iVital: A Real Time Monitoring System for First Response Teams*

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Abstract. Every day, thousands of first responders work to save the lives of others, sometimes without the adequate surveillance of health conditions. The VitalResponder is a project that aims at monitoring and control teams of first responders in emergency scenarios, using mobile technologies to capture and use real-time data to support real-time coordination. In this paper we present a system to capture, process, and display the vital signs of team members, which are made available to a first responders' team leader, for coordination and monitoring. The system addresses specific requirements of the field action, such as the mobility of actors, combining two of the most recent mobile technologies: the iPad (for the coordination view) and Android OS-based smartphones (for real-time sensor data acquisition).

Keywords: First Responders, Vital Responder, Vital Signs, Monitoring, Vital Jacket®, iPad, Android.

1 Introduction

Certain professional groups, such as first responders (a risky and hazardous professional class), work in dangerous and extreme environments. They are often exposed to high levels of stress and fatigue during extended periods of time [1][2]. Furthermore, it is know that these professionals present a lower life expectancy than the common population. One reason for this is the possibility of this exposure to stress and fatigue leads to serious cardiovascular problems and, in worst cases, to death [3]. In this context, there is the need to develop new systems and technologies in order to monitor the actions and vital conditions of these professionals under real work conditions. The better management of their stress and fatigue is expected to help with avoiding or detecting the hazards that can affect their health condition, since this area is relatively new and currently underdeveloped [4].

The Vital Responder project [5] aims at providing a first response monitoring system on critical emergency scenarios to support the assessment of stress and fatigue

* This work was partly funded by the "Vital Responder" project (CMU-PT/CPS/0046/2008) under the CMU-Portugal program of FCT and FEDER.

K. Pentikousis et al. (Eds.): MONAMI 2011, LNICST 97, pp. 396–404, 2012.

among the professionals, avoiding possible hazardous situations. Tracking and monitoring firefighters in real time is one of the main scenarios addressed in the project.

There are some projects with similar objectives, namely *esponder* [6] and *Proetex* [7]. These projects are not based on mobile devices, which can raise barriers to the main objectives of the VitalResponder – mobility in operational field [8]. In VitalResponder we are looking into mobile devices as a solution to provide both processing capabilities and to explore the new interaction paradigms to support first responder professionals in the field [9].

This paper presents an innovative proof-of-concept system, called iVital, which constitute one additional step towards this ambitious objective supported in mobile off-the-shelve devices. The iVital main objective is to provide a mobile solution to monitor teams of first responder's, supporting the role of a team coordinate, with access to the aggregate data. This data includes individuals' vital signs (e.g. ECG) and location (through GPS, when available). iVital is able to trigger alerts to the end user that could be crucial to support decision in emergency operations, such as forest fires or rescue missions.

2 Architecture

The iVital system has three main components (Fig. 1): a vital signs data collecting wearable unit, using the Vital Jacket® [10]; a processing and relay mobile device (DroidJacket) and a mobile team coordination station (iVital Base Station), capable of displaying real-time information from a team of firefighters, at a given critical or emergency scenario.

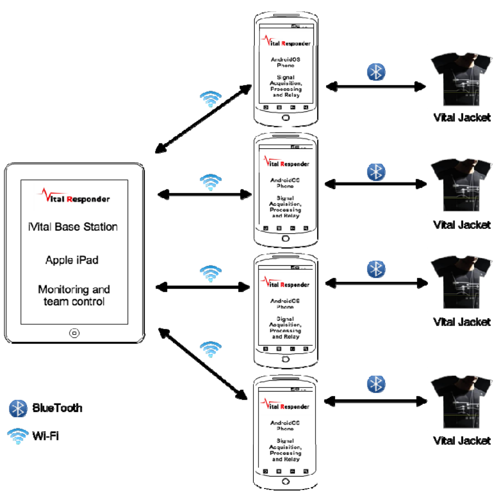

Fig. 1. iVital system architecture

The Vital Jacket® (VJ) is a wearable device that enables long term monitoring for individuals at sports, clinical scenarios and emergency situations. It is compliant with EU directive 42/93/CE and produced with an ISO9001 and ISO13485 certified manufacturing. It provides vital signs, location (GPS) and activity index based on accelerometers. Vital Jacket® relies on a Bluetooth connection to transmit the acquired data to the connected clients. The current version of VJ (non-customized commercial prototype version) used in the iVital solution is able to stream online data and also store on a SD Card for posterior analysis. The physiological data provided by VJ includes 1 lead ECG at 500Hz, accelerometers sampled at 10Hz and GPS location at 1 Hz.

