Out-Of-Hospital Body Movement Data Collection using E-Skin Sensors

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***Abstract*—Out-of-hospital care plays an important role in improving the quality of chronic pain management. It could assist with early diagnosis, intervention and treatment and prevent unnecessary admission to hospitals, enabling efficient medical and healthcare resources. Recent advances in wearable sensors and mobile computing technology can considerably transform and benefit out-of-hospital care. In this work, we demonstrate an out-of-hospital body movement data collection mobile application which utilizes the cutting-edge nanotechnology-based E-Skin sensors. We also describe and demonstrate the real-world application of the E-Skin sensors to continuously detect, measure and analyze body movements.**

Keywords—E-Skin sensors, body movement, out-of-hospital

I. Introduction

Chronic musculoskeletal pain (CMP) such as chronic low back pain and knee pain are the leading causes of disability around the world [1]. CMP has become a heavy burden on individuals due to the expensive diagnosis, treatment and rehabilitation costs and work absenteeism[2]. Traditional CMP management requires patients to visit doctors regularly to monitor their physical conditions or rehabilitation progress. However, the uneven distribution of health resources and health services makes it difficult for the patients who live in less developed regions or remote areas to have access to the healthcare services [3], [4]. Therefore, an out-of-hospital CMP management system can extremely benefit these patients by allowing doctors access data to monitor their physical conditions and rehabilitation progress remotely.

Recent studies show that physical activity is one of the major risk factors for developing CMP[5], [6]. Traditional CMP management use self-reported surveys and interviews to collect physical activity data at larger intervals (for example weekly monthly, or 3 monthly). The accuracy of the collected data is not guaranteed because most questions rely on patient recall. Physical activity data (occupational and recreational) is vital for helping medical professionals to have a better understanding about the relationship between CMP and physical activity. The collected physical activity data also contains personal information for doctors to tailor a personalized treatment for individuals.

Physical activity is constituted of different body movements. Many wearable sensors are capable of detecting and measuring body movements, such as vision-based systems[7] and inertial measurement units (IMUs) based systems[8]. However, there are some major drawbacks with these systems: 1) vision-based systems are limited to the laboratory setting and highly sensitive to the light condition; 2) IMUs based systems are built with rigid package which make them uncomfortable for long time use; 3) these systems are costly considering both hardware and software. With the advances in wireless sensing technology and mobile computing, electronic-skin [9] (E-Skin) wearable sensors have gained popularity. This is due to their intrinsic characteristics, such as high sensitivity, stretchability, and low-cost, which enable them to offer a second skin like feeling during the measurement [10]. Additionally, E-Skin sensor is capable of detecting slightest movements and has a quicker response time to body movement comparing to IMU based sensors. By using a simple Bluetooth module, the measured data can be wirelessly transmitted to any data processing device such as a smartphone or a tablet for establishing a pervasive body sensor network. The E-Skin sensors have been reported in different measurement scenarios, such as pulse signal detection [11] and finger movement detection [12]. However, only limited studies have considered the potential of using E-Skin sensors as an alternative to detect, measure and analyse body movements[9].

This paper introduces a body movement data collection mobile application using E-Skin sensors as part of the out-of-hospital CMP management system. The contributions of this study are: 1) the development of an objective body movement data collection approach for out-of-hospital CMP management; 2) implementation and empirical testing of the mobile

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application with comparison to existing body movement measurement sensors.

II. System Design

A. E-Skin Sensor Design

In this study, we used a graphite microflake hybrid conductive network-based strain sensor based E-Skin wearable sensor. It is developed by Monash University NanoBionics Group[13]. A silver paste is applied on both ends of the U-shaped strain sensor. After attached the electronic module, it is encapsulated under sports kinesiology tape. The electronic module is an nRF51822 Bluetooth Low Energy (BLE) system on chip (SoC) from Nordic semiconductor obtained from a distributor, Raytac Corporation [14]. It provides the capability of wirelessly transmitting the measured data to any BLE device, such as smartphones, which makes it extendable to a Wireless Body Sensor Network (WBSN) for monitoring the physiology signal of human body. In this work, we used a Samsung S7 smartphone to collect the measured data from three E-Skin sensors simultaneously. The transmission rate of each E-Skin sensor is set to 15Hz because of the smartphone BLE throughput limitation. E-Skin sensor has a 40 mAh lithium polymer battery. According to our lab test, it can be used continuously for one week on a single charge. The dimension of the E-Skin sensor is 120mm × 25mm × 2mm. The details about the calibration and validation of E-Skin sensors can be found in [13].

