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Real-time sitting posture correction system based on highly durable and washable electronic textile pressure sensors

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ABSTRACT

A real-time sitting posture correction system based on highly durable and washable textile pressure sensors was demonstrated. Textile pressure sensors consisted of conducting Ni-Ti alloy fiber with an excellent fatigue resistance and a pressure-sensitive polyurethane elastomer resulted in reliable capacitance change by an applied pressure in a range from 10 to 180 kPa with a sensitivity of 2.39 kPa^{-1}. The sensing performance was 100% maintained even upon repeated sitting action over 1000 times and harsh washing in detergent-solution. By analyzing the pressure detected at the different positions under the hip, thigh, and back, seven types of sitting postures including upright sitting, sitting with one leg crossed, and sitting with both legs lifted were successfully classified. Finally, real-time display on a monitor of the changes in sitting posture was simulated in order to allow the users to recognize and correct their body balance.

1. Introduction

These days, it is reported that approximately 75% of all employees have jobs that require working in a seated position, and people sit for about six hours each day on average [1]. Sitting is one of the important postures of the human being in daily life; however, it provokes considerably higher disc pressure than standing posture [2,3]. Inappropriate sitting postures such as sitting cross-legged, slouching, and leaning back can give rise to musculoskeletal diseases such as scoliosis, disc, or turtle neck syndrome [3,4]. Therefore, the development of a sitting posture monitoring system has received increasing attention in healthcare-related industries as well as the medical community owing to its extensive applications and significant impact. From the viewpoint of treatment and prevention of such musculoskeletal diseases, real-time sitting posture monitoring and inducement of a correct sitting posture are critical elements.

To classify the human body posture, visual information obtained from cameras was used at an early stage of the research [5,6]. However, this method causes an uncomfortable feeling in the subjects, and unnecessary recording triggers privacy concerns. To avoid these issues, estimation of the sitting posture through analysis of the pressure distribution using a pressure-sensor-equipped chair or cushion has been demonstrated [7–9]. Posture monitoring using pressure sensors has fewer privacy concerns and can provide intuitive weight information.

To measure the sitting posture pressure, various types of pressure sensors with different operation principles and device structures have been utilized, including thin-film devices with force-sensing resistors (FSR) [7,8], piezoresistive films [9], thin-film capacitors with pressure-sensitive rubbers [10], and textiles consisting of a pressure-sensing component and conducting fiber electrodes [11]. Among them, textile pressure sensors have attracted special attention as wearable electronics [12–14]. Textile pressure sensors can offer much more comfortable touch feeling and economical prices. Compared with a conventional FSR-based pressure sensors, the applicability of textile pressure sensors will vary according to the surface coming in contact with the human body, and the ease of integration and washing. In previous reports, Meyer et al. introduced textile pressure sensors to classify sitting postures [14]. Xu et al. successfully demonstrated a textile-based

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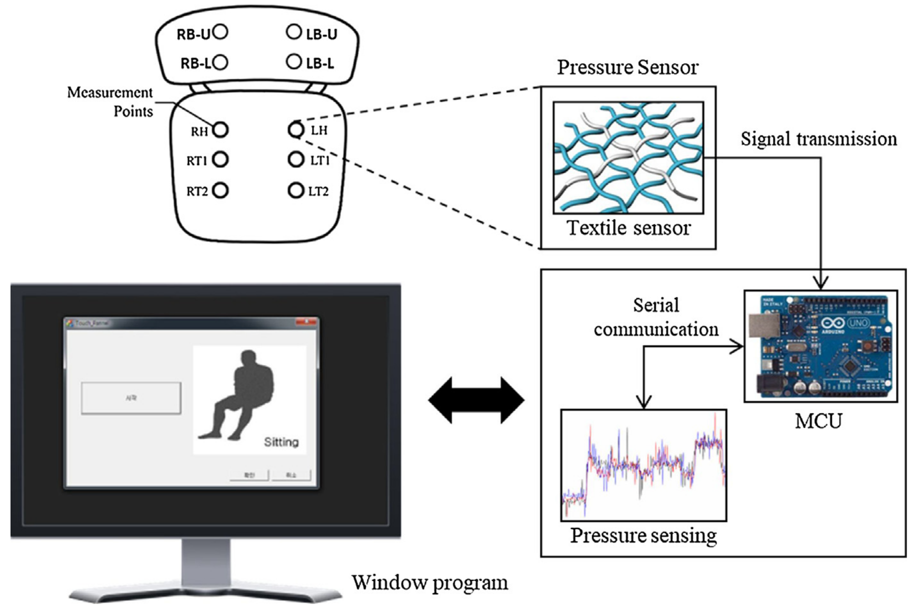

