Bioimpedance-Based Wearable Measurement Instrumentation for Studying the Autonomic Nerve System Response to Stressful Working Conditions

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Abstract. The assessment of mental stress on workers under hard and stressful conditions is critical to identify which workers are not ready to undertake a mission that might put in risk their own life and the life of others. The ATREC project aims to enable Real Time Assessment of Mental Stress of the Spanish Armed Forces during military activities. Integrating sensors with garments and using wearable measurement devices, the following physiological measurements were recorded: heart and respiration rate, skin galvanic response as well as peripheral temperature. The measuring garments are the following: a sensorized glove, an upper-arm strap and a repositionable textrode chest strap system with 6 textrodes. The implemented textile-enabled instrumentation contains: one skin galvanometer, two temperature sensors, for skin and environmental, and an Impedance Cardiograph/Pneumographer containing a 1 channel ECG amplifier to record cardiogenic biopotentials. The implemented wearable systems operated accordingly to the specifications and are ready to be used for the mental stress experiments that will be executed in the coming phases of the project in healthy volunteers.

1. Introduction
In the last decade, extensive research efforts in the field and advances in textile materials and instrumentation technology have supported the development and implementation of measuring garments for wearable measurement systems. Nowadays, there are commercially available simple wearable Heart Rate (HR) monitors for fitness e.g. polar heart rate strap, in addition also body worn multiparametric measurement systems can be found e.g. EQ02 life monitor manufactured by Equivil. The availability of such wearable measurement systems fosters the development of personalized health monitoring applications not only for chronic patients and home-care but also for personal working in dangerous conditions.

The ATREC project aims to perform real time analysis of mental stress of the Spanish armed forces during military activities using sensorized garments and wearable measurement systems. The first phase of the project aims to identify non-invasive indicators suitable for assessing on the autonomic...
nervous system and for that customized wearable instrumentation with sensorized garments have been made. The project is funded by the Spanish Ministry of Defense through the “COINCIDENTE” program (DGAM DNR 1003211003500) under the supervision of the Metrology and Human Factors Department, of “La Marañosa” Institute of Technology.

2. Methods and Material

In order to record the physiological signals that would allow studying the response of the autonomic nervous system to stressful situations in a non-invasive manner i.e. cardiac biopotentials, Galvanic Skin Response (GSR), skin temperature and respiration rate [1-3], the following textile-enabled instrumentation and sensor-based garments have been implemented.

2.1. Measuring Devices

Two devices have been built: one to measure GSR and temperature and a second device to record cardiogenic biopotentials and impedance plethysmography measurements. Both are battery operated with 900 mAh Lithium-Ion batteries, and are provided with an internal 4GB SD memory card to allow long-term recordings and off-line analysis.

2.1.1. GSR and Body Temp. This device enables skin impedance monitoring as well as ambient and body temperature monitoring. The reduced dimensions 50x35x15 mm enable its integration in a wearable measurement system like a glove or a measuring strap.

2.1.2. ECG amplifier and EBI plethysmographer. This device enables the recording of ECG and thoracic electrical bioimpedance (TEB) at a single frequency. The aim is to obtain the heart rate from the ECG signal and the respiration rate from TEB signal. Depending on the placement of the electrodes, the TEB measurement can provide also information about cardiac function, e.g. heart rate. Such reduced dimensions 50x35x20 mm make it suitable for its integration in a garment.

2.2. Sensor-based Garments

The following garments have been confectioned with textile electrodes made of conductive Shieldex® Fabric P130+B and integrating DS1825 temperature sensors manufactured by Dallas Semiconductor.

2.2.1. Glove for GSR and skin Temperature. Two textile electrodes have been integrated in the proximal phalanx of the index and the middle fingers of the glove for measuring the GSR and a temperature sensor has been placed in the tip of the ring finger of the glove to sense the peripheral skin temperature. Figure 1.a shows a glove with the GSR and Body Temp measurement device attached to the wrist with a strap.

2.2.2. Upper-Arm Strap for GSR and superficial Temperature. An upper arm strap with two textile electrodes integrated to sense the galvanic skin response in the skin surface between the electrodes has been confectioned. A temperature sensor is also integrated in the inner lining of the strap in order to

![Figure 1. Garments for GSR and temperature measurements a) glove and b) and c) upper arm strap](image)
measure the skin temperature. Figure 1.b shows the sensorized upper arm strap, also with the GSR and body temp measurement device attached to the arm in Figure 1.c.

2.2.3. Repositionable Chest Straps System for Cardiac and Respiration Recordings. A chest strap garment with repositionable textile electrodes to record 1-lead ECG from 2 textrodes and tetrapolar TEB measurements with other 4 textrodes has been developed. The possibility of placing the electrodes in any place along the horizontal and vertical straps enables the performance of different kinds of TEB measurements. Depending on actual placement of the textrodes around the surface of the thorax and abdomen, the TEB measurement will have more or less cardiac and respiratory components allowing us to perform a multi-parametric signal recording if required. The mobility of the electrodes is achieved by implementing a textile clamp using press-studs, see Figure 2.b.

3. Experimental Results
This section presents the measurements recorded with the devices and the sensorized garments.

3.1. GSR and Temperature
Skin temperature and GSR were recorded in several subjects. While skin temperatures produced very stable measurements around 34 °C with both garments, GSR measurements exhibited much more variability. Especially in the case of the GSR values recorded with the glove that showed remarkable jumps, most probably related with movement artifacts from the hand and fingers, see Figure 3.a. The GSR values obtained with the arm strap present much lower variability see Figure 3.b.

3.2. Thoracic Measurements
3.2.1. ECG recordings. Surface cardiac biopotentials were recorded in several subjects with the measurement system of Figure 2.a. The ECG recording plotted in Figure 4.a shows 60 seconds of ECG recording. As shown in the 4 seconds zoomed segment the recording is very fair, allowing for a straight detection of the R complex for heart rate assessment. The first 25-30 seconds show slow
3.2.2. Thoracic EBI recordings. TEB recordings were obtained with the measurement system presented in Figure 2.a in several subjects. A 60 seconds segment of the TEB recording obtained simultaneously with the ECG recording plotted in Figure 4.a is shown in Figure 4.b. The respiration activity is easily observable in the plot where the resistance increases and decreases accordingly to the respiration cycle. Note that the changes stop while the subject was keeping the breath for 20 seconds, between seconds 60 and 80.

4. Discussion and Conclusions
The preliminary measurements show that the GSR measurements obtained with the arm strap are more stable than the recordings obtained with the glove. This was expected since the robustness of the arm strap against movement is expected much better that the gloves with the textrodes on the fingers. In general, the devices implemented and the sensorized garments are functioning as expected.

The proper functioning of the implemented garments and devices allow us to conclude that the systems are ready for the next stage of this experimental phase: data recording in volunteers performing specifically design activities to cause stress. If the ATREC project is successful, a novel application based on EBI technology and textrode garments might be implemented further like in [4].

References
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