Textile-Based Humidity Sensor for Wearable Electronics

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Literature Review. Wearable electronic textiles (e-textiles) are gaining popularity due to their potential applications in the field of stimuli detector, health monitoring, energy storage, rehabilitation, and more (Meena et al., 2023). E-textiles have received substantial academic and commercial attention in various applications as they can enhance the functionality of clothing (Du et al., 2022). Textile-based humidity sensors can be a significant component of wearable electronic textiles to handle different skin diseases and wound management, as well as for microclimate control in clothing (Zhou et al., 2017).

Different types of wearable humidity sensors have been developed by transferring traditional humidity sensors onto textiles, including sensors that use different shapes, resistance, impedance, or capacitance (Lv et al., 2021; Ramachandran et al., 2021; Tai et al., 2020). Pereira et al. (2011) reported a textile-based humidity sensor that employed cotton as a hygroscopic material and conductive threads woven into textiles as electrodes. A carbon nanotube-based glass fiber humidity sensor was developed by Gao et al. in 2010. Carbon nanotube-coated cotton yarn and fabric made of polyelectrolytes were demonstrated by Shim et al. (2008), who also showed how they could be used to detect albumin and humidity.

In this study, conductive hemp fabric was developed through reduced graphene oxide (rGO) and polypyrrole (PPy) coatings, and the potential application of conductive hemp fabric as a humidity sensor was also investigated.

Experimental Methodology.

Materials. Hemp fabric was sourced from ……………., USA. Graphite powder, sulphuric acid, hydrogen peroxide, potassium permanganate, sodium carbonate, ethanol, 20% hydrochloric acid, and L-ascorbic acid were sourced from Thermo Fisher Scientific, USA. Pyrrole and ferric chloride were purchased from Sigma Aldrich, USA.

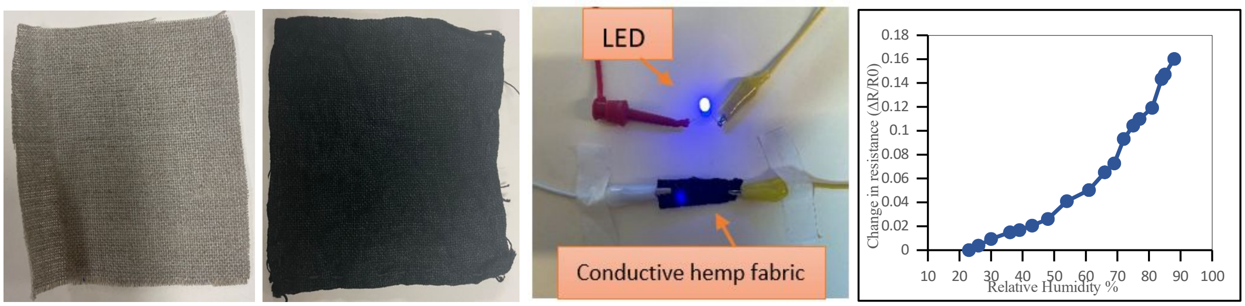
Scouring of hemp fabric. Hemp fabric was subjected to scouring with 3% sodium carbonate (on the weight of hemp fabric) and 2 g/l detergent at 80°C for 60 minutes in order to eliminate impurities and increase the absorbency of the hemp fabric. The scoured hemp fabric was dried for 24 hours at 50°C in an oven dryer.

Synthesis of GO. Graphene oxide (GO) was synthesized from graphite powder using the modified hummers method (Hummers Jr. & Offeman, 1958; Park et. al., 2008).

Preparation of rGO coated hemp fabric. A simple dip coating method was adopted to prepare rGO coated hemp fabric. For this purpose, 1 mg/ml stable GO suspension was prepared by ultrasonication for 30 mins at room temperature. After that, the scoured hemp fabric was immersed into the GO solution for 30 mins. Then the sample was washed with deionized water and dried at 50°C for 1 hr. The reduction of GO coated hemp fabric was done by using L-ascorbic for 1 hr at 90~95°C while stirring continuously. Finally, the sample was rewashed with deionized water and dried at 50°C overnight. This was defined as rGO-coated hemp fabric.

Preparation of rGO/PPy-coated hemp fabric. At first the rGO-coated hemp fabric was dipped into the pyrrole solution (0.5M conc.) for 30 mins where the material to liquor ratio was 1:20. Then the oxidative solution (0.5M conc.), ferric chloride, was poured dropwise into the pyrrole bath to initiate the polymerization keeping the bath temperature 0°C~5°C. Material to oxidant solution ratio was also 1:20. After 2 hrs, the sample was removed from the bath and washed with 20% hydrochloric acid and deionized water. Then the sample was vacuum dried overnight at 50°C. This sample was denoted as rGO/PPy-coated hemp fabric.

Results and Discussion.



(a) (b) (c) (d)

Figure 1: (a) Untreated hemp fabric, (b) rGO/PPy-coated hemp fabric, (c) Demonstration of rGO/PPy-coated hemp fabric's conductivity via connecting LED, (d) Humidity sensing performance of conductive hemp fabric

The electrical surface resistivity of the rGO/PPy-coated hemp fabric was measured following the AATCC Test Standard 76-2005. It was found that the coated hemp fabric is highly conductive, having a surface resistivity of 593 Ω/sq. only. The treated sample was used as an electrical connection to light a blue LED to exemplify its conductivity (Figure 1.c).

To test the performance of the rGO/PPy coated conductive hemp fabric as a humidity sensor, the relative humidity% was varied between 23%-88%, and the changes of conductive hemp fabric's resistance were noted simultaneously. It is found that with the increase of relative humidity%, the resistance of the sample also increased (Figure 1.d). The sensitivity of the resistance of the sample to relative humidity percentage suggests that rGO/PPy-coated hemp fabric has a potential application as a humidity sensor. The mechanism for water molecule absorption in a polymer composite is a complex process. It can be assumed that when the conductive hemp fabric was in contact with moisture, it absorbed water molecules and became slightly swelled. As a result, the conductive network, a network formed by the reduced graphene oxide and polypyrrole, was modulated and the distance between neighboring particles increased, leading to an increase in electrical resistance with the increased humidity (Li et al., 2007).

Conclusion. This experiment attempted to produce conductive hemp fabric that could be used as a wearable humidity sensor. The rGO and PPy coatings successfully converted the raw hemp fabric into conductive fabric. Later, the potential application of conductive hemp fabric as a humidity sensor was investigated and it was found that the resistance of rGO/PPy-coated hemp fabric was changed substantially with the change of humidity. It suggests that rGO/PPy-treated hemp fabric is a promising candidate for wearable humidity sensor.

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