Fig. 1. Schematic illustration for real-time sitting posture monitoring system based on textile pressure sensors.

pressure-sensing cushion for sitting posture analysis [11]. However, in order to make the posture monitoring system using textile pressure sensors commercially available, development of textile pressure sensors with high durability against mechanical deformations and the washing process is still required. Furthermore, to date, real-time sitting posture monitoring systems based on textile pressure sensors have not been demonstrated.

In this paper, we present a real-time sitting posture correction system based on highly durable and washable textile pressure sensors. Textile pressure sensors consisted of conducting Ni-Ti alloy fiber with an excellent fatigue resistance and a pressure-sensitive polyurethane elastomer resulted in reliable capacitance change by an applied pressure in a range from 10 to 180 kPa. The sensing performance was 100% maintained even upon repeated sitting action over 1000 times and harsh washing with detergent. Also, we provide a system configuration to operate textile pressure sensor arrays and a decision algorithm based on the errors of capacitance values to classify different sitting postures. Finally, we demonstrated the real-time display on a monitor of changes in sitting posture.

2. Device fabrication and system configuration

Fig. 1 shows the system flow of the sitting posture-sensing process. The final goal is to distinguish the user's sitting position and simultaneously display the status of the sitting posture in a monitor. To achieve the goal, the developed textile pressure sensors were located on the left and right sides of a chair, where they came in contact with the hip (LH, RH), thigh (LT1, LT2, RT1, RT2), and back (LB-U, LB-L, RB-U, RB-L).

The textile pressure sensors are comprised of a 90-μm-thick nickel-titanium alloy (Ni-Ti) fiber coated by 400 μm-thick polyurethane (Fig. 2). The Ni-Ti shape memory alloy fiber utilized in this study was purchased from Dynalloy as cold drawn. Composition ratio of Ni-Ti alloy was about 1:1. Then, the wire was heat treated at 480 °C for 5 min to generate a shape memory effect. The wire has smooth surface and uniform diameter along the fiber (Fig. S1 in Supplementary data). Polyurethane coating on Ni-Ti fiber was conducted using a home-built fiber twisting system (Fig. S2a in Supplementary data). Three polyurethane fibers were twisted and covered around the Ni-Ti fiber, then this assembly of the threads was instantly heated to 150 °C to fix their structure (Fig. S2b in Supplementary data). Cross-sectional view of the assembled strand was shown in Fig. S2c of Supplementary data, where their twisted structure did not unspool and polyurethane fibers strongly adhered to the Ni-Ti alloy fiber. The area where two strands cross each other is a metal-insulator-metal (MIM) structure that behaves as a capacitor according to the distance between two strands, as shown in Fig. 2b.

The textile pressure sensor arrays were connected to an Arduino Uno which has an ATmega328P as a microcontroller to measure pressure. It operates with 5 V power and has six analog-to-digital channels (ADC) that have 10-bit resolution. Signal delivery from the sensor to a PC was conducted via serial communication. Then, the transmitted signals were analyzed to create an algorithm that senses the sitting posture in window programming. We created an application that can distinguish the posture according to the pressure difference between the user's hips and thighs. The postures we distinguish are of seven types: standing, upright sitting, sitting with one leg crossed, and sitting with both legs lifted, leaning back to the left, leaning back to the right, and slouching in chair.

