Wearable Sensor of Humanoid Robot-Based Textile Chemical Sensors for Odor Detection and Tracking

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***Abstract*—This paper revealed the development and implementation of the wearable sensors based on transient responses of textile chemical sensors for odorant detection system as wearable sensor of humanoid robot. The textile chemical sensors consist of nine polymer/CNTs nano-composite gas sensors which can be divided into three different prototypes of the wearable humanoid robot; (i) human axillary odor monitoring, (ii) human foot odor tracking, and (iii) wearable personal gas leakage detection. These prototypes can be integrated into high-performance wearable wellness platform such as smart clothes, smart shoes and wearable pocket toxic-gas detector. While operating mode has been designed to use ZigBee wireless communication technology for data acquisition and monitoring system. Wearable humanoid robot offers several platforms that can be applied to investigate the role of individual scent produced by different parts of the human body such as axillary odor and foot odor, which have potential health effects from abnormal or offensive body odor. Moreover, wearable personal safety and security component in robot is also effective for detecting NH_3 leakage in environment. Preliminary results with nine textile chemical sensors for odor biomarker and NH_3 detection demonstrates the feasibility of using the wearable humanoid robot to distinguish unpleasant odor released when you're physically active. It also showed an excellent performance to detect a hazardous gas like ammonia (NH_3) with sensitivity as low as 5 ppm.**

Keywords— Wearable sensor, umanoid robot; Human axillary odor detection; Textiles chemical sensors; Volatile biomarkers; VOCs.

I. Introduction

Nowadays, the recent advancement of humanoid robot research has revealed significant potential for development of different robotics platform to serve various applications such as agricultural and industry robots, exploring robotics also medical robots. These humanoid robots were designed to resemble the functionality of five external human senses such as touch [1], hearing, taste [2], smell and sight [3], which could be used to overcome the fundamental human limitations. Therefore, the creation of robots for application variants plays a vital role in raising the quality of life both economically and socially. Many robotic researches demonstrate that innovators are committed to develop a robot to replace human in areas of risk and harm as a convenient and security object [4-5] and also in medical applications for monitoring health related hand sensory function [6]. Currently, there are mobile robots for detecting odors in a variety of purposes, such as a robotic vehicle to measure the leakage of chemicals or toxic gases [7], robot drones to monitor air quality [8] fish robots for monitoring the water pollutions [9] and Koala robots that have the Figaro sensors placed on at each side to detect the ethanol [10]. However, these applications of robots consider solely on detection of odors. We found that there is still no smelling robot that can be integrated directly into human body that can be worn as armor. Therefore, this work is one of our challenges to develop a prototype of the wearable humanoid robot which can be used together in variety of situations. To achieve this goal, we have designed and developed three different prototypes of the wearable humanoid robot based on textile chemical sensor; (i) human axillary odor monitoring, (ii) human foot odor tracking, and (iii) wearable personal gas leakage detection. Prototypes of these controls and data transmission system are with Zigbee wireless communication with convenience. They are suitable to be used particularly for personal care and as a self health monitoring system. Measurements were performed on nine gas sensors employed in the robot to detect the smell of body odor, foot odor and toxic gas in environment that causes health hazards.

Fig. 1 Schematic diagram shows the structure of wearable humanoid robot prototype for odor detection and tracking.

II. MATERIALS AND METHOD

A. Wearable Humanoid Robot System

The wearable humanoid robot is defined as a machine that possesses abilities of a human being. Such robots are characterized by wearable design, structure based on that of the human body, embedded devices for influencing and enhancing our emotional state, health, physical strength, and artificial intelligence allowing sensing the environment. There are three different prototype designs of wearable for detecting and analyzing volatile chemical and odor targets. The first prototype is human axillary odor monitoring used in the platform of the smart shirt worn as a close fitting usually aimed at capturing the body odor of wearer. Feeding back this information to the human reinforces body awareness which may help to improve their body odor. This prototype is based on embroidered chemical sensor on the fabric substrate. The second prototype is human foot odor tracking applied in platform of smart shoes to monitor the foot odor during daily activities in order to predict the health status. And the last prototype is wearable personal gas leakage detection that can be integrated into wearable pocket toxic-gas detector. The wearable pocket is capable of real-time monitoring the toxic-gas in environment by sending the signal warning in times when the toxic-gas concentration increases or spills.

B. Textiles chemical sensors

Here we present textile based on sensors suitable as wearable on humanoid robot. This is a novel approach to chemical sensing on a fabric. The sensors used in wearable humanoid robot olfactory are textile chemical sensors that specifically respond to human axillary and foot odor. Both prototypes used nano-composited sensing material as shown in Table.1 and were made from conductive threads embroidered onto the fabric substrate that is described in the previous work [11]. The fabrication of pocket gas leaking prototype involves crochet and immersion coating process as described in this paper [12]. All of these wearables consist of 2 sectors referred to as the operating system. The first sector is transmitter system in which electrical resistance measured by voltage divider in analog value is converted to digital signal by a microcontroller (MCU). The signal is all transmitted through the wireless ZigBee module. The second sector is receiver system which receives the signal from wireless ZigBee module to be sent to a computer.

