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Long-Distance Monitoring of Physiological and Environmental Parameters for Emergency Operators

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Abstract— **The recent disaster provoked by the earthquake in middle Italy has pointed out the need for minimizing risks endangering rescuers' lives. An European Project called ProeTEX (Protection e-Textiles: MicroNanoStructured fiber systems for Emergency-Disaster Wear) aims at developing smart garments able to monitor physiological and environmental parameters of emergency operators. The goal is to realize a wearable system detecting health state parameters of the users (heart rate, breathing rate, body temperature, blood oxygen saturation, position, activity and posture) and environmental variables (external temperature, presence of toxic gases and heat flux passing through the garments) and remotely transmitting useful information to the operation manager. This work presents an overview of the main features of the second prototype realized by ProeTEX with particular emphasis to the sensor's body network and the long distance transmission of signals.**

I. Introduction

In recent years an increasing awareness raised among civil authorities about facing emergencies which involve high number of civilians in wide populated areas. In scenarios like large fires, earthquakes, floods, terrorist incidents or large industrial accidents, professional rescuers must intervene maximizing efficacy whilst minimising their own risks. This has pointed out the need of providing emergency personnel with advanced support capabilities to continuously monitor their health condition and to coordinate their activities [1].

In this scenario, the emerging branch of wearable electronics [2-4], together with advance in information processing science and telecommunication [5], can play a considerable role: thus, it is now possible to develop information infrastructures fully integrated in garments that collects, processes, stores and transmits information about the wearer [6, 7] and about the surrounding environment where the subject lives and works. In this framework, an European project called ProeTEX (Protection e-Textiles: MicroNanoStructured fiber systems for Emergency-Disaster Wear [8-9]) has been launched in 2006, with the aim of monitoring vital signs of the emergency operators (heart rate, breathing rate, body temperature, blood oxygen saturation, position, activity and posture) and parameters related to the environment (external temperature, presence of toxic gases and heat flux passing through the garments). The project goal is to build a textile platform where all monitoring, communication and power management devices are integrated into one set of functional garments directly communicating with each other and with the already existing information management infrastructure. The project roadmap foresees the development of three generations of prototypes, based both on commercially available technologies and on wearable and portable devices realized by the project partners.

In the following sections, the main features of the second prototype are reported; in particular, the design and the features of the body sensors' network and the long-distance transmission are presented.

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II. System Design

A. Overview

The second generation of ProeTEX prototypes consists of three uniforms addressing Civil Protection', Urban and Forest Fire-Fighters' requirements, integrating sensors and electronics inside a T-shirt or *Inner Garment* (IG), a jacket or *Outer Garment* (OG) and a pair of *Boots*. Each sensor in the garments is provided with a dedicated electronic that contains the sensor analog front-end and a low power microcontroller which operates A/D conversion, processing and communication with a self-powered *Professional Electronic Box* (PEB) placed inside the OG. Since great part of the signal processing is done by these modules, only few derived data are sent to the PEB, strongly reducing the transmission system requirements. Data collected from sensors of the IG and OG are real-time transmitted to the PEB with a serial RS485 cabled infrastructure, meanwhile data coming from the sensors in the boots are wireless transmitted (with a Zigbee-like protocol). PEB collects data by the sensors with a frequency of 1 Hz (which means an amount of about 600 bytes per seconds) and transmit them to the Local Coordinator of the operation, far away from the disaster area, by means of a custom built wireless network (Operation Area Network), working with Wi-Fi protocol. Finally, a *Monitoring Software* visualizes data coming from many operators, and provides an infrastructure for generating alarms when dangerous conditions are detected.

B. Inner Garment

The IG is a subsystem devoted to the physiological monitoring of the operator's health status. *Textile electrodes* and fabric *piezo-resistive sensors* are integrated in a comfortable shirt to monitor Heart and Breathing Rates respectively, whereas non-textile sensors are embedded for Body Temperature and Oxygen Saturation. The whole garment (with the electrodes and the piezo-resistive transducer) is washable. An electronic board, hosted in a detachable band, connected to the shirt by means of a custom developed textile compatible connector, processes the sensors' signals and transmit to the PEB the user's physiological parameters, by means of cabled RS485 connection..