B. Body Movement Data Collection Mobile Application

As shown in Fig. 1, the body movement data collection mobile application consists of three major modules: 1) Data Pre-processing Module; 2) Body Movement Recognition Module; and 3) Body Movement Characteristic Extraction Module.

The Data Pre-Processing module is responsible for transforming raw multivariate time series data into processed time series data. The E-Skin sensor measures the skin deformation. The characteristics of the outputs are similar to the IMU sensors. The pre-processing of this type of signals involves de-noising, calibration, normalization and synchronization. The pre-processed data is then analysed in the Body Movement Recognition Module.

The Body Movement Recognition Module generates the classification results based on the data input and selected features. The performance of multiple classifiers such as SVM and Random Forest are tested and compared. The best trained model are used in this module. The classified body movements are then segmented and analysed by the Body Movement Characteristic Extraction Module.

The Body Movement Characteristic Extraction module analyses each movement and calculates the characteristic of each movement such as speed, acceleration, angle, intensity and dimension. The speed refers to the average speed of the movements. The acceleration refers to the speed changes during the movements. The angle refers to the maximum anatomical joint angle of the movement and the dimension means the direction of the movements such as left or right.

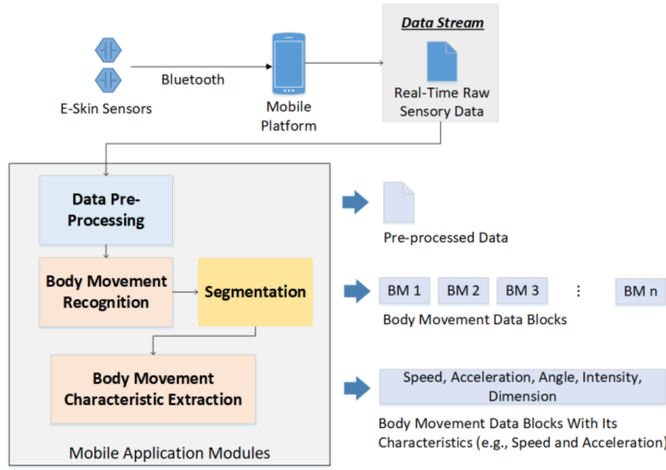
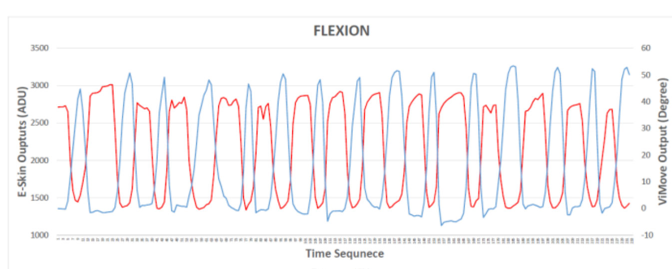


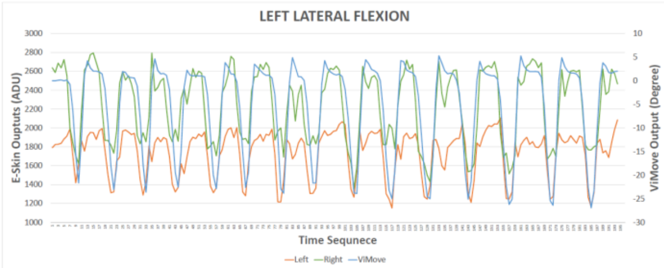
Fig.1. Body Movement Data Collection Application Architecture

Fig.2. Sensor Placement

These characteristics are calculated based on the E-Skin outputs and actual anatomical angle mapping model. This model is established by a series of experimental results. In the experiments, we compared the E-Skin sensors with a IMUs based body movement monitoring system (ViMove, DorsaVi, Australia) [15]. We used ViMove as the golden standard because it is clinically validated. We compared the results of two lumbar-pelvic movements measurements including flexion and lateral flexion. The sensor placement is shown in Fig. 2.