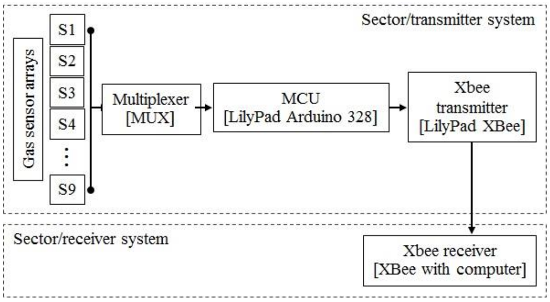

Fig. 2 Schematic circuit diagram of data acquisition for the textile chemical sensor-based wearable humanoid robot.

TABLE I. SPECIFICATIONS OF TEXTILES CHEMICAL SENSOR ARRAYS FOR ODOR DETECTION AND TRACKING

Sensor ID	**Textiles chemical sensors Based on Polymer/CNTs gas sensors**
❖ **Human axillary odor detection**	
S1	PVC/SWCNTs-COOH
S2	Cumene-PSMA/SWCNTs-COOH
S3	PSE/SWCNTs-COOH
S4	PVP/SWCNTs-COOH
❖ **Human foot odor tracking**	
S5	PVC/SWCNTs-OH
S6	Cumene-PSMA/SWCNTs-OH
S7	PSE/SWCNTs-OH
S8	PVP/SWCNTs-OH
❖ **Wearable personal gas leakage monitoring**	
S9	PSE/MWCNTs

III. RESULTS AND DISCUSSIONS

A. VOCs Sensitivity of Textiles Chemical Sensors

Volatile organic compounds (VOCs) detection: The textile chemical sensors which will be actually attached to the smart shirt or smart shoes were exposed to various single chemical volatiles to measure the sensing performance. For sensitivity of human axillary odor detection, S1-S4 sensors were exposed to ammonia, trimetylamine, and methanol. These volatiles are the most common volatiles in the human axillary odor. According to the results, S3 and S4 sensors show high sensitivity with ammonia and S1 and S2 sensors have high sensitivity with trimethylamine. But all S1-S4 sensors have demonstrated low sensitivity to methanol while comparing with amine group. The response of textiles S5-S8 sensors employed for human foot odor tracking, were exposed to the volatiles of foot odor such as dimethylamine, dipropylamine, and water. The results showed that all sensors in this category (S5-S8) have the highest sensitivity with dimethylamine and the lowest with water.

B. Wearable Humanoid Robot Olfactory Display

Human axillary odor detection: The results of the human axillary odor can be represented by the body odor profiles as calculated using the average response in each sensor. In this case study, we have three conditions for detection; i) detected without wearer, ii) in the morning, and iii) in the afternoon. The results in Fig.4 shows the pattern recognition based on principal component analysis (PCA) in which the body odor data can be separated into two clusters, without wearer and with wearer. However, the cluster that shows overlap in woman wearing in the morning and afternoon is not explained in this work and refers merely to different timings.

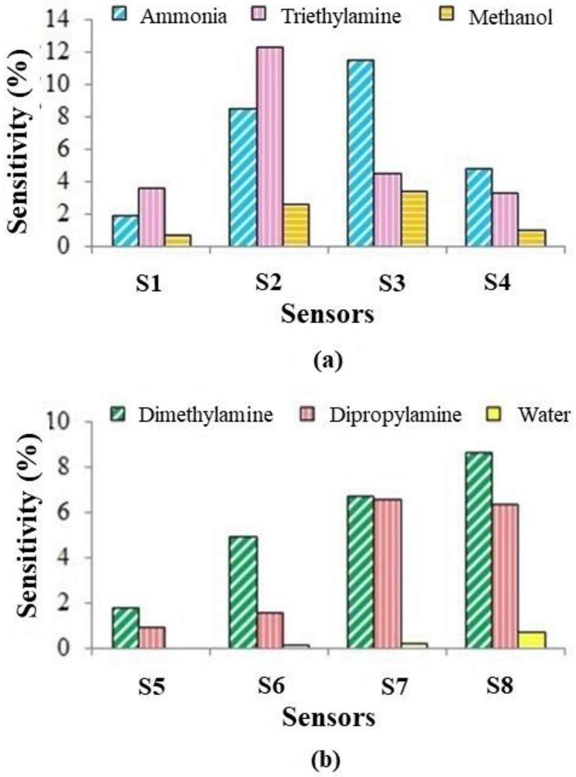

Fig. 3 The sensitivity of the textile chemical sensors; (a) S1-S4 sensors exposed to Volatile biomarker in Human axillary odor; (b) S5-S8 sensors exposed to Volatile biomarker in Foot odor.

Human foot odor tracking: The human foot odor tracking experiment consists of three conditions; detection of the foot odor without wearer, wearing socks for 1 hour and wearing socks for 2 hours. Moreover, we also compared the factor of wearer between woman and men. Odor samples were then classified into three groups, including i) without wearer, ii) women wearer, and iii) men wearer. The results shown in Fig.5 explain the difference in each duration of time and the physical characteristic dependent on the gender of the volunteer.

