ABSTRACT
Proetex is a European Integrated Project dedicated to the realization of a micro- and nano-technology-based wearable equipment for emergency operators. During the first 3 years of work, two different and progressively improved versions of a complete “smart” uniform for fire-fighters and emergency rescuers have been realized. These garments aim at monitoring both physiological parameters, position and posture of the operators and the presence of external potential sources of danger and to send these data to a remote coordinating unit. In the following, the main issues of the design and realization will be described and discussed.

Key Words: Wearable, smart textiles, sensors, protective garments

1. 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. In this framework, an European project called ProeTEX (Protection e-Textiles: MicroNanoStructured fiber systems for Emergency-Disaster Wear [6-7]) has been launched in 2006, with the aim of monitoring vital signs of the emergency operators and parameters related to the environment.

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. So far two versions have been produced and tested. In the following sections, the main features of the second prototype are reported.

2. SYSTEM OVERVIEW

The 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) (see Fig. 1) and a pair of Boots.

![Image of second ProeTEX Prototype](image)

**Figure 1.** Overview of the second ProeTEX Prototype. A. Inner Garment: I1: textile electrodes for HR monitoring (under the Vital Signs Board housing); I2: piezoelectric sensor for BR monitoring; I3: thermocouple for BT monitoring; I4: SPO2 sensor; I5: Vital Signs Board. B. Outer Garment: O1: external temperature sensor; O2: Heat flux sensor; O3: GPS module; O4: front visual alarm; O5: Acoustic alarm; O6-O7: Collar and Wrist accelerometers; O8: Textile motion sensor; O9: CO sensor; O10: Zigbee module; O11: Professional Electronic Box; O12: Wi-Fi module: O13: communication antenna (under the pocket layer, over the Wi-Fi module).

Data collected from sensors of the IG and OG (Body Area Network) are transmitted real-time to a self-powered Professional Electronic Box (PEB, hosted in the OG) through a serial RS485 protocol. In the meanwhile data coming from the sensors in the boots are transmitted wireless by means of a Zigbee protocol. Finally all data are sent out to the Local Coordinator of the operations, far away from the disaster area (Operation Area Network). This communication can be performed with a Remote Transmission System working with a Wi-Fi protocol. A Monitoring Software visualizes real-time all sensors’ data to the Coordinator, automatically activating alarms when dangerous contexts are detected. Similarly, a Victim Patch (VP) module has been conceived to be placed on the chest of victims in order to allow medical personnel to monitor in real-time their physiological parameters.

2.1 Sensor Modules

Since many sensors are placed inside the ProeTEX garments and a minimum number of wires is desired, each sensor unit has a dedicated electronic module that contains the sensor analog front-end and a low power microcontroller which operates A/D conversion, on line processing and communication with the PEB. In this way, only processed data are sent to the PEB.

Communication between each IG, OG module and PEB is guaranteed by a RS485 bus, except for the GPS module, which owns a dedicated connection. The Boots module is instead interfaced with the PEB through a wireless Zigbee connection developed by ZARLINK. Each module has a port for updating on board the firmware (algorithms and transmission protocols).
2.2 Inner Garment

The IG is the subsystem devoted to monitor the health status of the emergency operators without interfering with their activities.

Textile electrodes and fabric piezo-resistive sensors have been integrated in a one step process in a comfortable shirt to reveal cardiopulmonary parameters (namely, Heart Rate and Breathing Rate), whereas non-textile sensors have been embedded in the shirt for Body Temperature and Oxygen Saturation monitoring (see Fig. 1). The textile electrodes (as well as the piezo-resistant sensor) have been realized using SMARTEX technology: a stainless steel based yarn (by Lineapiù spa, Italy) have been knitted together to a ground yarn by using a tubular intarsia technique (with a flat knitting machine by STEIGER) to get a double face, whereas the external part is not conductive in order to insulate the electrodes from the environment. For the piezoresistive sensor realization, a Belltron® yarn from Kanebo has been used. As ground yarn a fire resistant yarn (by SOFILETA and THUASNE) based on meta-aramid fibres was used.

The architecture of the IG prototype is based on a T-shirt having two main areas devoted to specific tasks: an elastic region including all the sensors; a region containing a detachable on-board electronics. The textile sensors and electrodes are connected to the electronic modules through textile conductive cables integrated in a one step process in the shirt. Dedicated textile compatible connectors (developed by Ohmatex, Denmark, subcontractor of the project) are encapsulated in the fabric and allow the physical connection between the cables and the electronic components. In the second IG prototype the Vital Signs Board has been connected to the PEB (placed in the OG) by means of an external cable, whereas a wireless connection has been foreseen for the final release.

**Heart Rate Sensor** - Heart Rate (HR) is detected by acquiring an ECG lead through three textile electrodes integrated in the IG. An algorithm extracts HR value from the raw ECG signal. Specific textile solutions have been adopted to improve the contact electrodes-skin without hydrogel membranes.