3. Characteristics of textile pressure sensors

Pressure-sensor-embedded fabric was fabricated by weaving pressure sensitive Ni-Ti alloy fibers with knitting wool, as shown in Fig. 2a. The capacitance of the dielectric material sandwiched between two electrodes can be varied by the thickness d of the dielectric material, as in the following equation: $C=\varepsilon(A/d)=\varepsilon_0\varepsilon_r(A/d)$, where ε_0 is the permittivity in a vacuum, ε_r is the relative permittivity of the dielectric material, and A is the effective area of the electrode. Polyurethane is a representative elastomer with 100 MPa of elastic modulus, so it can easily deform and recover by applied stress. When pressure is applied to the crossed point of the polyurethane-coated Ni-Ti fibers, a decrease in the thickness of the polyurethane layer results in an increased capacitance signal. In order to fabricate the highly durable textile pressure sensors, 90 μm-thick Ni-Ti alloy fiber, which has a shape-memory effect, was utilized. Typically, copper (Cu) or silver (Ag) fibers were utilized as a conducting thread for electronic textile applications [10,14]. However, such common metals undergo deformation by slips in dislocations, which is an irreversible process. Therefore,

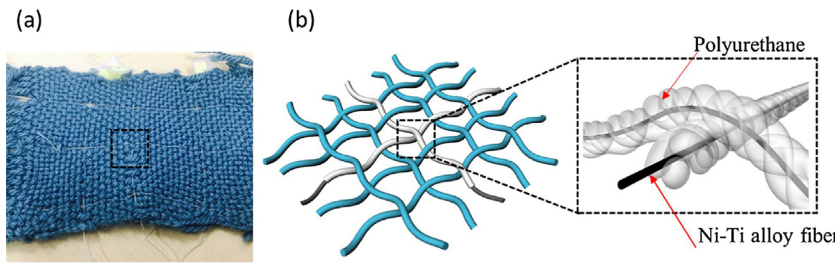

Fig. 2. (a) Photograph of pressure sensor arrays embedded into woven textile. (b) Schematic illustration of textile pressure sensor based on Ni-Ti alloy fiber coated with polyurethane rubber.

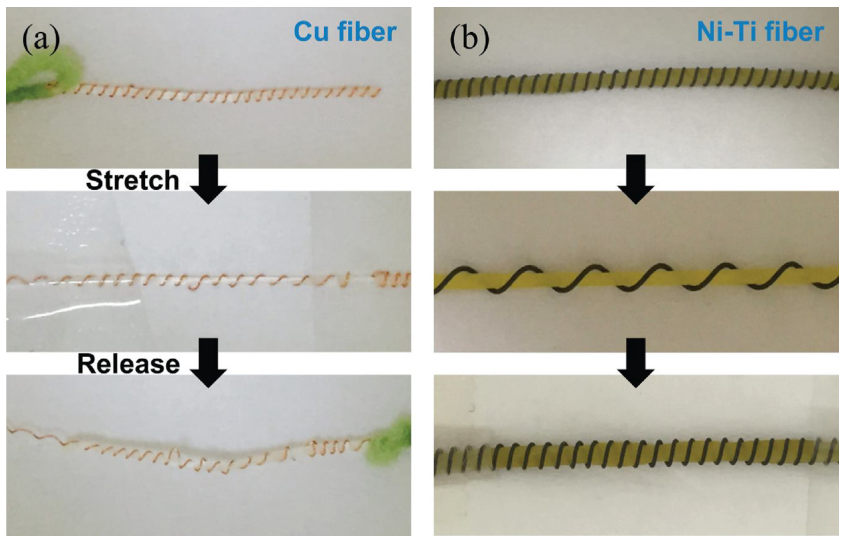

Fig. 3. Photographs for (a) Cu fiber after repetitive stretching and releasing for five times, and (b) Ni-Ti alloy fiber after repetitive stretching and releasing for 100 times.

