Establishing a Measurement System for Human Motions Using a Textile-Based Motion Sensor

Moonsoo Sung[1], Keesam Jeong[2], and Gilsoo Cho[1]

[1] Department of Clothing and Textiles, Yonsei University, Seoul 120-749, Korea
[2] Department of Medical Information Systems, Yong-in Songdam College, Yong-in 449-710, Korea
{mssung, gscho}@yonsei.ac.kr, ksjeong@ysc.ac.kr

Abstract. We developed a human motion measurement system using textile-based motion sensors whose electrical resistance changes with textile length. Eight body locations were marked and used for measurement, based on previous studies investigating the relationship between human muscles and activities. Five male subjects participated to the experiment, walking and running while the electrical resistance of each sensor was measured. Measuring and analyzing the variations in the electrical resistances of our sensors allowed us to successfully evaluate body postures and motions.

Keywords: human motion, human posture, measurement, textile-based motion sensor, electronic textile.

1 Introduction

Continuously and precisely measuring human postures and movements is critical to the monitoring of diverse human activities. Therefore, many studies investigate, the measurement of human motions with cameras or accelerometers [1, 2, 3] since the 1990's. Nowadays, many researchers use conductive fibers and yarns to develop motion sensors. Studies done with camera capture systems and accelerometer-based systems achieved stabilization of measurement techniques thanks to the accumulation of technology. However human activities are difficult to measure in real-time because of excessive measurement system sizes and of new settings needed for each measurement. On the other hand, textile motion sensors are simple and light. Paradiso et al. [4] and Catrysse et al. [5] have developed piezoresistive textile sensors and measured respiration volumes by attaching them around the chest. Because they were developed for respiration, these piezoresistive textile sensors are not sensitive enough to measure body movements, nor the direction and angle of movements.

Ravindra Wijesiriwardana [6] developed textile-based motion sensors that exploit magnetic field gradients. Magnetic coil bands made of copper wires and spandex fabric were attached around an upper arm (coil 1) and a forearm (coil 2). They predicted the angle of an arm's movement by analyzing variations in coil 1 and coil 2. The magnetic coil bands provided correct data, but magnetic waves had to be continuously supplied to the coils.

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We, the Smartwear Research Center, developed textile-based motion sensors from knitted fabric made of 100% stainless steel yarns [7]. The electrical resistance of the textile-based motion sensors changes according to fabric elongation. A prediction model for measuring body movements was developed by monitoring changes in electrical resistance resulting from changes at elbows. The Smartwear research center developed textile-based motion sensors from stainless steel yarns and spandex yarns to extend previous studies, measuring changes in electric resistance at outward points of the knees [8]. We planned the current study according to these results that distinguishing postures and motions is more useful than measuring correct joint angles in everyday life.

In this study, we focused on the development of textile-based sensors better than previous textile-based sensors. We do not purpose to measure joint angles but to identify movements. In the previous study, the sensors were made with a knitted structure and their elasticity was measured. In this study, the sensors are made of spandex fibers, which are elastomeric, solving the problem of previous sensors. We marked eight points on the lower and upper body to measure body movements.

2 Experiments

2.1 Development of Textile-Based Motion Sensor

The textile-based sensor was braided with 60% of filament yarns made of polyester (75denier) yarns covering with spandex yarns (75denier) and with 40% of stainless steel multifilament yarns (Fig. 1). The narrow band was used as a textile sensor, and the changes in its electrical resistance were mapped to changes in length extension. The spandex yarns distributed and smoothed the stretchability and recovery of the sensor, while the steel yarns conducted electricity, with changes in resistance corresponding to changes in length due to better contacts between stainless steel filaments.

The electrical resistance of textile sensors was measured with a FLUKE PM6304 Multi-meter. As a free test, we cut the sensor at 5cm, and measured the electric resistance at regular stretch intervals of 0.2cm. The electric resistance decreased to one third at a maximum stretch length of 6.2cm (24% extension), from 13.8Ω to 4.2 Ω.

2.2 Measurement Points of Textile Based Motion Sensors in Clothing

The measurement points of textile-based motion sensors in clothing were selected considering previous studies [9, 10, 11, 12]. Each sensor location matches a muscles commonly used in walking and running. Eight points were marked: two on the left and right side of the mesosternum (P.1, P.2) two 5cm below axillae (P.3, P.4), two at the bottom (P.5, P.6), and two outward the knees (P.7, P.8). Five centimeter long sensors were fixed as show on figure 3.