C. Outer Garment

The OG is a subsystem devoted to protect the rescuer, monitoring his/her activity and the surrounding environment. OG represents a mobile sensor network moving around the disaster area, according to operator's path. OG includes two tri-axial *Accelerometers* (used to detect extended periods of immobility, falls to the ground and body inclination), an *External Temperature* and an *Heat Flux Sensor*, a *GPS Module* (providing accurate user's position in open space), and a *Textile Motion Sensor*, sewed in the OG sleeve's to detect arm's immobility; furthermore, a *CO sensor* detects the toxic gas concentration near the user's face. Finally, acoustic and visual *Alarm Modules* are integrated, to launch warnings in case of danger. All cabled IG and OG sensors are powered by a Lithium- Polymer (LiPo) battery, placed in the PEB, which guarantees an autonomy of up to 7 hours.

D. Boots

The prototype includes a pair of boots, integrating a sensor for monitoring CO_2 concentration in the air:. the miniaturized sensor is powered by a rechargeable battery and communicates with PEB by means of a Zigbee module: the whole plant – sensor, electronics, battery and Zigbee module – is a 58x48x16 mm board positioned in the boot housing.

E. Remote Transmission and Monitoring

A self-standing Long Range communication Module (LRM) - enabling the transmission of data coming from the body area network to the remote Monitoring Software in a range up to 1-1.5 Km far way from the disaster area – was developed. The network must be 'self-standing' (since standard communication networks could have collapsed as a consequence of the catastrophic event), flexible and modular, according to changeable dimension of the disaster area. To reach a flexible, light and modular system, a Wi-Fi protocol was selected [10]. In fact, Civil Protection and Fire-Fighter services of many countries usually adopt TETRA [11] for voice transmission: this technology was born to support emergency with modular infrastructure, reduced set-up time and handset devices, even supporting data transmission; unfortunately, the data rate provided, 7.2 Kbit/s per time slot, is quite low to guarantee enough bandwidth for future developments (i.e. support for camera on the rescuer's helmet or picture transfer). An alternative solution is the cellular system, both 2nd generation, such as GSM/GPRS [12][13], or 3rd one, that is UMTS [14]. User terminals are very efficient in energy management, reliable and easily integrated. Especially UMTS services provide a suitable transfer rate for multimedia contents, but they rely on fixed infrastructure, made up of base stations and wired links whose availability after a catastrophe is not guaranteed. Our system should operate in emergency context and be completely independent with nodes deployed as soon as possible on the interested area; from this viewpoint, the best solution is WiMAX [15]: a technology for broadband wireless access, working both in line of sight or no line of sight conditions and high mobility environments. It is not limited to point-to-multipoint topology, and can exploit a mesh architecture. The major drawback is related to the fact that this technology is still under development and products are not optimal in terms of energy consumption yet; this is a critical aspect for wearable system. According to all these facts, it has been decided to adopt a Wi-Fi protocol [16] that somehow summarizes all the aforementioned requests: Wi-Fi offers *link capacity* for services beyond data monitoring (voice and pictures transmission), *independent infrastructure* and *well-engineered devices* to preserve battery charge. Thus a modular and extendible Wi-Fi infrastructure, based on 3 extendible Nodes, was developed. Each node is based on a single board PC (ALIX3c2, by PCEngines) with a 500 MHz AMD CPU, a Compact Flash socket, two mini-PCI slots, one RS232 serial port and one Ethernet port for communication. The board hosts a mini-PCI Wi-Fi LAN card for data transmission, connected to two antennas through SMA connectors, and installed inside a 113x163x30 mm aluminium box. Since it operates with a DC voltage power supply between 7÷20 Volts, to allow communication of more than four hours, a two cells Li Po battery was embedded, model MP157130, by Multiplex Inc (7.4 Volts, 2100 mAh).

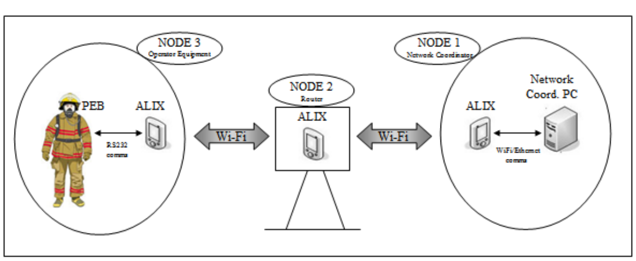

Fig. 1. Architecture of the Long Range communication Module.