work hardening occurs owing to the multiplication of dislocations, which results in fatigue failure. By contrast, a Ni-Ti shape memory alloy is deformed by the reversible movement of twin boundaries of martensite at below Austenite finish temperature (Af) [15]. Thus, there are no microstructure changes even after many instances of deformation. Motivated by this point, we anticipate that Ni-Ti alloy fiber with Af of 70 °C has an excellent fatigue resistance and no occurrence of work hardening under repetitive deformation at room temperature. To clarify the fatigue resistance of the Ni-Ti shape memory alloy fiber, the fibers were repetitively bent and unbent with a diameter of curvature of 24 mm at room temperature. As a result, we confirmed that the Ni-Ti alloy fiber did not experience fatigue failure, even after deformation of 10,000 times. Additionally, Fig. 3 shows a comparison of the reversibility of Cu and Ni-Ti fibers under repetitive stretching deformation. The samples were prepared by wrapping Cu or Ni-Ti fiber coil in an elastic rubber, in which the fiber coils are deformed together with the elastic rubbers. When the copper coil was repetitively stretched and released five times, the Cu coil did not return to the original shape with some kinks (Fig. 3a). By contrast, in the case of the Ni-Ti coil, it perfectly returned to its original shape even after 100 times of deformation without any kinks. This is due to its excellent fatigue resistance because the Ni-Ti alloy fiber did not show superelastic behavior below 70 °C (Fig. 3b).

For electrical conductivity, the resistance of Ni-Ti fiber was about 170 ohm/m, which was somewhat higher than the resistance of conventional silver-coated conducting threads (120 ohm/m). However, the conductance of Ni-Ti fibers is unchanged even after repetitive deformation tests, as mentioned above, and a washing process involving dipping in detergent-dissolved water, mechanical rubbing, rinsing with water, and drying steps. Regarding the conducting threads with multifilament yarn coated with silver, it is known that their resistance tends to increase after a washing process [14]. These results imply that Ni-Ti fibers can be utilized as a highly reliable and washable conducting fibers for electronic textile applications.

Fig. 4a shows the capacitance change of the unit pressure sensor embedded in the fabric by varying the applied pressure. The pressure sensitivity, defined as $(\Delta C/C_0)/\Delta P$, where P denotes the applied pressure, and C and C_0 denote the capacitance with and without an applied pressure, respectively, was estimated based on the slope of the trace shown in Fig. 4a. The capacitance of the textile-embedded sensor increases in a linear relationship to the applied pressure in a range from 10 to 180 kPa with a sensitivity of 2.39 kPa^{-1}. In order to check whether there is any abnormality in the performance of the sensor, the sensor was placed on a flat surface and a subject weighing 46 kg repeated the action of sitting and standing 1000 times. In the Fig. 4b, as a result, the difference in capacitance between when the force was applied (sitting) and not applied (standing) was maintained at approximately 1 pF. The textile pressure sensor made of Ni-Ti had strong durability and was not easily damaged by repetitive bending or pressing. As a preliminary test, the capacitance changes in unit according to the different sitting postures were investigated for the sensors located under the right hip of the subject. As shown in Fig. 4c, the capacitance value of the unit device placed under left hip was distinguishably varied according to the different sitting postures. Dramatic increment and recover to the original value was induced by the sitting (1) and standing up (2) motion. When a subject crossed his right leg over the left leg (3), a higher capacitance than that obtained