Fig. 1. Textile-based motion sensor

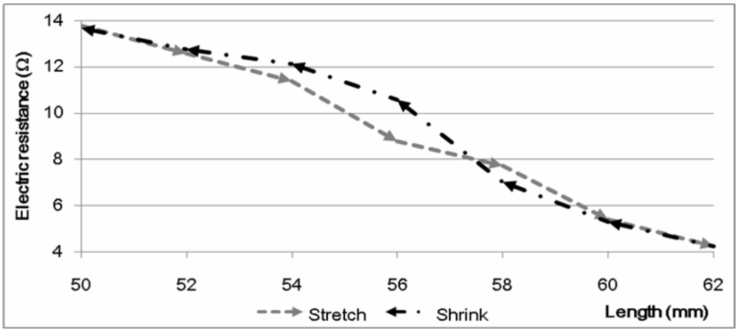


Fig. 2. Electrical resistance of the fabric sensor according to stretch and shrink

2.3 Suit Containing the Sensors

We used a commercial suit produced by a sports brand for our measurements, because it shows identical extension through all sections. The upper garment was a men's short-sleeve consisting of 78% polyester, 13% nylon and 9% spandex. Pants were 71% polyester, 21% polypropylene and 5% spandex.

2.4 Subjects and Protocol

Subjects. We selected five male college students and their average age 24.8 (±2.86) years old. Their average height was 177 (± 1) cm and their weight was 67 (± 0.8) kg.
Protocol. The subjects wore the suit, and were asked to walk and run during 3 minutes. A cycle of walk and run, was defined as moving the right arm and left leg in first step, then left arm and right leg in second step. The walking speed was 1.2 seconds per 1 cycle and the running speed was 0.8 seconds per 1 cycle.

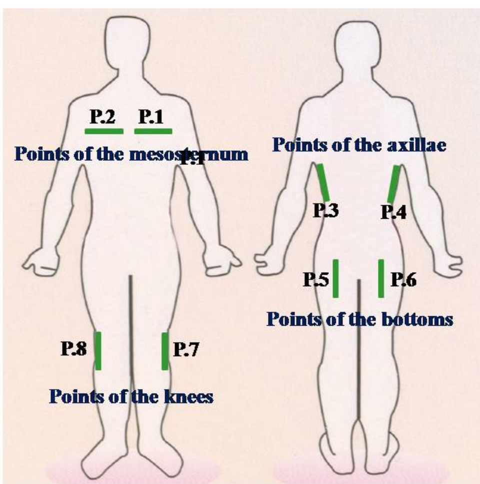


Fig. 3. Measurement points for the sensors

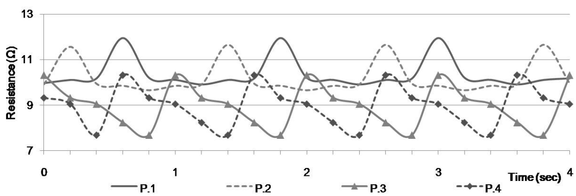
2.5 Real-Time Measurement of Electrical Resistance

The electrical resistance was measured with an Agilent data 34970A acquisition/switch unit and an Agilent benchlink data logger. The changes in electrical resistance were measured in real time.

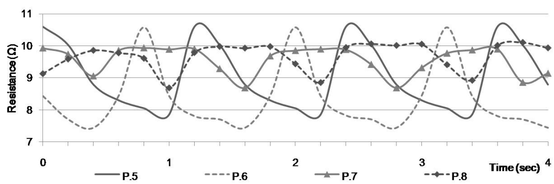
3 Results and Discussion

3.1 Real-Time Changes in Electrical Resistance While Walking

Figure 4 and table 1 show the changes in electric resistance and features in each body part due to the walking motions of the 5 subjects.