In its basic set-up, the three nodes of the LRM infrastructure are (

Fig. 1): Node 1, *Remote Module*, to be connected to the Local Coordinator PC with the Monitoring Software by a wireless (Wi-Fi protocol) or wired (by using an Ethernet cable) connection; it is provided with an omni-directional antenna - with a 5.5 dB gain - and a directional one - 15 dBi gain, 3 dBi pattern equal to 90° x 15° (provided by Stella Doradus). Node 2, *Re-Broadcasting Module*, provided with an omni-directional antenna - 5.5 dB gain - and a directional one - 15 dBi gain, 3 dB pattern equal to 30° x 30° planar antenna. Node 3, *User Module*, to be integrated in a suitable pocket of the ProeTEX OG. The module is connected by a RS232 Serial Cable to the PEB and by SMA cables to two textile antennas, integrated in the OG, made of a rectangular ring micro-strip patch. Patch and ground plane are built of high-conductivity electro-textile material on a flexible foam fire-retardant and shock-absorbing. User node communicates to Node 1 both directly or passing through Node 2: thus a 3 or 2 Nodes LRM configuration is possible.

III. Test of the Communication Infrastructure

Tests were carried out in order to evaluate the maximum distances which can be covered by the "ad-hoc" communication system, both in terms of maximum distance between the user and Node 2 (short range communication) and between Node 2 & 3 (long range communication).

A. Short Range Trials

Wi-Fi communication between Node 3, placed in the user's OG, and Node 2 was tested to check if the coverage distance may be affected by use of flat textile antennas in Node 3 (with respect to the communication by traditional antennas), and to evaluate the role of body orientation (since the worn antennas are directional). A test was performed in open space by asking subject wearing the OG to move away from Node 2 and facing it with the front, back, left & right side of the garment. During trials the GPS position of the OG was recorded by means of sensor integrated in the prototype, until the detection of the first loss of connection. After 4 trials, the experiment was repeated connecting Node 3 to an omni-directional commercial antenna, identical to the one used on Node 2; once again, position of user moving away from the base station was recorded with the GPS sensor until the first loss of connection. The test results, reported in the top of Table 1, show that the use of textile antennas affect the performances of the system with respect to the reference one in terms of directionality, since the best performances of the textile antennas (back side of the jacked exposed to Node 2) are comparable with the ones of the commercial one (maximum distance reduction 5.2%), while changing the body orientation means a maximum distance reduction of more than 27.1% with respect to the reference. Moreover, even in the best environmental conditions, the coverage area obtained by using only one Node 2 is not enough for a real operative scenario, therefore further work should be done to develop an infrastructure composed by more than one retransmission unit.

B. Long Range Trials

The communication between Node 2 & 1 was tested by quantifying their maximum distance in different conditions of visibility, due to the presence of obstacles and buildings. During tests Node 1 and the monitoring post were set in a specific position (at ground level in open space), while Node 2 was moved in different locations at increasing distances from the base station. Once a testing position was reached, Node 2 was set up and the antenna manually oriented toward Node 1 (no pointing devices were used, in order to simulate a real operative scenario), then the communication was tested and the GPS coordinates recorded. Different trials were carried out with this experimental setup. The bottom of Table 1 shows the results of two these trials, reporting the distances in which the communication worked properly or not. During the first trial Node 2 was moved toward an open space area, enabling the transmission up to 1.3 km far from the base station (with loss of connection just when it was placed close behind buildings). During the second trial Node 2 was moved toward a urban area, with buildings and high vegetation: these conditions caused a notable decrease in the maximum distance covered by the communication infrastructure (about 600 meters, but strictly related to a partial visibility between the two Nodes' antennas).

