore be modeled as workflows. The workflow model offers a powerful representation of collaborative activities and is well suited for scenarios where many entities must perform a set of tasks in some order to achieve a common goal. The need to specify ERPs as dynamic workflows requires to identify (or design) a suitable process definition language and modeling notation that allows to define the set of tasks that should be executed, the temporal and causal order of process tasks (i.e. the routing or control flow), and the data flow between these tasks. Over the years different modeling languages and notations have been proposed, such as the Business Process Execution Language (BPEL)[1], the Business Process Modeling Notation (BPMN)[2] and YAWL (Yet Another Workflow Language - van der Aalst and ter Hofstede, 2005). In (Sell and Braun, 2009) the authors propose and present a workflow model for representing emergency plans. The application of workflow modeling principles and languages to emergency management settings introduces additional requirements for the choice of a suitable process modeling formalism. The definition of ERPs is typically performed by organization coordinators or team leaders, who are domain experts in the emergency management field, but are not "technical people", modeling experts or IT business analysts and process designers. As emergency management processes are highly time-critical and response activities have to be defined and performed quickly and efficiently, the definition of process models needs to be supported by

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[1] WS-BPEL 2.0 – `http://docs.oasis-open.org/wsbpel/2.0/wsbpel-v2.0.html`.

[2] BPMN 1.2 – `http://www.omg.org/spec/BPMN/1.2/`.

advanced modeling notations and tools that guide the designer in defining tasks, control-flow elements and all relevant attributes. Even if process templates and configurable process models are used (La Rosa and Mendling, 2008), graphical process modeling notations play a key role in abstracting and representing tasks and their relationships. According to (Bider, 2005), three main factors should be considered for selecting a modeling notation: *i)* the properties of processes to be modeled; *ii)* the characteristics of the modeling environment; *iii)* the intended use of process models. A process model can be used at different levels of abstraction, ranging from the representation of high-level real-world *abstract* processes to the detailed specification of machine-readable *executable* processes managed by a PMS for automatic execution. As a consequence, the intended use of a process model introduces restrictions and requirements on modeling language and visual process representation.

According to the careful requirements analysis we performed, deeply described in (Catarci et al., 2010; Humayoun, Catarci, de Leoni, Marrella, Mecella, Bortenschlager and Steinmann, 2009), a process modeling approach based on separation of abstract processes and executable processes enhances user experience, allowing process designers to focus on process goals, required activities, the order in which they are performed and involved participants. It is in fact unrealistic to assume a complete awareness of low-level modeling language syntax by the users. When modeling a process, the designer focuses on the control-flow perspective, which determines task relationships and execution order. With respect to the control-flow representation, process modeling languages can be classified according to two main paradigms: graph-based and block-structured (Kopp, Martin, Wutke and Leymann, 2009). *Graph-based* notations (e.g. BPMN) are based on a graph-oriented representation, where control flow is specified via arcs that represent the temporal and logical dependencies (control links) between activities. *Block-structured* languages (e.g. BPEL) are based on the concept of process blocks and the control flow is defined by nesting process constructs. Basically, the two approaches differ in the way they represent conditional and parallel routing (i.e. splits and joins) and loops. Nowadays most process management frameworks offer graphical notations that support process modeling and creation, aiming at visualizing process models mainly from a control-flow perspective. However, it has been argued that for inexperienced users the learning curve is often too steep (Hornung, Koschmider and Lausen, 2008). On the other side, user modeling expertise is considered as key success factor of process modeling (Bandara, Gable and Rosemann, 2007). In our experience, a graph-oriented process visualization (applicable for both graph-based and block-structured languages) helps inexperienced users in creating and understanding process models. However, on the basis of interviews, user observation, questionnaires and analysis of existing documents and procedures, we identified the need to integrate visual process models with hierarchical task representations. Emergency operators work in a cooperative environment where each participant is classified according to roles and sub-roles, and the team as a whole executes complex tasks in order to achieve well-defined goals. Representing tasks through a hierarchical tree structure allows to model and manage the complexity of tasks in a cooperative environment. By defining a task hierarchy, tasks are decomposed into sub-tasks and they can be linked to goals and sub-goals. Specifically, any task can be expressed in terms of goals that are reached when the corresponding task is accomplished. The task hierarchy statically represents this task decomposition, reflecting cognitive and behavioral/psychological emergency management user models that allow to adopt Hierarchical Task Analysis (HTA - Dix et al., 1997) and Groupware Task Analysis (GTA - van der Veer, Lenting and Bergevoet, 1996) methodologies. As the task hierarchy does not contain any task ordering constraints, the hierarchical task decompositions are complemented by process models where temporal relationships between tasks are formally determined by process control flow. A comprehensive modeling approach based on visual process models and tree-based hierarchical task decomposition allows to capture and represent both dynamic and static task relationships, providing emergency operators with complementary perspectives on the activities to be performed.