DroidJacket is the main processing and relay element of the iVital system. DroidJacket runs in an Android-based smartphone. It is responsible for collecting the sensing data from VJ, run a set of analysis on the signal and relaying it to registered listeners through Wi-Fi connections using the IEEE 802.11 protocol, using TCP/IP Sockets (Fig. 2). In the iVital scenario, the iPad Base Station is the single listener (others could be active). DroidJacket is also responsible for performing basic processing over the received data in order to identify specific situations from technical issues (e.g. loss of connectivity) to more critical events found in ECG (such as arrhythmias) or in activity patterns (fall or low activity events) by means of the data received by the accelerometers.

The Base Station handles the incoming data from the DroidJackets through Wi-Fi connection (currently tested with 4 simultaneous connections) and displays the location of the team members in a map view, as well the individual status of both vital signs (e.g. heart rate, ECG) and the mobile device (e.g. battery and connection status). The Base Station application runs on an iPad tablet.

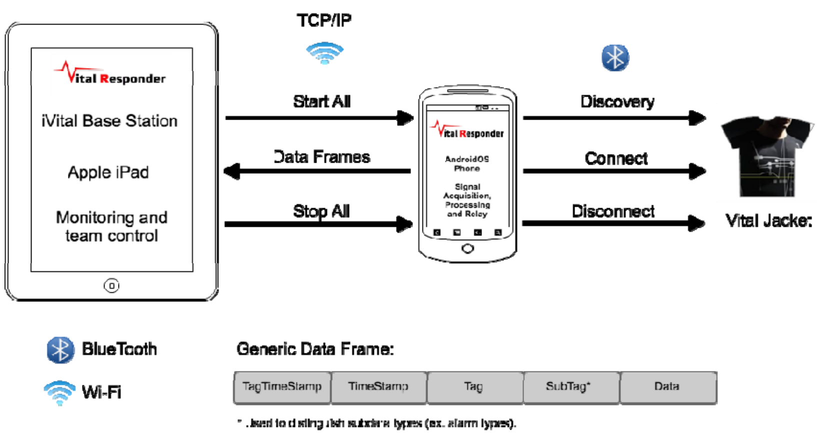

Fig. 2. Communication between elements. On the top: messages exchanged between the system components establish connectivity and receive the data frames. On the bottom: the Generic Data Frame format.

Every node is identified by an Internet address (IP), which is configured at the iVital Base Station. First, the DroidJacket connects to the VitalJacket by using the Bluetooth commands for discovery and connect; afterwards, once the DroidJacket receives a start ALL command from the Base Station, it initiates the signal relay (the signal is processed and enriched with events) until the stop ALL command stops the communication. The communication between all elements uses a tag-oriented protocol. Each data frame transmitted is formed by: (i) a common header consisting of a timestamp tag followed by the timestamp value, (ii) a tag to identify the type of data that are being encapsulated and (iii) the data itself (Fig. 2).

3 System Features

3.1 Pulse, Detection of Arrhythmias and Falls

The DroidJacket component processes the sensing data acquired by the Vital Jacket® (Fig. 2 a)) with three main objectives: (i) basic processing and relaying, specially to perform data reduction to limit the amount of transferred data to external clients, (ii) first line of visualization and (iii) first line of automatic alarms detection (Fig. 2 b)). In the iVital system configuration, the DroidJacket defaults to a background mode when the data visualization it's not needed, since it's not realistic for the firefighters to interact with the mobile device while performing field tasks.

One of the main sources of biomedical information in iVital is the ECG signal, from which DroidJacked provides pulse information using the Hamilton–Pan Tompkins method [11]. DroidJacked uses the RR interval method for arrhythmias detection (using the approach proposed by M. G. Tsipouras et al [12]) and the heart rate for sinus tachycardia detection. The accelerometers (either from Vital Jacket® or the Android mobile device) are used to estimate changes in activity and posture that can be correlated namely with falls (an abrupt change) or loss of conscience (lack of activity). Currently, we have integrated in iVital, the fall detection algorithm proposed by Sponsaro [13].

The alarm mechanism in iVital is focused on identifying and notifying situations that, in operational conditions, could represent critical or, at least, worth consideration as potential hazards. For that, the automated algorithms previously referred are used to raise alarms, automatically sent from DroidJacket to the Base Station or other online observer in the same network.

iVital provides an overall view of the team; it aggregates both data and alarms from the connected DroidJackets, each carried by one team member. iVital automatically raises alarms relative to the monitored individuals, but adapting on the level of urgency; the more severe, are signaled with explicit audio and visual warnings; less urgent warnings are less intrusive, like those dependent on location (via GPS) or on technical operational conditions, as the loss of connection or low battery level (with respect to an individual DroidJacket). Table 1 presents all the alarms, firing condition and the associated level of urgency.