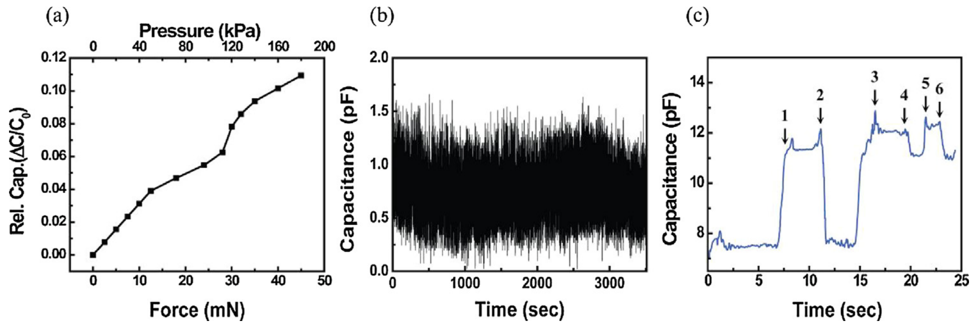

Fig. 4. (a) Capacitance change of the unit pressure sensor embedded in the textile as a function of applied pressure. (b) Real-time capacitance signal of textile pressure sensors under 1000-times repetitive loading (sitting) and unloading (standing) cycle. (c) Capacitance of textile pressure sensors located under left hip of subject when subject changes posture in following order: 1 – upright sitting, 2 – standing, 3 – sitting with right leg crossed over left leg, 4 – upright sitting, 5 – sitting with both legs lifted, 6 – upright sitting.

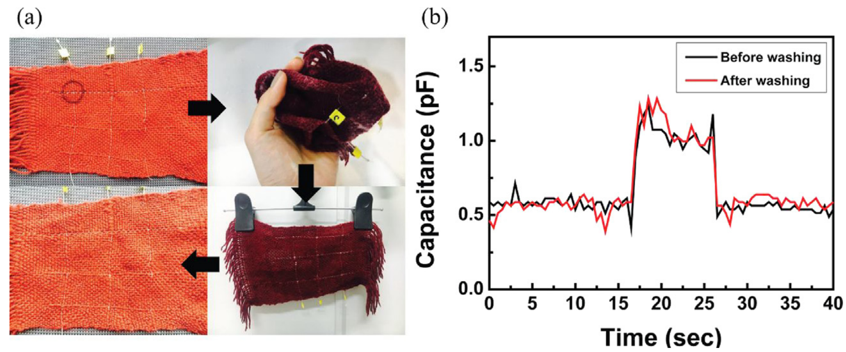

Fig. 5. (a) Pictures showing washing process of textile pressure sensors. Black circle mark drawn with water-based pen was removed after thorough rinsing in water and strong rubbing. (b) Comparison of capacitance change of the textile pressure sensor with sitting motion before and after washing.

from upright sitting posture was observed owing to a left shift of the center of the body mass. Then, when a subject corrected his posture to the upright sitting (4), the capacitance value recovered to the value of the first upright sitting. When a subject lifted both legs (5), the highest capacitance was observed. These results indicate that the proposed textile pressure sensors are sensitive when distinguishing the different sitting postures.

To test the washability of the textile pressure sensors based on Ni-Ti alloy fibers, the changes in the capacitance of the sensor before and after the washing process were compared. The textile sensor was marked as a circle with a water-based pen. To remove the circle mark, the fabric was dipped in detergent-dispersed water and thoroughly rubbed by hand, and then rinsed with water and naturally dried (Fig. 5a). Fig. 5b shows the capacitance change when the subject sits on the textile pressure sensor. Even after a harsh washing process, an identical signal for the sitting pressure was observed. It confirms that the textile pressure sensor based on the Ni-Ti alloy fiber coated with PU elastomer has washing resistance, which is a requirement for practical use.

Fig. 6 shows the change in capacitance obtained from the textile pressure sensor arrays according to various types of sitting. Fig. 6a shows the result obtained from the hip (LH), the upper part of thigh (LT1), and the lower part of the thigh (LT2) on the left side. The measurement was initiated in under a no-pressure condition. When the subject sat in the chair for about 10 s (1), each value in the active area increased by more than 0.5 pF. When the right leg was crossed over the left leg (2), the capacitances at LH, LT1, and LT2 increased at the same time. When returning to the upright sitting position (3), the measured capacitance value became similar to the value of the first upright sitting. In the case of crossing the left leg over the right leg (4), pressure was not applied to the three areas of the left side (LH, LT1, and LT2), so it was measured as similar to the standing position. The capacitance values increased again as high as first sitting when returning to the upright sitting (5). When sitting with both legs lifted, the hip position LH had an increased capacitance value compared with that of the upright sitting (6), while the values of LT1 and LT2, where no pressure was applied, decreased. When returning to the upright sitting position (7), the capacitance values recovered to the values of the upright sitting again. As the subject stood up (8), all of the capacitance values on the left side decreased to a level similar to the standing position.

