Design of smart clothing for Belgian soldiers through a preliminary anthropometric approach

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Abstract

A good design of smart clothing for soldiers is crucial element for safety, security and ergonomic factors. These have to be addressed together with the traditional wearability and comfort ones. Anthropometric and gender considerations, as well as textile requirements are to be included into the design core.
In that process, we can distinguish two main macro areas to establish the product's requirements: the technological issues and the design issues. Both areas are essential for the product design. While the first is related to biosignal sensor technologies, the second includes physical and design factors such as anthropometry and gender issues, body positions, adherence, elasticity and wearability of the garments.
A preliminary activity was dedicated to investigate the two macro areas on smart garments taking also in consideration the role of the subject and the relative anthropometric data. A total of 1615 male Belgian soldiers aged between 18 and 35 years were investigated.
An integrated smart military equipment design will be the final outcome of the research.

Keywords: Military, Anthropometry, Smart Clothing, Wearable Monitoring, Human Factor

1. Introduction

Smart clothing or "intelligent textile" represents the new class of wearable textile design era 2.0 with interactive technologies, intended to be attractive, comfortable and 'fit for purpose' for the identified user. The fields of applications are very different such as healthcare, fitness, sport (Perego et al. 2012), lifestyle, space exploration, public safety and military (Sahin et al. 2005).
Researchers of the Georgia Institute of Technology working on a US Defense Advanced Research Project Agency grant were the first to suggest to embed sensors into military garments (Bonato 2005).
The main goal was to monitor the status of the soldier and to reveal eventual injuries and their influence on his/her health. Scataglini et al. (2015) recently classified the current main applications of smart clothing in military field in health monitoring, environmental safety monitoring, stress management and empowering human function.
Sensing clothing offers the unique opportunity to implement a real non intrusive monitoring, i.e. it represent an extraordinary tool for observing and analyzing the complex Human-Machine-Environment system in specific tasks (Fig.1).

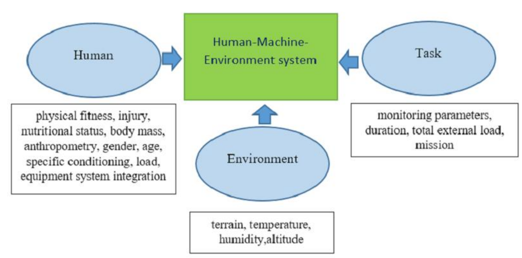

Figure 1: Human-Machine-Environment system and the main parameters to be monitored specifically in the military applications.

Nowadays the new wearable technologies can integrate advanced functions such as monitoring mechanical, environmental and physiological parameters in an ecological and in non-intrusive approach.
The smart clothing can allow for monitoring of vital signs (heart rate, breathing rate, temperature), emotional factors (HRV-Heart Rate Variability, EDA-ElectroDermal Activity) related to fatigue, stress and effort.
Stress, training, fatigue and environmental conditions have a great influence on human-machine-environment system performance, and they are those currently used in the military field for soldier assessment but in a laboratory setup and not in a real conditions. Furthermore, they can have a

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proactive significance in evaluating the effect of equipment and its design on the overall system (soldier+equipment) performance for future developments.

Starting from these assumptions, the collaboration between Politecnico di Milano, the Belgian Royal Military Academy and the Military Hospital Queen Astrid aims at developing an integrated wearable setup for the garments and the equipment design evaluation for monitoring the Belgian's soldiers performance.

The main requirements for smart clothing are functionality, usability, monitoring duration, wearability, maintainability and connectivity (Gilsoo 2009), but comfort is another key and transversal factor (also among the previous features) to be considered.

The impact of comfort on wearable monitoring technologies has been recognized as an important aspect of its design.

Wearing an uncomfortable system compromises the soldier's ability to do his/her job, the benefit of the system is greatly reduced (Tharion et al. 2007).

The functional design process, as well as the knowledge and intuition about the body interface gained from the study of functional design methodologies can help to broaden the scope of interdisciplinary variables considered in the design of wearable technology, and thereby produce a more successful design.

The design process has to begin with anthropometric data retrieval and analysis of the user, and the identification of the user's needs.

Anthropometry, or measurement of the body, is a key element of the clothing design and the placement of smart textiles around the body. Volume, shape, weight and adherence to the body of wearable devices must be designed to not affect or interfere with natural movements.

Design must also take into account the wearability in situation-specific movements required for the accomplishment of a task. In more extreme situations, where weight is a crucial factor as well as volume, stationary or dynamic balance has to be preserved and not modified.

Finally, but not exhaustively, other architectural requirements are the connectivity between the textile sensor/component and the electronic part and also the connectivity towards the external world.

Once these design criteria have been established, the initial aesthetic design is created within the framework of the user's needs.

The purpose of this paper is to present the methodological approach and the definition of requirements and specifications for the design of smart clothing for military applications, using Belgian soldiers as case study.