Geo-View vs. Activity View

An interesting feature that emergency operators require (this is confirmed by the tests performed in the WORKPAD project and reported in (Catarci et al., 2010)) is the geo-awareness of colleagues and affected objects, with the capability to track real-time movements and changes. This feature assumes a greater importance if coupled with an overlay dealing with collaboration and process views about tasks to be executed. In Figure 2.a a mock-up of the idea is shown. The operator on her/his PDA has an interface allowing to continuously switch among the classical *list-based* Task Handler (allowing to see the list of tasks assigned to her/him – see also the following suggestion about task assignment) and a *geo-based* Task Handler, in which positions of assigned tasks are shown, together with positions of operators. In such a view, the operator has an immediate perception of tasks and their positions, and this facilitates both the taking in charge of them (e.g., the nearest operator is induced to take it) and the monitoring of efficient executions. When tasks are assigned, specific visual metaphors (e.g., the tasks nearby to the operator's position blinks) allow the operator to easily catch them. This feature has not been fully implemented in the WORKPAD project, due to the technical difficulties, in current mobile applications, to integrate geo-visualization libraries with code specific for Task Handlers. But the final tests and suggestions for improvement from the operators show that this feature would be highly appreciated by operators. In order to realize it, open interfaces to geo-libraries should be available on mobile platforms, as well as usability studies on the best realization of it.

Tied to this suggestion, there is the issue of indoor localization of operators. Whereas outdoor localization is currently available on mobile platforms (the US GPS and the future European EGNOS/Galileo), indoor localization is still an open issue, and a very few solutions are available. Some of them adopt personal inertial measurement units (IMUs - cf. ENSCO[3] and Woodley, Petrov, and Meisinger, 2010), other creates a network of landmarks (at least four are needed) which transmit in the bandwidth VHF/UHF, coupled with a DTOA (differential time of arrival) technique, thus allowing an operator-carried terminal to locate itself with a precision of about 2 meters (therefore comparable to the one of GPS/EGNOS/Galileo).

Network Infrastructure

One of the main strengths of the project concerned the possibility to keep connected the different team members one another without the assistance of any fixed communication infrastructure. In fact, in an emergency management scenario, it is not feasible to set up any centralized solution for the maintenance of the network connection between operator's devices. Furthermore, standard communication networks like HSDPA (High Speed Downlink Packet Access) or UMTS (Universal Mobile Telecommunications System), may delay the situation may and be unavailable due to collapse of transmitters or overloading of network capacity.

During the project lifecycle, we started by adopting a first solution concerning the use of Mobile Ad-hoc Networks (MANETs – Conti, Basagni, Giordano and Stojmenovic, 2004). A MANET is a self-configuring network of mobile devices connected through wireless links. Each device in a MANET is free to move independently in any direction, and will therefore change its links to other devices frequently. The advantage is that no fixed infrastructure is needed to guarantee the connection between the devices (PDAs or laptops) connected to the MANET. Each device can send packets through the wireless links. When a device receives traffic unrelated to its own use, it acts as router and forwards all data on a path directed to the destination, by exploiting its routing table. The primary challenge in building a MANET concerns the equipment of each device in order to continuously maintain the information required to properly route traffic. Starting from the experience gained during the demo drill, we understood that to keep updated the route tables can consume a big amount of the PDA's memory, by causing the impossibility to use the device for greater priority computations (such as the execution of tasks or the services invocation). Our tests in WORKPAD showed that MANETs do not scale adequately, with an exponential growing of the memory usage with the increasing of PDAs connected to the MANET itself. In particular, with more than 4 devices connected simultaneously, the module that updates the routing table crashes with higher and higher probability.