Fig. 6b shows the results simultaneously obtained from the sensors on the right side. A similar tendency in capacitance changes was observed according to the sitting posture change. In contrast to the left-side sensors, when the right leg was placed over the left leg (2), the pressure was not applied to the measurement areas of the right side so that the value decreased similarly to the standing position. In the posture of sitting with the left leg placed over the right leg (4), the force applied to the right side increased so that the capacitance values also increased by more than 0.5 pF in all three measuring parts. Sitting with both legs lifted (6) resulted in a higher capacitance value in the RH region than those of regions RT1 and RT2. As the subject stood up, the capacitance values of all regions returned to the initial capacitance values obtained in the standing position.

Next, in order to detect the sitting postures of leaning and slouching, pressure sensing at a subject's back was demonstrated by using textile pressure sensor arrays. Fig. S3 in Supplementary data shows the photographs of the textile pressure sensor arrays attached on the backrest of the chair and the leaning and slouching postures of the subject. Fig. 7a shows the result obtained from the sensors located at the upper (LB-U) and the lower part (LB-L) of the back on the left side. When the subject sat upright on the chair, at this time the back touched the backrest of the chair (1). So both upper and lower parts of the sensors were pressed by the back and the capacitance value increased. When the subject leaned

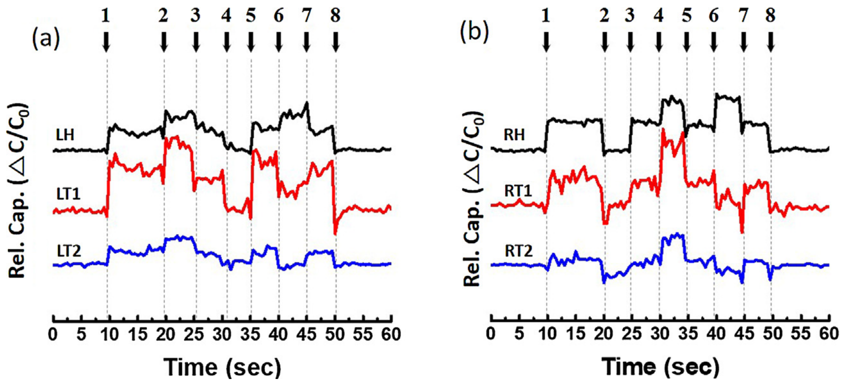

Fig. 6. Change in relative capacitance of textile pressure sensor array obtained from (a) left and (b) right side of sitting cushion according to various sitting postures; 1-upright sitting, 2-right leg crossed over left leg, 3- upright sitting, 4- left leg crossed over right leg, 5- upright sitting, 6- sitting with both legs lifted, 7- upright sitting, and 8- back to standing position.