2. Materials and Methods

2.1. Introduction

Wearables have a close, even intimate, relation with the human body. This relation is physical, physiological and functional. For this reason, the design of "intelligent" garments involves two different macro areas: design issues and technological issues (Fig.2). The design issues comprehend specifically physical and design related factors such as anthropometry, gender issues, body positions, wearability, elasticity and adherence of the body fixing element or of the garments. The technological issues comprehend the requirements related to the technology as sensing and processing, data transmission and power supply (Andreoni et al. 2015).

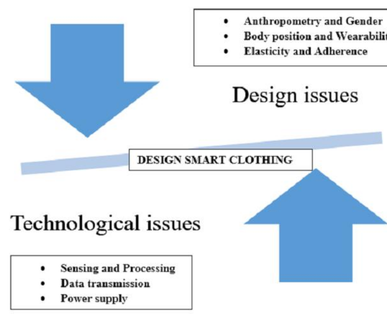

Figure 2: The two macro areas of the design process

2.2. Antropometric data

The Belgian Military Hospital Queen Astrid has a database called "Total Health" where the anthropometric data of the Belgian soldiers are stored. In the database, it is possible to filter anthropometric data considering also the category of affiliation. The database contains a total of 1615 male subjects aged between 18 and 35, that were measured at the time of their recruitment. For each subject, the stature or standing height, the sitting height, the weight and the age are available. The following Table 1 and 2 show the main statistics of these data.

	Mean±SD
Height	178.8±0.8
Sitting height	91.55±0.63

Table 1: Stature and sitting height of the studied population expressed in cm.

	Mean±SD
Weight	79.3±18.7
Age	28.44±1.13

Table 2: Weight (kg) and age (years) of the studied population.

From the values of mass (weight) and height of the individual, the BMI (body mass index) is computed to have a general representation of the human phenotype. The BMI is a way to quantify the amount of tissue mass (muscle, fat, and bone) in an individual, and then categorize that person as underweight, normal weight, overweight, or obese based on that value. Commonly accepted BMI ranges are underweight: under 18.5, normal weight: 18.5 to 25, overweight: 25 to 30, obese: over 30. Table 3 shows the BMI of the studied population.

BMI	24.8±0.35

Table 3: Body Mass Index (kg/m^2)

The soldiers in that population have a normal BMI and the related standard deviation is small demonstrating a small inter-subject variability.

2.3. Anthropometric data extrapolation

To obtain the dimensions of the segment lengths of the average Belgian soldiers, we used Drillis and Contini tables (Drillis et al. 1966) that express the segment length as a fraction of body height, H. Especially we were focusing on the upper body part. Starting from the shoulder, the chest, the waist and long sleeve segments (see Fig. 3) with measurements expressed as a proportion of the body height we are able to calculate the segments dimension and design the shirt model.

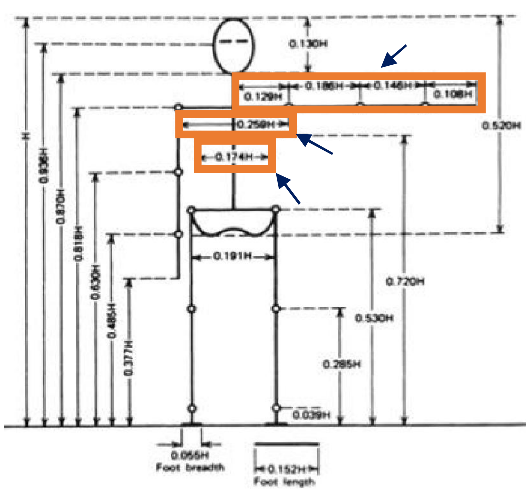

Figure 3: Body segment lengths expressed as proportion of body height (H) by Drillis and Contini and the identification of body segment lengths related to the thorax (grouped in boxes marked with arrow) expressed as proportion of body height (H).

3. Results and Discussion

3.1. Experimental design body position and wearability

Designing smart clothes requires first the identification of the measuring parameters, the design requirement, the placement of the sensor onto the body and their wearability. For the sensors' positioning, according with (Gemperle et al. 1998) we need to consider areas that have relatively the same size across adults, areas that are larger as surface areas and finally areas that have low movements (see Fig.4).

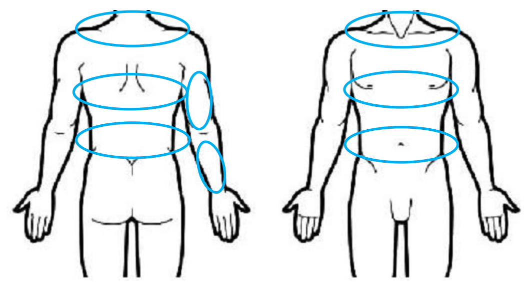

Figure 4: Areas of the upper body parts for the sensor placement according with Gemperle et al. (1998) criteria.