**Breathing Rate Sensor** - The first IG prototype has been realized in two versions which are characterized by a different approach to monitor the respiratory activity: version 1 includes a fabric piezoresistive sensor that changes its electrical resistance when stretched. This sensor is sensitive to the thoracic circumference variations that occur during respiration; version 2 is based on four textile electrodes able to carry out an impedance pneumography. This methodology consists of injecting a high frequency (50 kHz) and low amplitude current by means of the outer electrodes and measuring the impedance changes on the thorax by the inner ones: a relationship between the air flow through lungs and the impedance variation allows the respiratory cycles monitoring. Two different versions of BR sensor have been realized for the second IG prototype: a new piezoelectric sensor in wire form has been implemented by UNIPISA on one shirt (version 1). This passive sensor shows an high signal to noise ratio together with low sensitivity to motion artifact. This device replaces the impedance pneumography. A specific module has been realized for the piezoelectric sensor: the front-end converts the charge variation of the piezoelectric sensor through a charge amplifier and the microcontroller performs the necessary operations in order to extract the BR from the raw signal. The other version includes as for the first prototype a fabric piezoresistive sensor (version 2).

**Body Temperature Sensor** - A LM92 temperature sensor has been sealed in a Polyamide Foil and then has been embedded in the shirt in a proper pocket at the left armpit level. Insulation textile layers shield the body temperature measurement from the effects of the environmental temperature.
SpO2 Sensor - An optical transducer based on CSEM technology, made of several couples of optical emitters and receivers has been integrated in a unit at breastbone level. A built-in processor triggers the best located transmitters to dynamically select the highest signal levels; a processor selects samples, stores values in memory and sends them to PEB through the RS485 bus.

2.3 Outer Garment

The OG is the subsystem devoted to protect the rescuer, monitoring his/her activity and surrounding environment.

The OG has been produced in three different configurations, depending on the application: specifically, the prototype for Civil Protection is based on the official uniform of the Italian Civil Protection operators. Urban and Forest Fire-Fighters prototypes use fire-proof jackets adapted from the uniform produced by Brunet-Lyon for French Fire-Fighters.

All OG configurations include two tri-axial accelerometers, an external temperature sensor, a newly developed textile motion sensor and a commercial Carbon Monoxide monitoring sensor. Forest Fire-Fighters and Civil Protection operators have also an integrated GPS module, whereas Urban Fire-Fighters do not, since they operate inside buildings where reliable GPS signals are rarely available. Moreover an Heat Flux Sensor has been included both in Urban and Forest Fire-Fighters OG, in order to prevent operators from skin burn when facing flames.

Regarding data transmission, all OGs incorporate a Long Range transmission Module. The Civil Protection system has also an Alarm Module, that is a subsystem launching visual and acoustic warnings when one or more sensors detect operator dangers beforehand.

Even if electronics and all cabled sensors are powered by an embedded Lithium-Ion Polymer (LiPo) battery inside the PEB, a new flexible battery, designed by CEA, has been experimented in Urban Fire-Fighter OG in order to increase functionality and ergonomics of garment. The battery allows a working time over two hours with a nominal voltage of 3.8 V.

External Temperature & Heat Flux Sensors (by INSA) - The External Temperature Sensor is placed under the OG external coating at shoulder operator level; this set-up avoids environmental disturbances and optimizes higher temperature detection as requested by BSPP Fire-Fighters. A 5.9x2.1x0.9 mm ATEXIS [10] platinum sensor with a -70°C to +500°C range and platinum coated nickel wires has been chosen. The Heat Flux sensor is placed in the proximity of the platinum sensor, inside the third comfort layer of the OG at shoulder level as well. The sensor has a 50 mm diameter, 420 µm thickness and a sensivity of 75 µV/W/m². The presence of the Heat Flux sensor is necessary because the very efficient protection provided by the OG textile equipment makes difficult the recording of thermal environment.

GPS Module - An ANN-MS-0-005-0 Active GPS Antenna from U-Blox [11] was chosen. It provides an accurate measure of the absolute position of the user in open space (outdoor and far from buildings or high obstacles). The sensor performances drastically decrease when approaching or entering into buildings. Nevertheless this information is considered important by rescuers working in large operative areas, where they can’t be directly visually monitored.

Alarm Module - The alarm module has been designed by CSEM and consists of a power red led driven by a microcontroller which makes the led flashing at different frequencies depending on the type of alarm. It includes also an audio alarm board with a buzzer control. Two self-powered alarm modules have been integrated in the Civil Protection OG on the front side of the trunk and in the back face at shoulder level. Redundancy guarantees higher visibility in case of structure collapse or flooding.