(a) Upper body



(b) Lower body

Fig. 4. Real-time changes in electrical resistance while walking

Table 1. Three characteristics of electric resistance while one cycle walking

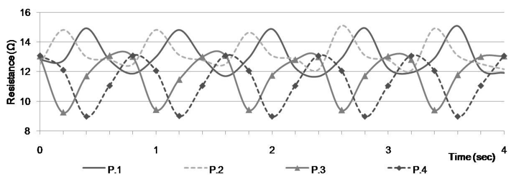
	P.1	P.2	P.3	P.4	P.5	P.6	P.7	P.8
Maxium value (Ω)	11.96 ±0.24	11.66 ±0.25	10.31 ±0.11	10.32 ±0.10	10.60 ±0.08	10.58 ±0.08	9.94 ±0.20	10.11 ±0.19
Minium value (Ω)	9.91 ±0.24	9.66 ±0.23	7.69 ±0.11	7.66 ±0.11	7.86 ±0.07	7.44 ±0.09	8.68 ±0.18	8.86 ±0.18
Avg. of gradient (between max and min)	3.40	3.32	13.13	13.13	2.74	3.13	2.08	2.08

The curve shown in figure 4 was produced by averaging the data of the five subjects, after discarding unexpected values, from repeated testing. Although depending on the subject there were minute time differences in moving each body part, the 5 subjects showed a similarly shaped curve. The electric resistance change measured for the upper body showed a smaller overall slope than that for the lower body, because there is less motion in the upper body than in the lower body while walking.

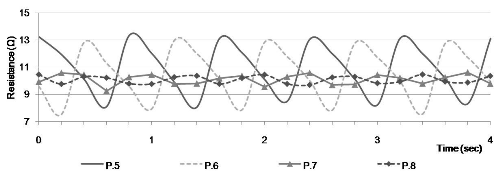
Electric resistance change trends characteristically appear at the mesosternum for the upper body and at the knee for the lower body. In the case of the mesosternum, during the transition time between motions, a stable period of steady resistance occurs. Large electric resistance change is observed for the left and right side of the axillae, which show gradual changes and a bit of stable period. With the walking motion, significant individual differences appeared, due to the impact of individual walking habits, in the range of electric resistance change measured at 4 points on the upper body.

3.2 Real-Time Changes in Electrical Resistance While Running

Figure 5 and table 2 show the changing electric resistance and features in each body part due to the running motions of the 5 subjects.



(a) Upper body



(b) Lower body

Fig. 5. Real-time Changes in electrical resistance while running

Table 2. Three characteristics of electric resistance while one cycle running

	P.1	P.2	P.3	P.4	P.5	P.6	P.7	P.8
Maximum value (Ω)	14.88 ±0.17	14.90 ±0.17	13.06 ±0.03	13.10 ±0.01	13.17 ±0.10	12.85 ±0.08	10.49 ±0.10	10.40 ±0.07
Minium value (Ω)	11.93 ±0.16	12.32 ±0.17	9.38 ±0.07	8.98 ±0.02	8.24 ±0.18	7.74 ±0.18	9.63 ±0.12	9.77 ±0.02
Avg. of gradient (between max and min)	7.36	6.44	9.19	10.28	8.20	8.51	2.15	1.55

As with the walking motion, the electric resistance data was averaged from repeated testing after discarding unexpected values, and then analyzed. For the running motion, there were virtually no subject-dependent motion time differences.

The main difference observed between running and walking is that the stable periods found at the exterior of the knee and at the left and right side of the mesosternum are very brief due to the acceleration. Besides, the difference between the minimum and maximum electric resistances increases, because the motion becomes significantly bigger when running. As the stable period and the duration of a motion cycle from start to completion shorten, the slope of the “running” curve steepens, the impact of individual walking habits becomes insignificant.

3.3 Establishing a System to Measure Human Motions

Based on the “walking” and “running” data, a way to link electric resistance changes to motions was considered. Three features emerge from our analyses.

First, when resistance change is produced due to motion, a fluctuation period and a stable period co-occur. In both the walking and running motions, the sensors attached to the exterior of the knees accurately show the fluctuation and stable period patterns. The grounds for motion differentiation could be established based on the existence and nonexistence of such fluctuation and stable periods and their lengths. As presented in the summary of our experiments, the data collected from the sensors attached to the exterior of the knees showed a relatively long stable period for walking and a shorter one for running.

Second, the length of cycle collected from the sensors attached to the upper and the lower body differ. This indicates differences in speed, and allows the evaluation of not only walking or running speed but also the balance of the upper and lower body. For example, if the lower body appears slower than usual compared to the upper body, the subject’s motion is unbalanced.