As shown in Fig. 3, there are regular data patterns that can be derived from E-Skin outputs considering different movements. For example, we can identify the flexion based on the patterns in the bottom E-Skin outputs and identify left and right lateral flexion based on the regular patterns of left and right E-Skin outputs. According to the results of linear regression, shown in Table I, the E-Skin outputs has a relatively linear relationship with the actual anatomical angle (measured by ViMove). The results show that E-Skin sensor is capable of detecting and measuring different body movements. Based on this finding, we can establish the mapping model between E-Skin outputs and actual anatomical angle that is the key component of the body movement data collection application.





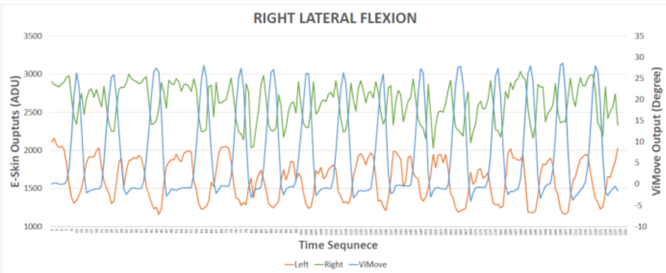


Fig.3. Sensor Outputs for Flexion and Lateral Flexions (left and right)

TABLE I. LINEAR REGRESSION RESULTS

Independent	R	R^2	Adjusted R^2	Std. Error
Flexion				
Bottom E-Skin Output	0.894	0.799	0.798	8.9508
Left Lateral Flexion				
Left E-Skin Output	0.817	0.667	0.665	5.6078
Right E-Skin Ouptut	0.832	0.692	0.690	5.3957
Both	0.893	0.798	0.796	4.3810
Right Lateral Flexion				
Left E-Skin Output	0.798	0.637	0.635	6.4473
Right E-Skin Ouptut	0.496	0.246	0.243	9.2878
Both	0.804	0.646	0.643	6.3804

III. DEMONSTRATION CONTENT

Our demo consists of two parts: First we will show the performance of our data collection application on knee movements. In this part, we will use both E-Skin sensors and ViMove system. The sensors will be attached on one of subject's leg. The subject will be instructed to sit on a fixed chair and bend his/her knee from 90 degrees to 180 degrees. We will present the comparison of the results from both E-Skin sensors and ViMove system. Second we will present the performance of our data collection application on lumbar-pelvic movements detection and measurement. In this part, we will attach three E-Skin sensors on the subject's back and instruct him/her to do each flexion and lateral flexion for five times. The real-time collected data will be shown with an Android phone. Then we will run the analysis module to generate a measurement report for the detected movements and their calculated characteristics.

IV. CONCLUSION

This paper demonstrates the design of an out-of-hospital body movement data collection mobile application with E-Skin sensors. Compared to traditional body movement measurement sensors, the total cost of E-Skin sensor is around 20 AUD which is cheaper than ViMove and it is more comfortable for long time use according to the feedback from the experiments' participants. With the BLE SoC, E-Skin sensor can wirelessly connect to a smartphone and transmit the measured data. E-Skin sensor also has a longer battery life for continuously monitoring over one week. By using multiple E-Skin sensors, we are able to detect different body movements and calculate the characteristics of each movement. The body movement data collection mobile application described in this paper could contribute significantly to the out-of-hospital CMP management and improve efficiency of health resource distribution by enabling continuous and remote monitoring of patients' physical activity from the comfort of their homes. Additionally, this paper provides empirical evidences for future research using similar sensors like E-Skin in healthcare.

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