Considering the Belgian soldier equipment, we eliminated the neck areas and the arms areas choosing the chest areas, due to the equipment interaction and the shooting movements (see Fig.5). (Timmermans et al. 2009) concluded also that intervertebral distances in the thoracic spine are different for healthy individuals with different trunk length and different body length.

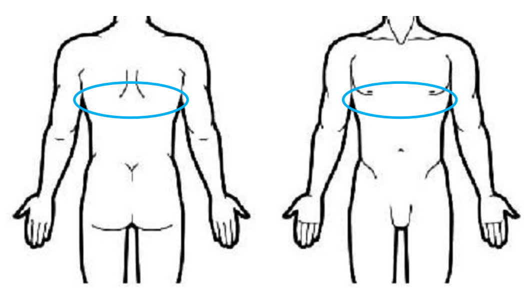

Figure 5: Areas of the upper body parts for the sensor placement of our smart shirt as an unobtrusive placement.

Elasticity is obtained by criteria imposed by design in order to preserve comfort and wearability of the smart clothes. High stretch fabrics provide mobility and tight-fitting fabrics enhance performance. At the same time, the adherence should not be invasive to avoid obstruction of posture and movements and the creation of thermal discomfort. According with these criteria the smart shirt was designed with stretch fabrics, cut close to the body for enhanced performance.

3.2. Technological issue and requirements

The first generation of the wearable device technology 1.0 (Suh et al. 2010) that is based on passive textile, has been updated by a technology called wearable 2.0. generation that presents a new textile called interactive textile (i-textile). The new generation provides an integration of the electronics elements into the fabric structures.
The smart shirt based on the wearable 2.0. is intended for monitoring the heart rate activity (ECG) and the body acceleration. The base fabric made from textile fibers (polyamide and elastane) is accompanied of textrodes embedded into the clothes. The textrodes performance depends on electrode polarization and electrode impedance. The improvement of the conductive properties of textile allows a good electrode polarization properties and low electrode impedance.
The low conductivity can be adjusted with conductive material. In fact the textile electrodes are made by adding conductive material to the textile. We can distinguished textrode made by metal yarns (like conductive rubber, silver-coated polymer foam, metal-coated or sputtered fabrics) and yarns that contain electro conductive fibers (like polymeric or carbon-coated threats). (Andreoni et al. 2015) classified also the merits and demerits of textrodes. The main advantage of using the textrode is the not invasivity in terms of skin irritation for long monitoring due to the unnecessary use of the electrogel. The disadvantage can be the poor skin/electrode contact that can be resolved by the insertion of a small sponge under the sensing surface.
The choice of the sensing material determines the wearability, the durability, maintainability and the manufacturability of the products.
In relation to the maintainability, the smart shirt preserves washable capability for several washings (›50).
In relation to wearability the electrodes (textrodes) configuration for the heart electrical activity monitoring respectively on the left and right side of the chest in correspondance of the 10th rib with a mutual distance of 15 cm. This body sensor placement allows a stable configuration due to the rib cage position. The adherence does not limit the movement and the relative performance.
Data connection between the textile/component and electronics is facilitated by snap bottoms (nickel free material). A single bipolar derivation is used to record the ECG signal. The setting is intended for measuring only the heart rate (HR) without taking in consideration other ECG physio-pathological features. Regarding the electronic part, an actigraph based on a commercial system was used (PROTHEO I, SXT - Sistemi per la Telemedicina, Lecco, Italy). The monitoring device contain a 3D acceleration sensor (MicroElectroMechanical System, LIS3L06AL, STMicroelectronics, Geneva, Switzerland) a Bluetooth transmission module and a rechargeable Li-ion battery (Andreoni et al. 2013).
The smart cloth is able to monitor the ECG value (one single lead) and the body movements (triaxial accelerometer) of the Belgian soldiers. Bluetooth communication allows the real time communication with an APP suited for the purpose.
The information can either be stored or immediately transferred to a nearby computer for the successive analysis.
Smart shirt capabilities can potentially monitor the soldier's performance in terms of training, injuries and psychological status monitoring.
Future perspective can be address to the introduction of textile component/sensor in other part of the equipment element adding other sensor functionality (see Fig.6).

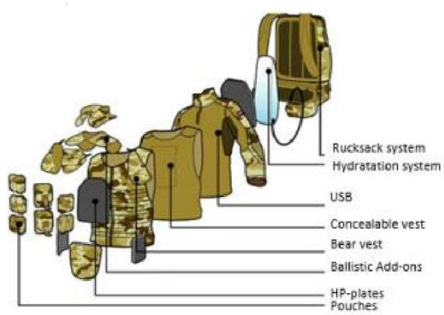

Figure 6: Belgian military upper body equipment

4. Conclusion

In the future, other textile components and sensors in other parts of the equipment, adding additional sensor functionality, can be introduced. Anthropometric average soldier dimensions can be used to design ergonomic military tools, equipment (Pourtaghi et al. 2014) and for our purpose the smart shirt.

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