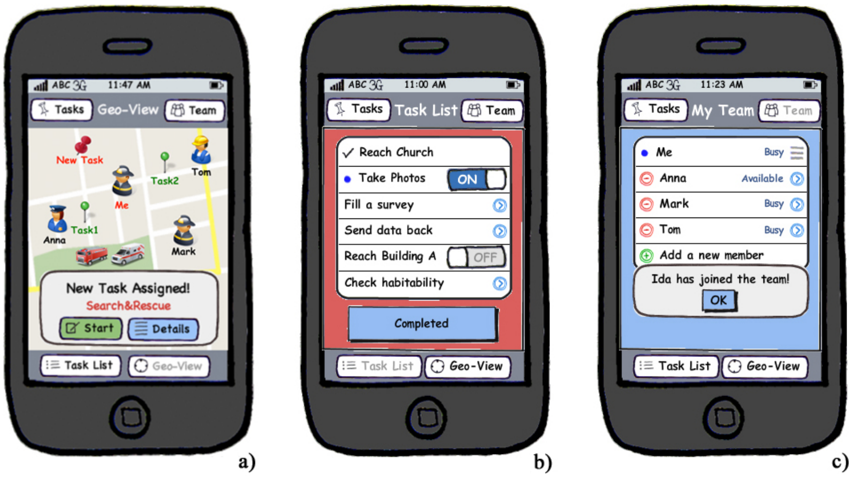
The alternative was to provide the networking infrastructure by deploying a Wireless Mesh Network (WMN – Akyildiz, Wang and Wang, 2005). A WMN is characterized by a backbone composed by several Mesh Routers that are connected with each other by multi-hop router paths. Every device connects to one of the mesh routers and can communicate with other devices that are connected to other mesh routers, either. WMNs have the advantage that mesh routers perform dedicated routing and manage by themselves the routing tables, so as to decrease the load of end-point devices. Some mesh routers can also act as gateway and provide connections to back-end servers. The main disadvantage is that during an emergency it is unfeasible to suppose mesh routers to be already deployed. A realistic solution is to provide directly Homeland Security's vehicles by mesh routers. Such vehicles, that provide the power supply for the routers, can be placed in the perimeter of the area and cover it completely. In sum, WMNs reduce the usage flexibility but minimize the network load for clients and guarantee a stable connection for the operators acting in the field.

Designing a User Interface for Mobile Devices

When designing the user interface of a system, the first aspect to consider is how and where users address their mental attention. The human beings receive continuously a huge quantity of stimuli from the environment. In (Sternberg, 2002), attention is defined as the totality of information cognitively manipulated by a person. The attention allows human beings to consider stimuli in a judicious way, prioritizing them, and taking into account only the most important ones. This judiciousness is used to increase the probability of a rapid and accurate answer. Activities in critical and emergency scenarios are highly-stressing situations for the users, who

[3] `http://www.geonav.ensco.com/solutions/inertial_navigation_tracking.htm`.

generally give more priority on the physical stimuli concerning the activities to execute than on those coming from software applications. Therefore, when designing user interfaces for mobile, pervasive, and critical scenarios, it is important that the task handling interface should attract the user's attention only when it is strictly required. In few words, we want the system to act as an automatic process for the users, which scarcely need for cognitive resources when using the system itself.



a) b) c)

Figure 2. Mock Up of the geo-based Task visualization and of the Task Handler

The first step in designing the user interface was to understand how to organize the needed information in screens that have a reduced size, such as PDA; this is a critical issue, as the operator should quickly access a lot of information, whereas the dimension of the screen could cause this retrieval to take several steps. Moreover, during an action, it is usual that an operator, whose attention is completely turned to the task assigned, can forget the exact arrangement of the information items on the screen. Therefore, s/he should be able to recover in her/his mind the arrangement of the items through a fast glance from the PDA's screen. As already widely studied and demonstrated (Luck and Vogel, 1997), the maximum number of items that a subject can store instantaneously in a reduced time (approximately 200-300 milliseconds) is about 4 items. This categorization brought us to divide the available information in 4 macro-categories (see Figure 3.b), without filling the screen with huge set of objects.