Third, depending on the movement form, the range of electric resistance change measured by the sensor attached to the same area, that is, the difference between the maximum and minimum value, differs. When the data from the walking and the running motions in this study are compared, the difference between the maximum and minimum value for each sensor is greater for running than for walking. Thus, as the motion becomes larger and faster, the change in electric resistance increases. In other words the higher the slope of the measurement in a section, the larger the difference between the maximum and minimum value. This conclusion will be verified with data collection and analysis through additional tests. If a program exploits these three characteristics, the motion form, speed and acceleration may be measured simply from electric resistances.

The following table is a numeric summary, focusing on the aforementioned three characteristics, of the data obtained in this study.

Table 3. Three key characteristics of the electric resistance of textile-based motion sensors

	Walking(one cycle)	**Running(one cycle)**
Stable section of electric resistance changing (ms, millisecond)	504 ± 22.6	204 ± 54.9
Cycle duration(ms, millisecond)	999 ± 122.5	644 ± 28.2
Avg. of gradient between max and min (Left and right sides of knees)	2.93	8.36

4 Applications

As summarized in the results, we can determine the form and overall motion speed as well as acceleration from the motion measurement system using resistance changes in textile sensors. Reflecting these abilities, we propose the following four applications.

First, we may correct the posture of athletes. For example, consider a batter's or a golfer's swing: the swing form, the overall swing speed and the instantaneous acceleration at a given point can be measured and then corrected. Athletes such as batters and golfers produce records through the athletic form of swings. To improve their performance, while increasing the overall swing speed is important, the overall body balance during a swing and the acceleration at the instant the ball is hit by a bat or club are the most important factors. To make such corrections, it is possible to construct a system to detect and analyze an athlete's motion and posture using textile-based sensors.

Second, with the increase of the elderly population, the measurement system can be applied in the health care of aged patients. Because of physical infirmities, the activities of elderly patients are limited. Although their health may improve through concentrated care, such care must be accompanied with appropriate activities or exercises. Without carrying around a heavy and uncomfortable device or having it attached, but just by wearing clothing, it will be possible to determine if a patient is getting enough exercise and, based on this, prescribe him or her appropriate exercises and activities.

Third, the system can be used as an input device for various instruments. By attaching textile-based motion sensors at finger joints or the body's major muscles, the movements can be measured, providing as a glove-type input device or a video game controller.

Fourth, it can also be used for simple medical purposes. Currently the most researched bio-monitoring area is in the ECG measurement field founded on textile-based electrode systems. Although the current technology cannot be used for precision medical diagnosis, it can be used to detect abnormal symptoms occurring in everyday life and then to get further diagnostic checkup to prevent serious diseases. Such ECG monitoring wear only needs the current state of the patient. Simply put, it is natural for the heart beat to quicken and breathing become hard when running fast. However if the heart beat speeds up and the breathing becomes hard while resting or walking slowly, it is abnormal. If the symptom is intense, the patient may of course go to a hospital for an examination. But if the patient does not feel or is not greatly conscious of the symptom, then most of the time no visit is made at a hospital. Therefore, serious diseases can be prevented, if a motion measurement system employing textile-based motion sensors and a bio-monitoring smartwear using textile-based ECG electrodes are developed and used.

5 Conclusion

In this study, a resistance change textile was made and applied to clothing to realize a textile-based motion measurement system. Through tests measuring electric resistance in real-time, particular changes were found for walking and running motions. We also determined that designing a movement measurement system using electric resistance changes in textile is possible if the measured data is combined to a program exploring their characteristics. Although very simple, this sensor can provide quantitative data expressed numerically in various ways depending on human needs.

6 Future Works

Since 5 subjects with similar physical characteristics were selected and used for tests in this study, generalizations may be unreasonable. Thus, we will focus subsequent studies on generalization based on movement data obtained from subjects with diverse physical characteristics.

The electric resistance measurement device used in this study could not be carried around. We need to replace this with a portable instrument for a realistic construction of a textile-based motion measurement system. To do this, a wireless measurement board capable of measuring 8 to 12 channels is currently being developed, and a portable device combining this with a wireless transmitter-receiver is also being designed.

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