The other main function related to the alarms it's the "Search and Rescue" option. This feature offers a quick way to map and help a first responder in need. If an alarm is triggered signaling a possible fall, for example, the team coordinator can select to initiate the “Search and Rescue” procedure; a message is sent to the nearest first responder in the field, with the emergency coordinates, and then the DroidJacket application is able to guide the user to the injured first responder (using only sound signals).

Table 1. Alarms Classification Table

Alarm	Condition	Urgency
Arrythmia	Classification rules as described [12]	Red
Fall	Classification algorithm based on [13]	Red
Tachicardia	Hearth Rate >= 120	Orange
Gps Signal	No GPS signal from User	Orange
Connection	No connection to the DroidJacket	Orange

3.2 Base Station – Data and Alarms Visualization

Although composed of several components (Fig. 3), the most distinguishing feature of iVital is the mobile base Station supported in a off the shelve Apple iPad tablet. Since the beginning of the project, the user interface has been a priority to accommodate the requirements identified in collaboration with Vital Responder’ first responder project partners. The option for iPad is based on its ease of use, rich interaction and extended graphics potential. This effort led to the current user interface (UI) presented in (Fig. 3 c).

All the information is easily accessible and intuitively presented, to avoid confusing the less technology-savvy users. The visibility and accessibility of each information type took into account the relevance level identified in the requirement analysis phase.

In the Base Station UI (Fig. 3 c) the user never loses the notion of the team member’s location, since the use of a map provides an overview of the intervention area and each team member location. The team leader can check the status of each member just by looking at the bottom ribbon and, if appropriate, touch one of the icons in the map (representing the actual position) to open the details of each element, which are those provided by the DroidJacket: Hearth Rate; Triggered Alarms; Graphic ECG tracing; Hearth Rate Graphic History; Vital Jacket Battery Level. The bottom bar also offers the state of the alarms for each firefighter, warning if s/he is in danger. To complement this operational information, the user can access a few external applications, such as checking the current weather conditions (at the top bar).

In terms of the software implementation, the base unit is based on a modular design that allows the instantiating to each logical monitored entity (a first responder), access to communication and processing resource, and a visual instantiation in the UI – each of these modular units are managed by the Base Station through independent threads. Currently the UI is tailored to teams of 4 elements but, technically, the current implementation can scale up to 12 – with some GUI refactoring. This limitation is mainly related with processing incoming data as observed in experimental trials described in the next section.

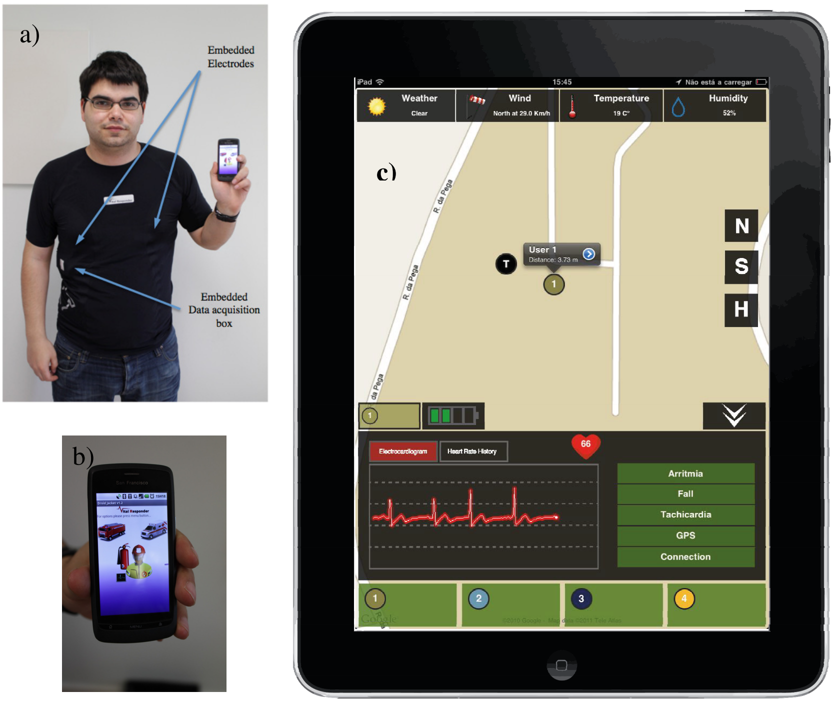

Fig. 3. The iVital interfaces: (a) The Vital Jacket® provides sensing data is connected to the AndroidOS phone running the DroidJacket application (through Bluetooth); (b) some first line visualization is presented in DroidJacket, but is the iPad Base Station (c) which presents the relevant information to team coordinator, including the individual quick access on the bottom (1 to 4), ECG tracing, heart rate and alarms on the left – these elements can be dismissed and change colors when an alarm is triggered. The team location can be visualized placed on the map (and operational information, like the weather condition).

