Textile-Based Sensors for Biosignal Detection

Subjects: Others

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Biosignals often have to be detected in sports or for medical reasons. Typical biosignals are pulse and ECG (electrocardiogram), breathing, blood pressure, skin temperature, oxygen saturation, bioimpedance, etc. Typically, scientists attempt to measure these biosignals noninvasively, i.e., with electrodes or other sensors, detecting electric signals, measuring optical or chemical information.

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1. Introduction

Transforming textiles from objects protecting people from temperature, rain, etc., into functional textiles with additional properties belongs to the emerging trends of our time. These so-called smart textiles often contain electronics, integrated by different degrees, to create special designs; to couple jackets to smartphones; to enable tracking of firefighters or automatic emergency calls for avalanche victims; or to allow for the detection of biosignals, especially of athletes, the elderly and ill people who should be monitored for longer durations [1][2][3][4][5][6]. Besides these sensors, it is necessary to include communication, a power source and a data processor, again with different degrees of integration [7][8][9].

While full integration of sensors and the additional electronics into textile fabrics is not always easy at the recent state of technology, the advantages of this approach are clear. Electrodes with direct skin contact can be prepared from more skin-friendly material and in more comfortable shapes than, for example, common ECG electrodes or the relatively rigid chest straps known from pulse measurements in sports. The additional possibility to embed all necessary cables into the textiles, too, makes a long-term ECG based on textile electrodes and textile-integrated electronics much more comfortable than the still common version with rigid equipment, several cables and glued electrodes [10][11][12].

While the first textile-based sensors used conductive yarns or fabrics to measure electronic signals, such as voltage or conductivity to measure ECG or strain, more sophisticated material compositions have been investigated in the meantime, allowing for a broader spectrum of measurements. Here, we give an overview of recent research on diverse physical sensors, usually based on detecting electronic properties, and some chemical sensors which can be used to detect different gases, but also diverse health-related biomarker molecules [13][14][15], which can be created by combining conductive, semi-conductive and isolating materials with different dielectric properties by different techniques on the fiber or yarn level or on complete textile fabrics. This updated overview furthermore discusses the advantages and still existing challenges of textile-based biosensors, focusing on most recent, as well as fundamental, papers to cover a broad range of possibilities and problems in this field of research.

2. ECG Measurement

An interesting approach was chosen by Silva et al. , who prepared ECG electrodes for the integration in swimsuits [16]. Here, the problems of surrounding water, as well as drag during swimming, had to be taken into account. They prepared textile electrodes from stainless-steel yarns by knitting different structures to reach an optimum skin contact and glued them on the proband's skin with adhesive tape so that, at this stage, only the impact of water was taken into account. However, relaxed and stretched electrodes showed surprising functionality, since the signals measured in a state when the proband was submerged in water were even less noisy than measurements in dry state, which can be attributed to the improved skin contact due to the water film between skin and electrode. Muscular contractions and arm movement showed a strong impact on the detected signal, as it is usually found for measurements with textile electrodes and generally has to be filtered.

This problem of motion artifacts has been addressed in a recent study by An and Stylios [17]. They investigated the skin–electrode impedance for different durations and frequencies, using different knitted electrodes, and found a silver-plated knitted fabric of a defined minimum size to be ideal. In addition, they combined these textile electrodes with a miniaturized flexible printed circuit board with a motion sensor and found that both ECG and motion could be measured simultaneously in this way. However, no attempt was made to use the motion signals to reduce motion-related noise in the ECG signals.

While the previously reported textile ECG electrodes were knitted, elongation of these electrodes usually causes artifacts in the measured ECG signals. This is why Arquilla et al. used different sewn and embroidered electrodes [18]. The electrodes were prepared from silver-coated yarns, stitched onto an inextensible fabric and investigated by gluing them with tape on the chest of 8 probands. Interestingly, they found no significant differences between these textile electrodes and commercial gel-electrodes, regarding the detectability of the R-peak. Unfortunately, no unfiltered signals were shown, so that no evaluation of the P- and the T-wave was possible.