Table 1
Maximum Coverage Distance

Textile Antennas, Coverage Distances	Side [towards Node 2]	Max Distance [m]
	Back	147
	Left	145
	Right	115
	Front	113
	Omni-Directional Antenna	156
Node 1-2 Coverage Distances		
Distance [Km]	Obstacles [Buildings]	Communication [Yes/No]
< 0.6	Yes	Yes
> 0.6	Yes	No
< 1.3	No	Yes
> 1.3	No	No

IV. Operators' Monitoring Software

An interesting issue related to the rescuers monitoring during their intervention in an operative area is the way data are shown to the operation managers, remotely coordinating the rescuers' activities: they have to monitor many parameters related to the activity of many operators, therefore the way data are shown to them is really meaningful. Since a significant additional information to the data recorded by the sensors is provided by the real time localization of each user on a map of the operative area, a prototype graphic monitoring software was developed: it is based on the free software Google Earth, provided by Google Inc., and allows to simultaneously monitor up to three users. The use of a free software as Google Earth was preferred at this step of the project with respect to the use of more precise geo-localized maps because it allows to freely use the ProeTEX system everywhere with a reasonable accuracy, without the need to look for specific maps of each area in which the system is going to be used.

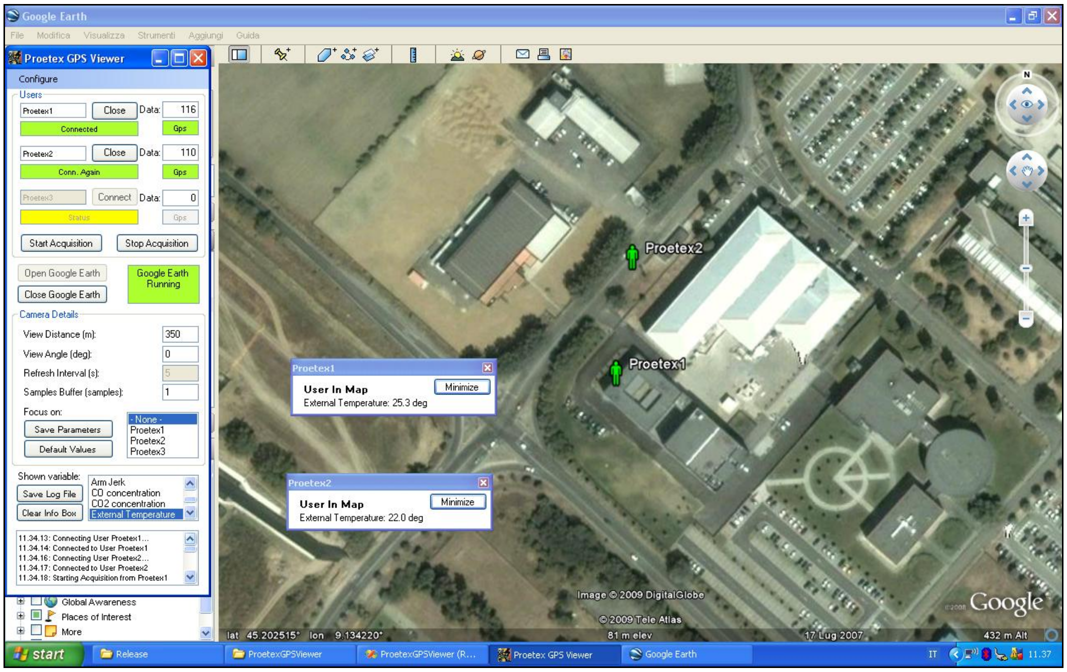

Fig. 2. Screenshot of the Monitoring Software

The concept of the software is to provide the operation manager a tool enabling to real time control the position of the users, identified by icons whose colour is automatically changed according to the values of the recorded variables and to the availability of each user. If a loss of connection is detected, the icon's colour is turned to grey and the last recorded GPS position is shown. If a user is available, a check of the variables values is done: if one or more variables are outside the "normality" range, an alarm is generated by turning the colour of the user icon to red, otherwise the icon is plotted in green. At present and just for demonstration purpose, the detection of dangerous conditions is based on the comparison between the currently available environmental and physiological data with thresholds set by the software user, but more complex and reliable alarm generation techniques are being investigated. Finally the software allows to show in text format in popup windows the current value of one or more variables recorded by all the available users: once again the colour of the text in the popup is related to the availability and "normality" of the recorded data, according to the above described coding.

Fig. 2 reports a screenshot of the monitoring software: two operators (here called "Proetex1" and "Proetex2") are being monitored; both are visible to the monitoring software, and the variables recorded by their sensors do not point out dangerous conditions (green icons). The popup windows show in text format the data requested by the software user in the left panel menu ("External Temperature", in this case).

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