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Abstract

-Textile based sensors which can be used to measure the chemical composition of bodily fluids represents a major advancement in the area of wearable technology. BIOTEX is an EU funded project aiming to develop such sensors with a particular interest in monitoring perspiration. A textile based fluid handling system has been developed for sample collection and transport. Sodium, conductivity and pH sensors have also been developed. This paper details the integration and testing of these sensors. Results show that the developed system can collect and analyze sweat in real time during exercise and transmit this data wirelessly to a remote receiver

Keywords

time, wearable, exercise, during, technology, sweat, real, analysis

Disciplines

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Wearable Technology for the Real-time Analysis of Sweat during Exercise

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Abstract—Textile based sensors which can be used to measure the chemical composition of bodily fluids represents a major advancement in the area of wearable technology. BIOTEX is an EU funded project aiming to develop such sensors with a particular interest in monitoring perspiration. A textile based fluid handling system has been developed for sample collection and transport. Sodium, conductivity and pH sensors have also been developed. This paper details the integration and testing of these sensors. Results show that the developed system can collect and analyze sweat in real time during exercise and transmit this data wirelessly to a remote receiver.

Index Terms—Wearable Technology; Biochemical Sensors; pH Sensor; Sodium ISE; Conductivity Sensor; Wireless Sensing

I. INTRODUCTION

TEXTILE based sensors offer an unobtrusive method of continually monitoring physiological parameters during daily activities. This is of particular use when determining the effect of certain activities, or when assessing patients with a chronic condition [1], [2].

To date, research has focused on the development of devices which monitor physical parameters such as heart and respiration rate. However, fluids such as sweat, urine and tears can give information about a person's physiological condition and should also be considered.

BIOTEX is a consortium of 8 EU partners, (see www.biotex-eu.com) aiming to develop dedicated textile based biochemical sensors. One of the main fluids of interest to this study is sweat as it is easily accessible and can be used for the diagnosis of disease. For example, chronic heart failure is characterized by sodium and water retention which takes place up to a week before symptoms such as tachycardia occur [3].

In the case of prolonged exercise, sweat monitoring could

be used to record and prevent the onset of conditions such as dehydration and hyponatremia. These are generally caused by under or over hydration respectively and can lead to serious and occasionally fatal health complications [4].

This paper describes the testing and integration of textile based pH, sodium and conductivity sensors. Results are shown to illustrate the functionality of the system. It is seen that potential applications exist in personal health monitoring.

II. EXPERIMENTAL PROCEDURE

One of the major challenges affecting the development of textile based biochemical devices is achieving adequate sample collection and delivery to the sensor site. To overcome this, a fluid handling system, based on a polyamide lycra® blend has been developed. This material is chosen because of its moisture wicking properties. A channel is defined by screen-printing an acrylic hydrophobic paste either side of the fabric and acts to transport sweat from the inlet past the sensors and into the absorbent where it is stored. This creates a passive pumping mechanism, controlling fluid flow.

The pH sensor is colorimetric, using two LED's (one functioning as an emitter and the other as a detector) to measure the colour change in a pH sensitive dye [5]. As the pH of human sweat generally lies between pH 5 – 7, Bromocresol Purple (BCP, $pK_a = 6.2$) was chosen and is fabricated directly on the channel by co-immobilizing the dye with tetraoctyl ammonium bromide. The sodium and conductivity sensor were supplied by CEA-Leti (www.-leti.cea.fr) and the University of Pisa respectively. Both are fabricated on a kapton surface which is placed across the fluidic channel to analyze sweat as it is transported towards the absorbent

Sensor outputs are recorded using a control system designed by CSEM. It contains a graphical touch screen display, a removable memory stick for data transfer and storage and Bluetooth communication for short-range data streaming. The control unit and fabric patch with sensors is shown in Fig. 1.

For on-body testing, the sensors are enclosed in a waistband which ensures the fabric patch maintains good contact with the skin during exercise. It is also used to block ambient light, may affect the operation of the pH sensor. Subjects are asked to cycle at a self-selected pace for a period of 30 – 60 minutes. During this time, reference measurements are made approximately every 5 minutes

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Fig. 1. Image of (a) pH, conductivity and sodium sensor integrated with CSEM electronics and (b) magnified image of pump and kapton patch.

Fig. 2. Image of the waistband used to house the fabric patch, reference patch and sensor during on-body trials

III. RESULTS

The operation of the sodium and conductivity sensor with the control unit is tested by placing the kapton patch across the channel of the fluid handling system. Solutions containing 0.02, 0.04, 0.06 and 0.08 M Na^+ are then pumped through the channel at a speed of 17 $\mu\text{l}/\text{min}$. For each solution 20 - 30 minutes is allowed for the sensors to settle at their final value. The results are shown in Fig. 3.

Fig. 3. Response of sodium and conductivity sensor tested on the patch with solutions of 0.02, 0.04, 0.06 and 0.08 M Na^+

It can be seen that the conductivity sensor responds quickly while the sodium sensor is prone to drift. This is attributed to inner phase boundaries which are not as well defined as those of classical ISEs, where inner filling solutions are used.

The flow of sweat past the sensors on the kapton patch can have an effect on their response. This can clearly be seen in the case of the conductivity sensor for flow rates of 4, 8, 14 and 17 mg/min. As shown in Fig. 4., when the flow rate is increased, the measured conductivity decreases. This suggests that it is important to know the sweat rate during testing. This will be done using a sweat rate sensor designed by the University of Pisa. It measures the gradient of water concentration or humidity existing on both sides of a membrane.

The pH sensor has been tested in on-body trials and Fig. 5. shows that it gives results which correspond to those obtained using a skincheck1^{TM} on-skin pH meter. Preliminary attempts to integrate the sensor with the control unit have been successful, as shown in Fig. 6, where the LED's are clearly able to differentiate between patches soaked in artificial sweat

from pH 3.5 – 6.5. Future work will focus on testing the system in on-body trials.

Fig. 4. Response of conductivity sensor to increasing flow rates

Fig. 5. Response of pH sensor during exercise trial

Fig. 6. Response of LED's to fabric soaked in artificial sweat at pH 3.5 – 6.5

IV. CONCLUSION

In this work, the integration of a textile based fluid handling system with sodium, conductivity and pH sensors has been outlined. It has also been demonstrated that this system provides a platform for the development of wearable biochemical sensors. In-vitro and in-vivo testing of sensors has been completed. It can be seen that each sensor has the potential to be used for the real time analysis of sweat.

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