From several studies on the psychology of users, when using interfaces, they tend not to read whole words but only some letters in order to understand their meanings. So, we designed WORKPAD user interface with familiar formats and fonts, which are also big enough. That allows operators to remind word easily. Another important step was to understand how to capture the operators' attention while they were carrying out tasks. For this, we have made a significant use of popups and sonorous alarms to achieve the results (see Figure 3.c). Considering the accessibility and ergonomics issues, we have taken into account the fact that these devices may be used in extreme conditions. So, particular precautions were taken when designing the user interface. In particular, an effective and easy-to-read choice of colors; the highly contrasting color chosen in order to be clearly visible in particular light conditions (e.g., in night missions). Moreover, the interaction with the interface takes mostly place through fingers, instead of the stylus. Hence, the user interface elements were sized and spaced out in order to avoid the users to press on wrong elements.

If, as previously said, the use of stylus pen is absolutely to be avoided, also touch interface (such as iPhone interface or interfaces like HTC Sense) are too much demanding, in some occasions, in terms of attention required to the operators. The real challenge is ultimately the development of fully vocal interfaces: the operator, equipped with microphone and headphones (either wired or Bluetooth, even if the first are better for energy consumption reasons and avoidance of possible interferences) receives commands (e.g, the assignment of a task) from the devices and through a limited vocabulary of terms, invoke applications, provides feedbacks, etc. Current mobile platforms are starting to offer frameworks and libraries on top of which to develop such a type of interfaces[4]. But more research is needed in order to understand the better way of designing such interfaces, and to avoid issues due to environmental noise.

[4] Cfr. Microsoft Speech API (SAPI) and the Speech SDK for Windows Mobile, the Java Recognizer Intent in Android, the Carnegie Mellon University SPHINX framework for Apple iPhone.

Health Status as Context Information

Context awareness is largely considered as an enabling factor for mobile pervasive computing (Satyanarayanan, 2001) and refers to the ability of a system to gather information about the environment and to adapt its behavior based on this contextual information. Emergency operators act in complex pervasive scenarios, highly dynamic in space and time, where users and devices are characterized by high mobility patterns, and software applications used to support their activities run in a dynamic and heterogeneous environment. If operators' activities are managed according to a process-oriented approach, context-aware workflow management becomes fundamental. Managing processes in pervasive mobile environments requires a workflow management system that is able to reason on context information and that automatically reacts to contextual changes by using contextual information for enhancing process execution and coordination (Sørensen, Wang, Nødtvedt and Nguyen., 2006). The operational context is given by the physical environment (i.e., the affected area) and by other heterogeneous contextual information originating from various sources (cf. Dix, Rodden, Davies, Trevor, Friday and Palfreyman, 2000 for a complete classification of context information). Context information can directly influence process management life-cycle. Contextual events may start or terminate process instances, change pre- and post-conditions of an activity, affect process goals, determine process execution paths and trigger exceptions. In addition, context data can be used to enhance task assignment algorithms and policies.

Currently, research efforts on mobile context-aware emergency management systems mainly focus on the exploitation of infrastructure and system related data (e.g., device capabilities and status, resource availability, absolute and relative positioning of mobile resources and users), and are often limited to location-based context awareness and service provisioning. However, systems designed to support emergency operators during the response phase should rely on more complex context models and consider first responders as primary source of contextual data. Context models should hence be enriched in order to include the emotional and physiological state of first responders acting in the field under physical and psychological stress conditions. Heart attack, as a result of exertion and stress, is considered as a leading cause of death for first responders (Corbett, 2009). This motivates the need to design and implement innovative architectures and services able to capture, process and monitor psychophysical user parameters to be used as context information. Recent technological advances in low power microprocessors, sensors and wireless communication have fostered the development, in the healthcare domain, of a new generation of non-invasive, unobtrusive personal medical/health monitors (e.g. Jovanov, Lords, Raskovic, Cox, Adhami and Andrasik, 2003; Varshney, 2007). It is therefore possible to foresee a scenario where first responders are equipped with individual sensors able to track and measure different health parameters. Sensors can be embedded in wearable devices and in first responders' protective clothing (textile sensors) without interfering in user activities (Curone, Secco, Tognetti, Loriga, Dudnik, Risatti, Whyte, Bonfiglio and Magenes, 2010). Data collection and transmission can rely on a wireless personal area network (PAN) or body area network (BAN) based on short-range communication links (e.g., Bluetooth) with low power consumption. Operator's PDA may act as gateway in charge of collecting and pre-processing data produced by the sensors, making them available as context data to other systems over a WLAN or a MANET. Health and psycho-physiological status evaluation typically requires to collect measures about different vital signs, such as heart-rate variability (HRV) and Electrocardiogram (ECG), body temperature and external temperature, breathing rate, skin-conductance level, pulse and blood pressure; additional information may be provided by complementary technologies, e.g. monitoring voice-carrier frequency. Although the technology for supporting the acquisition of these measures is today available, there are still open issues to be solved when acquired measures have to be integrated as context data in a process-oriented system. Main challenges are related to the need to define how to handle context information coming from different sensors. This requires to define a suitable data representation model that enables reasoning on context information and allows the system to react to context changes. The ability to continuously monitor health status of first responders can have a profound impact on running processes and activities. Contextual events signaling stress or fatigue of an operator should trigger automatic recovery and compensation procedures that may require to restructure the planned process, reassign tasks, add new resources, etc. In the same way, vital signs monitoring allows to better evaluate operators' workload, going beyond workload characterization based on the number of assigned tasks and task execution time. This leads to the definition of new algorithms for task scheduling and assignment aiming at balancing between process performance and first responders’ safety.