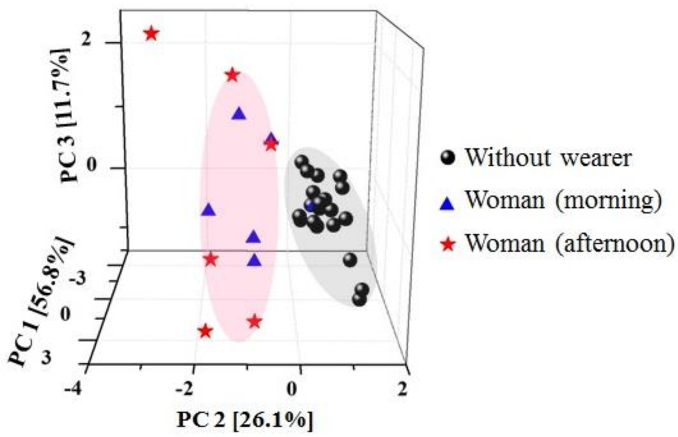

Fig. 4 Principal component analysis (PCA) performed on human axillary odor data obtained without wearer and during activities at the morning and afternoon of women volunteer.

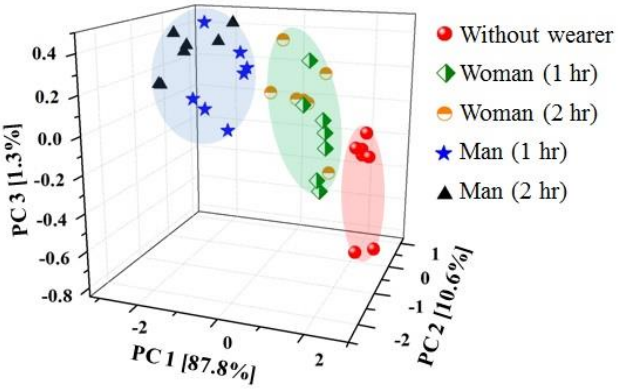

Fig. 5 Principal component analysis (PCA) performed on foot odor data obtained without wearer and during activities in 1 hour and 2 hour of women and men volunteer.

Wearable personal gas leakage monitoring: The sensitivity of the textile sensor toward various volatiles found in the real environment that causes toxicity are measured. The various volatiles are acetone, ammonia, acetic acid, pyridine, and ethanol. Fig.6 (a) shows the response of S9 which was produced from the nano-composites namely, PSE/MWCNTs. From the results, it was found that acetone, ethanol, and acetic acid presented low sensitivity whereas, ammonia and pyridine presented high response. This explains that S9 is sensitive to nitrogen atoms found in the atmosphere in the form of ammonia and pyridine. Since ammonia yielded the highest sensitivity, the next step was to study the correlation between the concentration of ammonia and the sensitivity of the textile sensor as shown in Fig.6 (b). We observed that the sensitivity increases with rising ammonia concentration.

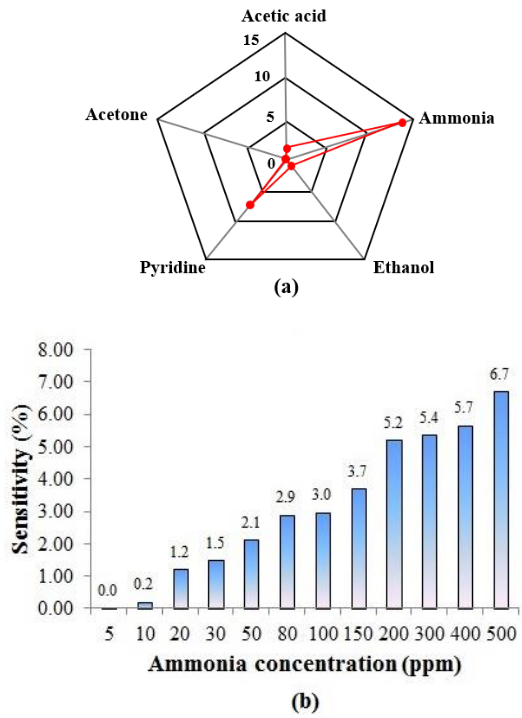

Fig. 6 The sensitivity of textile sensors (a) Radar plot of the sensitivity (S9) when exposed to individual volatile with a concentration of 1,000 ppm and (b) the sensitivity of S9 when exposed to various concentration of ammonia.

IV. CONCLUSIONS

The textile based on sensors enable technology to be integrated into wearable robot for measuring the odor of human body, foot, and toxic gas. Here we present three different prototypes of textile based on sensors – a human axillary odor monitoring, a human foot odor tracking, and wearable personal gas leakage detection. These prototypes have nine different types of sensing materials capable of responding to target odor. These odors have been classified by statistical method principal component analysis (PCA) and showed the sensors ability to respond to the odor correlated with the concentrations. The results indicate the potential of the smart textile fabric as a consumer point-of-care wearable to track the health status and assist in detecting toxic gas leakage in the environment.

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