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DESIGN AND DEVELOPMENT OF CONDUCTING POLYURETHANE FOAM SENSORS FOR BREATHING FREQUENCY MEASUREMENT

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ABSTRACT

Textile electrodes are a new and potential choice for long term and continuous monitoring of bio-signals. In this research, a novel dry foam electrode fabricated by embroidering conductive yarn on the electrically conductive polymer foam. The compressible conducting smart foam has been developed by coating polyurethane (PU) foam with inherently conducting polyaniline **(**PANi).The developed smart foam was characterized based on surface resistance and ageing . The foam electrodes have been designed and developed by embroidering conductive silk zari yarn on the developed smart foam. The results show that developed smart foam has the surface resistance of 7KΩ/square and the ageing tests show that there is only a negligible deviation in the surface resistance. The use of this smart foam sensor in a prototype breath monitor is also reported.

KEY WORDS: Breathe monitor, electrode, polyaniline, surface resistance, textile sensors

INTRODUCTION

The measurement of breathing rhythm is one of very important physiological indices. The respiratory rhythm is generally measured by multifunctional medical measuring instruments measuring a number of the man's physiological indices but it can also be measured by a separate measuring system. Since clothing is in direct contact with the human body, an attempt was made to build a textile clothing interface; such that adds a new function to clothing – apart from functionality and aesthetics, interactive adaptation to external stimuli. The most important function of the prototype sensors discussed is monitoring the man's health.

Inherently conducting polymers such as polypyrrole and polyaniline are often referred to as a “synthetic metals”, which possesses the electrical and magnetic properties of a metal, while retaining the mechanical properties of a polymer. Active research has been carried out to investigate the application of these materials in corrosion protection, rechargeable batteries, electrochromic displays, conducting composite materials, biosensors, chemical gas sensors, actuators, microextraction platforms, electronics, electrochemical energy sources, optical devices and smart fabrics [1–5].

Enzo Pasquale Scilingo et al shown that fabrics coated with conducting polymers, in particular, polypyrrrole, have piezoresistive and thermoresistive properties. They investigated these properties showing that can be used to realize strain sensors, which may have useful applications in the broad area of man–machine interfaces. In particular, these fabrics are easily integrated into truly wearable, instrumented garments capable of recording kinaesthetic maps of human motor functions with no discomfort for the subject [3]. Brady, S., et al developed a simple novel pressure sensing material by coating polyurethane (PU) foam with inherently conducting polypyrole (PPy) and they reported that the developed sensor can be used as a breath monitor[4]. Janusz Zieba et al developed three prototypes of textronic sensors made from optical, piezoelectric or electro conductive fibres for measuring respiratory frequency [7]. Tania Pola et al reported that the textile electrodes are well suited for measuring ECG and the best results were achieved with the embroidered electrodes, which have a large contact area with the skin [8].H-Y Song et al designed textile electrodes woven with conductive yarn in the jacquard woven structure and studied the bio signal of the ECG measurement [9].

In this study, a novel dry foam electrode, fabricated by electrically conductive polymer foam covered by embroidering the silk zari yarn, was proposed. The compressible conducting smart foam has been developed by coating polyurethane (PU) foam with inherently conducting polyaniline **(**PANi).The characterization of the smart foam sensor is presented. The use of this smart foam sensor in a prototype breath monitor is also reported.

MATERIALS AND METHODS

Chemicals and materials

Aniline, concentrated HCl, and ammonium persulfate (APS), all A.R. grades, from S.D. Fine Chemicals Ltd., India were used. Aniline was distilled twice before use. MilliQ water was used as the solvent for polymerisation and washing. The polyurethane (PU) foam substrate, was obtained from Resto-Foam, Coimbatore and was first washed with soapy water and then rinsed with excess MilliQ water and dried in air prior to use. Silk zari yarn of 75s Ne was purchased for the construction of electrodes. These yarns are highly conductive, more flexible and soft and are pliable.

Smart foam synthesis

The conductive foams were prepared by in situ chemical polymerisation of the appropriate monomer, i.e. polyaniline, to retain the elasticity present in the foam substrate. In this process, freshly distilled 0.5M aniline was dissolved in the bath containing 0.35N HCL solution for diffusion. A vigorous stir was given to the bath containing mixtures of aniline and aqueous acid to attain the homogeneous mixing. The dry pre-weight polyurethane foam was placed in the above solution at 40°c and allowed for 2 hours to soak well with the monomer and dopant solution. 0.25M ammonium per sulfate was separately dissolved in

0.35N HCL solution for polymerization. The aqueous oxidizing agent in the separate bath was then slowly added in to the diffusion bath to initiate the polymerization reaction. The oxidant to aniline ratio was kept at around 1.25. The whole polymerization reaction was carried out at 5°c for 1hour. After completing the polymerization process, the coated polyurethane foam was taken out and washed in distilled water containing 0.35N HCL and dried at 60 °c.