4 Scalability and Autonomy

The initial tests, involving four DroidJackets and a Base Station, showed that to obtain a scalable Base Station it was needed to optimize (i.e., reduce) the amount of data transmitted to the Base Station. The solution was to down-sample the transmitted data to a necessary and sufficient flow, enabling the reliable monitoring of first responders. For example, the ECG signal frequency sent to the iVital Base Station was reduced to 50 Hz (by the DroidJacket) which is enough to display the ECG waveform. Still, the analysis of the data is performed on the DroidJacket at 500Hz, which is the standard for clinical analysis [14]. The same reasoning was applied to online data relay as presented in Fig. 4. This means we used a model that has a data reduction stage at the DroidJacket level, enabling the multi-stream processing at the Base Station level.

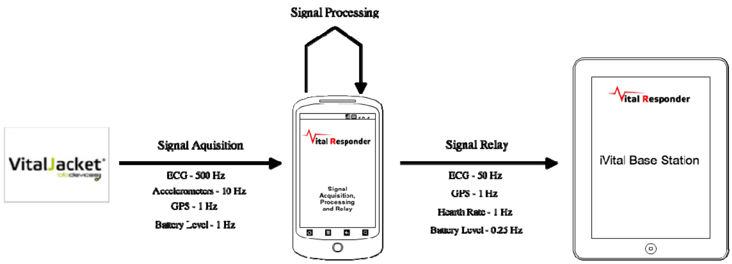

Fig. 4. Optimizing communication using data down sampling

After these initial scalability tests, we found that the devices autonomy could raise operational problem to the iVital system. In iVital, the autonomy issues were related to the DroidJacket (an Android smartphone, in our tests, the Optimus San Francisco model) and on the Base Station (on iPad). In what concerns the Vital Jacket®, autonomy was not a problem as it has already proven to support continuous monitoring for a week and can easily be replaced by a charged unit on the fly. In general, the mobile devices presented an average autonomy of 5 hours for the Optimus San Franciscoand and 6 hours for the iPad while executing the simulated tasks. We are still addressing communication strategies that, while not compromising the functionality, could optimize the use of battery power. The presented data down sampling solution goes in that direction.

5 Conclusions and Future Work

We described the iVital system as a proof of concept of a team monitoring solution, fully supported in mobile devices (Vital Jacket intelligent garment, Android based Smartphone and Apple® iOS iPad), which is a novelty with respect to other solutions [6] [7]. Although a more homogeneous solution based solely on the Android platform was possible, we demonstrated the potential of using the “best of two worlds”: the Android OS multithreading and the iPad user interface. The option of using the same data transfer protocol throughout the system layers also improved the flexibility and extensibility (although not the focus of the present work, some tests with iPhone and Windows Mobile devices were also were successfully performed). The choice for a smartphone solution enables firefighters to use a familiar interface. iVital also provided valuable experience on how to address common usability problems, namely tuning response timings [15], taking into account the user interface requirements under specific processing and communication related constraints. This will be especially useful in the Vital Responder solution.

Although fully functional, iVital lacks from field-testing, which will take place later in the Vital Responder project. It is also planned the integration of a multihop sensors network capabilities with the iVital system to provide both location and network connectivity. Only in that realistic scenario, it will be possible to perform more rigorous usability tests in order to prove or dismissed current iVital design options.

As a proof concept under the umbrella of the Vital Responder project, the iVital solution was constrained by two main operational compromises. The first was that all Wi-Fi communication were supported on standard Wi-Fi network available in our university campus as, currently, Android does not support the Ad-Hoc mode. The second was the need to have only the DroidJacket directly connected to the Vital Jacket, as only the Android platform provided public Bluetooth API, non-existent in the iPad (at the time of writing). This potentially leaves the system in a deadlock situation, so the solution was to work in a way that enables iVital DroidJackets the ability to define their own mobile wireless network – a more reasonable option in realistic operational contexts.

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