Accelerometers - Motion sensors have been designed to detect posture, accidental falls to the ground and immobility of the operator. They are realized by means of two accelerometer
modules developed by UNIPISA, one placed in the jacket collar (for monitoring trunk movements) and the other in the right sleeve (to achieve more accuracy in activity detection since an operator can move his arm while not moving trunk). Each module is based on a tri-axial accelerometer (ADXL330 by Analog Devices [12]) and a low power microprocessor (Texas Instruments MSP430F149) for A/D conversion, real-time signal processing and transmission of the extracted information (activity and fall detection flags) to the PEB.

Textile Motion Sensor (by UNIPISA) - It is applied to the external part of the OG insulation layer, and it is used to detect immobility. The transducer is made of conductive elastomeric strip (200x20 mm wide) printed on an elastic fabric and integrated in the sleeve’s elbow region. Since the elastomer shows piezo-resistive properties, movements can be detected by analyzing sensor signal. The processing algorithm is implemented in the microcontroller (Texas Instruments MSP430F149) of the sensor’s module [13], that is used to send the information (an activity flag) through the RS485 bus.

CO sensor (by DCU) – A Carbon monoxide sensor is placed in the OG lapel near the user’s mouth and nose. The sensor is integrated in the outer shell layer of the OG, while electronics is protected from the heat by fixing it under the insulated layer. A waterproof and gas permeable coating protects the sensor. The device (CO-D4 by Alphasense [14]) is selective and sensitive for CO range between 0 and 1000 ppm; its output is fed through a transimpedance amplifier to convert current to voltage so that it can be read by the analog port of a microprocessor (Texas Instruments MSP430F149). The working range is 0-410 ppm: the microcontroller performs data conversion, extracts CO concentration and implements the protocol routines required to send the information through the RS485 bus.

2.4 Boots

Boots prototypes have been developed and tested by DIADORA both for Civil Protection and Fire-Fighter brigades. The prototypes respect UE standards for protection shoes and are already arranged for integrating sensors in the sole. The heel zone is wide to guarantee stability of users, the upper part is made with leather and materials resisting to fire and heat, elastic flex points have been inserted in the upper part to allow high flexibility and a new lacing system have been realized to improve functionality. Furthermore, to avoid abrasion and increase comfort, breathable and waterproof lining have been inserted inside.

CO2 Sensor - The Boots have been equipped with a CO2 transducer, which enables faster detection of toxic gas before it reaches the respiratory tract. A specific housing has been created in the upper part of the boot, able to maintain the sensor in contact with air. A CO2 D1 sensor by Alphasense [14] ha been chosen and tested by DCU. Power supply is furnished by a rechargeable battery whereas communication with PEB is realized by means of a Zigbee module (by ZARLINK) connected with the sensor: finally, the whole system – sensor, electronics, battery and Zigbee module – is hosted in a 58 x48 x16 mm box inserted in the boot pocket.

2.5 Remote Transmission and Monitoring

Besides wearable technologies for sensing and data processing, also a remote communication infrastructure (between the rescuers and the local coordinator) has been developed within the project. This is realized by means of a software interface and a long range communication system.

Monitoring Software - It manages data received by PEB; data detected by sensors and collected by PEB are wireless transmitted to the remote software, developed by EUCENTRE. Data exchange is based on “query-answer” protocol. Queries, generated by the software,
request data from the device: then PEB generates answer strings and sends them to the PC, where data are displayed in text and graphical forms and saved in files for further off-line analysis; in the meantime an on-line processing generates automatic alarms when the variables overcome previously set up thresholds.

Remote Transmission System (LRS): communication between the PEB and the PC is set up by means of a Wi-Fi based communication system (realized by EUCENTRE), allowing the communication of data up to 1 Km far from the operator. Wi-Fi protocol was selected as a good compromise between portability, lightness and performance. Wide planar textile antennas (placed in the front and back sides of the jacket), developed by UGENT [15] are used to transmit the signal from the OG. The bandwidth of the antennas is more than 280 MHz, whereas return loss and influence of humidity have been analyzed; the interaction between electromagnetic field radiation and operator body was investigated too, and it was found below SAR limits as requested by EU regulations. In order to cover a communication range of more than 1 Km, a 13.5 dBi sector antenna with a 3 dB pattern equal to 90° x 15° [16] is adopted between the farthest nodes.

2.6 Victim Patch

The Victim Patch is an IG replication devoted to victims: it is realized in the form of a textile patch containing HR, BR and Body Temperature sensors, which can be placed on lying down subjects’ chest. The patch is cabled and connected to a Victim Electronic Box (VEB) having the same role of PEB in the OG: precisely, VEB monitors all data sensors and transmits detected data to the Monitoring Software through an embedded Bluetooth module. Moreover VEB has an its own display allowing real-time monitoring of data in text or graphical formats. Each VEB has an identification number, thus multiple patches can be remotely monitored by health personnel far away from the victims.

3. REFERENCES