Task Assignment Policy

When allocating tasks to the users involved in business process executions, PMSs typically adopt a *pull-based approach* where the system offers each task to one or more user qualified for it, e.g. using a role-based distribution approach. Through the task handler, a user is able to choose among the offered items and to commit to undertake the execution. When an operator selects an offered work item, it is withdrawn from the list of tasks of the other participants and is no longer on offer. S/he can then start the execution of the selected work item.

This approach, that covers the *Distribution by Offer – Multiple Resources*, *Resource-Initiated Allocation* and *Resource-Initiated Execution – Allocated Work Item* resource patterns (Russel, van der Aalst, ter Hofstede and Edmond, 2005), is motivated by the fact that, in business settings, a PMS has to leverage the interests, priorities, needs and constraints of single participants, and the overall revenue of the organizations they belong to. Emergency management processes are highly critical and time demanding as well as they often need to be carried out within strictly specified deadlines. Therefore, it is unfeasible the use of a pull mechanism for task assignment, since the risk is to have some task(s) waiting indefinitely for being chosen and executed. In emergency management, the overall effectiveness of rescue operations must have the highest priority. Consequently, it is preferable a *push-based approach*, corresponding to the *Distribution by Allocation – Single Resource* pattern, where the system dynamically selects an operator qualified for executing a given task (e.g., using a *role-based* or a more specific *capability-based* distribution approach) and directly allocates the work item to the selected operator. In order to allow each operator to focus on a specific task at a time, user selection and task allocation should ensure that *i)* each operator is assigned no more than one task, and *ii)* each task is assigned to exactly one operator. According to our experience, the task assignment policy has to be complemented with a priority-based allocation mechanism. During an emergency, changes in the operational context may occur unpredictably and at any time (a landslide or a collapse may modify the operational theater, a software or hardware resource may disconnect or fail, etc.). This may require to modify and automatically adapt a running process instance, by introducing new tasks to be assigned and executed. For example, the movement of operators around the affected area requires that tasks are assigned in a smart way, by exploiting on the fly the capability and geographic position of each team member. Even if each first responder gets assigned at most one work item, an operator executing a task should not be considered unavailable for further assignment. Assuming that each task has a given *priority*, the system can assign more tasks to a single operator if their priority is higher than the one of the current task under execution. Process participants, through their task handlers, can then rank the assigned tasks according to their priority and select the work item to be started. If a task with higher priority is selected, the current running task is temporarily suspended and preempted.

CONCLUSIONS

In this paper we have presented a set of suggestions for future research activities (e.g., further investigation on indoor localization of first responders, on vocal interfaces, etc.) and lessons learned to be taken into account when designing mobile applications for first responders supporting their collaboration (e.g., MANETs too much demanding, better to prefer WSNs, push-based assignment of tasks, etc.). Indeed, the practical experience gained in WORKPAD has been considerable, and we argue that sharing all what we have learned and proposing new research issues is a valuable contribution to the research community working on supporting emergency operators.

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