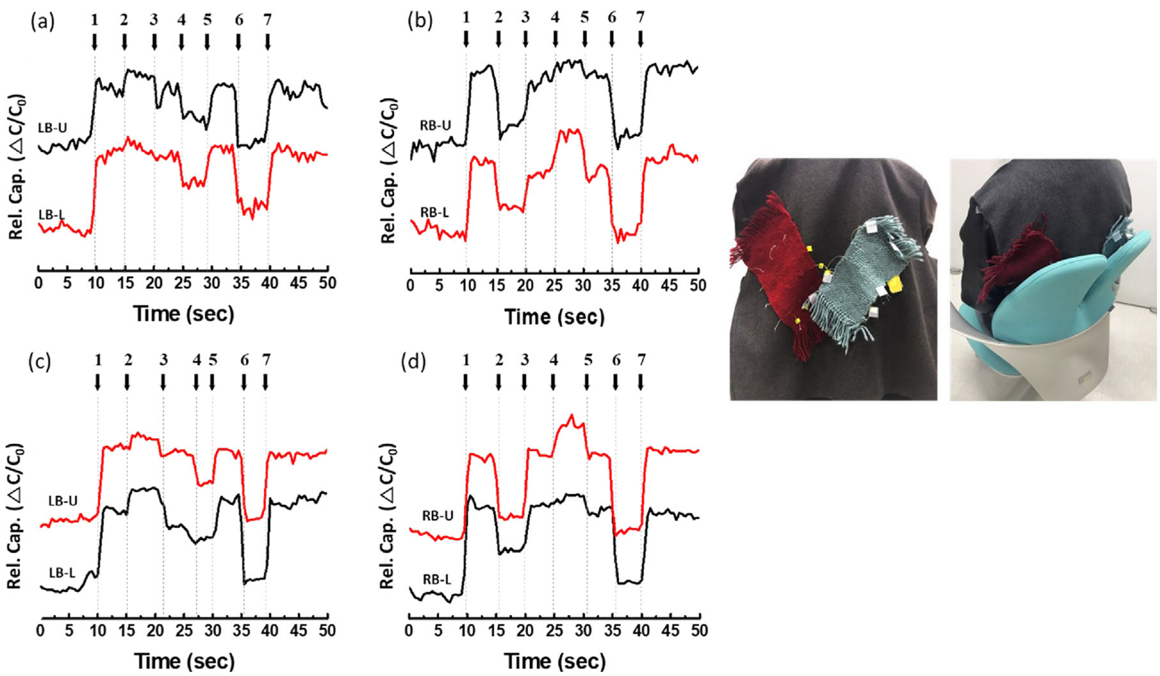

Fig. 7. Change in relative capacitance of textile pressure sensor array attached on (a) left and (b) right side backrest of the chair according to various sitting postures; 1-upright sitting, 2- leaning back to the left, 3-upright sitting, 4- leaning back to the right, 5- upright sitting, 6- slouching, 7- upright sitting. Change in relative capacitance of textile pressure sensor arrays sewn on (c) left and (d) right backside of the subject's vest according to the various sitting postures. Changes in sitting postures was same as above. Photographs of the textile pressure sensors attached on the backside of the vest was shown next to the sensor signal results.

back to the left, the pressure was applied more to LB-U, resulting to the higher capacitance value than that measured at upright sitting (2). When returning to the upright sitting position (3), similar capacitance value to that of the first upright sitting was detected. In the case of leaning back to the right (4), the pressure applied to the sensors was reduced at both upper and lower part of left back, so the capacitance values decreased. The capacitance values recovered to the value as high as first sitting when returning to the upright sitting (5). When the subject slouched in a chair (6), the back did not touch the backrest of the chair so that the capacitance decreased down to the initial capacitance values obtained in the standing position. Upright sitting returned the capacitance value of the upright sitting (7).

Fig. 7b shows the results simultaneously obtained from the sensors positioned at the upper (RB-U) and the lower part (RB-L) of the back on the right side of the back. In contrast to the left-side sensors, when the subject leaned back to the left (2), the pressure was not applied to the measurement areas of the right side so that the value decreased similarly to the standing position. In the posture of leaning back to the right (4), the force applied to the right side increased so that the capacitance values increased more than the value obtained at upright sitting position. These results clearly showed that the proposed textile pressure sensors and the designed algorithm were applicable to distinguish and monitor the sitting posture in real time.