Conductance measurement

The PANi–PU foam was cut into specimens with dimensions of 20 mm×20 mm×10 mm. Conductive self-adhering foil was used to connect the two opposite end of the foam to the HP 34401A constant current multimeter .The data was collected by a PC using the software supplied by the manufacturer (HP multimeter software Version 1.1).

Aging behavior of smart foam

The goal of this experiment was to quantify the aging of the smart foam, i.e., to evaluate how the rest value of resistance changes with time. In particular, we evaluated the time dependence of the resistance of smart foam by performing daily measurements with a digital tester, over a period of 10 days. All of the measurements of resistance reported here are referred to a unit length of 1 cm.

Design of a novel dry Foam Electrode

The design of our proposed dry foam electrode is shown in Figure1. The electrode was designed to contact the skin by electrically conductive polymer foam with the compression set about 5–10% and it was embroidered using electrically conductive silk zari yarn (conductive about 0.07 Ω /square) to establish an electrical contact similar to that of the dry silver electrodes. In the developed electrode the conductive yarn is on the surface of the foam and hence it has a good contact with the skin. The size of our dry foam electrode is 20 mm (L)x 20(W)mm x10 (H) mm. Three electrodes were designed on the base foam using hand embroidery technique. The embroidered foam electrode was attached to a elastic belt. The belt can be tightened by adjusting the end Velcro.

Figure 1 : Images of the fabricated sensor

RESULTS AND DISCUSSION

General properties of PANi coated PU foam

The PU foam used in this experiment was a nonconductive, light grey, soft, sponge like material that could be reversibly compressed. When it was coated with polyaniline, it became conductive and green in colour. The tactile properties (i.e. soft and compressible) were retained. The physical stability of the PANi coating on PU foam was found to be excellent. It was able to withstand vigorous washings (rubbing, squeezing) with water. When a piece of PU– PANi was cut through with a scalpel it was seen that the polyaniline had completely penetrated into the PU matrix, resulting in a completely green mass inside out. The monomer aniline molecules were able to penetrate into the PU matrix and the oxidative polymerisation process resulted in a PANi –PU composite rather than simply a PANi coating adhered onto the PU surface. This finding explain the excellent physical stability of the coating, however, it results in film thickness determination by methods such as SEM impractical because there is no distinctive layers to be seen.

Aging behavior of smart foam

The resistance of smart foam changes if maintained in open air. To quantify the phenomenon, we evaluated the time dependence of the resistance of smart foam by performing daily measurements with a digital tester, over a period of 10 days .The results are shown in Table 1. As shown in the Figure 2, the behavior of the resistance with time is fairly linear.

Table 1 : Resistance value KΩ / sq versus days

No of days	Resistance value kΩ /sq
1	7.1
2	7.2
3	7.2
4	7.1
5	7.2
6	7.0
7	7.1
8	7.1
9	7.1
10	7.1

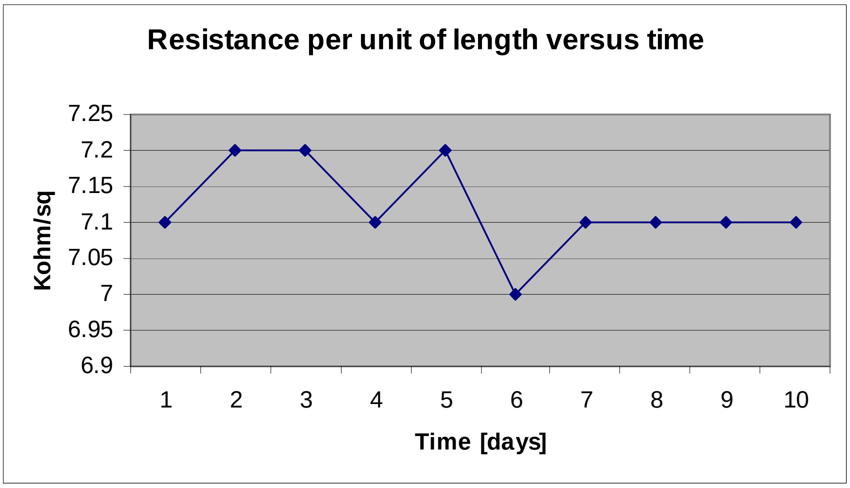

Figure 2 : Resistance per unit of length versus time

Recording breathing frequency

In this study respiration rate was used as the target response, as it is a useful physiological signal where rate of cyclical response is the target measurement. For the sensor, that means that the objective is the ability to count peaks to determine respiration rate. While other elements of respiration are also useful (volume of breath, gaseous composition), in this study the measurement of interest was simply the frequency of respiration in breaths per minute (BPM). Many other means of monitoring respiration require the user to don head-mounted apparatus or special sensing straps.