Finally, it should be mentioned that after the first attempts to measure ECG with textile electrodes, the progress found in the literature—or even translated into commercially available long-term ECG measurement systems with textile electrodes—is still limited. Several challenges have to be met, such as the generally bad electric contact from dry electrodes to the skin, undesired changes of the electric properties upon washing and wearing, even changes of the resistance due to stretching the electrodes, and last but not least displacements of the electrodes with respect to the body as soon as a proband moves or even breathes. Most recent attempts are aiming at solving one of these problems by improving either the textile structure or a conductive coating or by developing special clothing exerting sufficient pressure of the electrodes onto the skin to improve the electric contact. On the other hand, some groups try to develop evaluation algorithms which filter the important features from the usually noisy signals.

3. EEG Measurement

Besides ECG and EMG sensors, there are also attempts to use textile electrodes for electro-encephalography (EEG). Especially at the head, it is important to use soft electrodes to avoid pressure-points during sleeping [19]. Löfhede et al. prepared textile electrodes from a conductive knitted fabric with silver plating, pressed against the skin by a foam, and improved skin /electrode contact by adding a gel or saline solution [20]. They found similar signals for both kinds of electrodes, comparing slightly different yarns and knitted structures, and also no significant differences between gel and saline solution as a method to reduce the contact impedance. The contact impedance was modeled in their study by an equivalent circuit model dominated by capacitive behavior.

Shu et al. designed the textile EEG electrodes to be sweat-absorbing in order to solve the problem of high skin/electrode impedance [21]. By using a multilayer textile fabric which includes not only a conductive layer, but also a sweat absorption layer, they could reduce the skin/electrode impedance and simultaneously reduce crosstalk interference between neighboring electrodes.

Several other groups investigated different textile electrodes to measure EEG signals for different purposes [22][23][24][25] or even developed a realistic, durable head phantom for the validation of EEG electrodes [26].

Nevertheless, it must be mentioned that Tseghai et al. reviewed recent approaches to produce textile-based EEG systems and pointed out severe problems with flexibility, stickability, washability and missing comparison with standard EEG systems, making the transfer of the scientific results into real commercial application hard [27]. These problems are equivalent to the aforementioned one, regarding other textile electrodes, although not explicitly mentioned in most reviews.

4. Moisture Detection

In the previous descriptions of all electrodes working with skin contact, the role of moisture on the quality of the detected signals due to the reduction of the skin/electrode impedance was mentioned. Moisture detection should thus be possible, in the simplest way, by measuring the impedance or, even easier, the direct current (DC) resistance between two conductive fibers or conduction lines in a defined distance. Indeed, this principle is adopted in many moisture sensors. Chen et al. combined it with a passive RFID (radio-frequency identification) tag to enable using the embroidered sensor without a battery [28][29].

Grethe et al. developed flexible, highly textile-integrated moisture sensors by spinning, printing and coating techniques [30]. They showed a sensitivity of these sensors in the range of 25–80% relative humidity and suggested their utilization in diverse areas, such as environmental control, medical textiles, working clothes or personal safety systems.

Pereira et al. investigated textile moisture sensors to prevent patients lying in bed or sitting in wheelchairs from pressure ulcers by integrating a conductive matrix in garments [31]. Using a multifilament yarn from poly(lactic acid) (PLA) with carbon nanotubes, Devaux et al. prepared a textile-based humidity sensor with good repeatability and fast reversibility [32].

Mecnika et al. prepared embroidered humidity sensors from conductive yarns [33], while Wendler et al. used multi-layer braiding to prepare a capacitive moisture sensor, working from 22 to 94% relative humidity at a high sensitivity [34].

As this short overview shows, textile-based moisture sensors are less problematic to produce than most of the aforementioned textile sensors. However, aging can occur in different ways, especially by oxidation of metallic parts, resulting in the necessity to recalibrate the sensors after washing or even after wearing to avoid erroneous results.

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