In this study, the foam sensor has been used for developing a breathing monitor, whereby the foam sensor is incorporated into a elastic belt to wrap around the ribcage area. The movement of the ribcage during breathing exerts pressure on the conducting foam causing an increase in conductivity of the material. Figure. 3 shows a real time trace which illustrates the repeated movement of the ribcage of a volunteer (SB) during breathing. This simple experiment shows that the breathing device is able to trace the rate and amplitude of breathing.

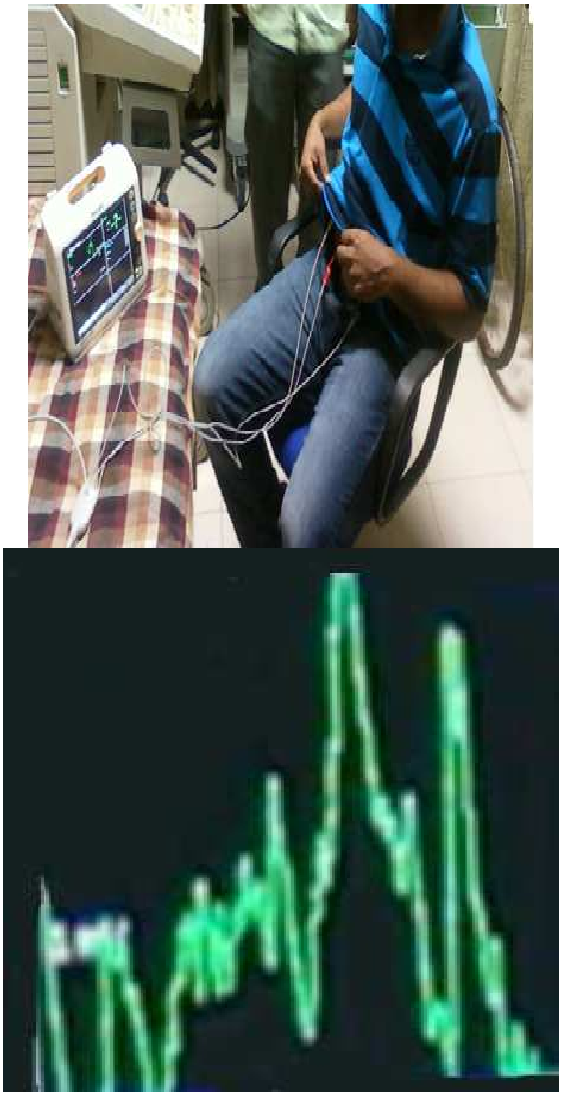

Figure 3 : Real time trace of foam sensor to monitor ribcage movement while breathing

Figure 4 : The developed Smart Garment

Although this kind of event detection can be achieved by other sensors, the main advantage of this particular sensor is in its physical qualities. The foam structure retains the attractive tactile and mechanical properties of foam, which are similar to those of many textiles. Thus, it is easily integrated into standard garments without requiring any decrease in comfort on the part of the user, and without creating any significant visual indication of the presence of a sensor. These benefits allow the interface to be as subtle and unobtrusive as possible. The sensor is also inexpensive, durable, and washable: all attractive factors for wearable technology. Further, the wearability scenarios to which the sensor is best suited (garment integration, minimally invasive sensing) are those in which many applications require a lower level of precision from body sensing. Figure 4 shows optimised sensor design that incorporated into wearable garment; it may useful to monitor breathing of patients that required special care.

CONCLUSIONS

A novel dry foam electrode is developed using polyaniline coated polyurethane foam and silk zari yarn, and experimentally validated in this study. Experimental results showed that developed smart foam has the surface resistance of 7KΩ/square and the ageing tests show that there is only a negligible deviation in the surface resistance. Compared to other fabric based electrodes, the softness of the foam substrate in our foam electrode can also increase the contact area of the skin–electrode interface. The application of this conducting foam in wearable sensor has been demonstrated. It indeed provides a novel prototype of a dry electrode for clinical and research applications

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