In addition, to further demonstrate the feasibility of the textile pressure sensors as a wearable electronic devices, the sensors were sewn on the backside of the subject's vest and detection of pressure changes according to the leaning and slouching postures were tested. As shown in Fig. 7c and d, trends of capacitance changes in wearable textile sensor arrays were almost similar to the results obtained from the sensors attached on the backrest of the chair according to the shift of different sitting postures. This result clearly shows that the proposed textile pressure sensors can be applicable to human body interactive wearable devices.

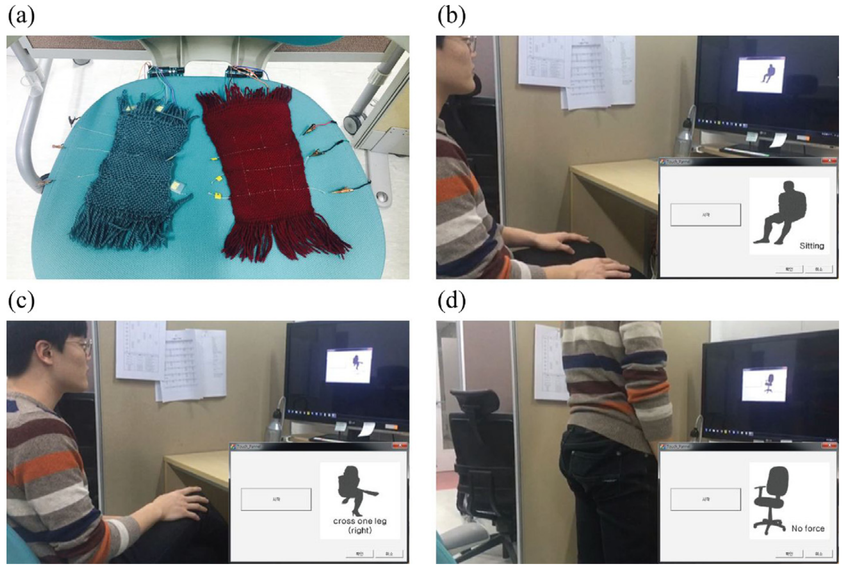

Fig. 8. Photographs of demonstration of sitting posture correction system: (a) textile pressure sensors and connection with Arduino unit attached to chair. Different postures were displayed on computer monitor in real time according to changes in postures from (b) sitting (c) crossing the leg, and (d) standing.

4. Real-time sitting posture correction system

In order to avoid crosstalk, signals obtained from diagonally positioned three (or two in the case of the sensing from the back) sensors in the sensor arrays were collected. As following circuit, the chosen pressure-sensitive capacitors were connected with Aruduino Uno microcontroller which is used as an interface between sensors and PC by serial communication. We made a simple circuit which consists of Arduino Uno and textile sensors and wrote a code for capacitance meter so that Arduino Uno can detect the capacitance values of each chosen capacitor. As shown in Fig. S3 in Supplementary data, 6 analog input channels of Arduino are connected with three capacitors (C1, C2 and C3) located diagonally in an array. In this system, relative capacitance variation was estimated from the change of the time constant of the RC circuit according to the applied pressure. The time constant defined as the product of the resistance and capacitance, in fact, is proportional to the capacitance since the resistance of the circuit does not change. A decision algorithm is performed based on the errors of capacitance values between the left and right sides of each measurement region. First, we have to reduce fluctuations of signals generated on measured area and remove noise. In previous literature, Huang et al. succeeded in eliminating noise from signals of sensitive force sensors by adopting a noise filter and simplifying signal analysis [16]. They filtered signals only above the reference value; those signals were 0 otherwise. After that, filtered signals were converted into binary values over time. However, we need weighted values based on differing strengths applied to the hips to distinguish the posture of crossed legs or lifted legs. Therefore, we fixed two reference values of variation for each sensor, and converted the values into 0, 1, or 2. We set the lower reference variation value when it had an error over 15%, and higher when it had an error over 22% as compared with the initial value of no force at the hip position. Each error range was determined as result of measurement. Other positions of active areas were processed in a similar way but for different error ranges. Through the application program we developed, a group of simplified values as detected and converted in this way was matched to a combination of ideal values required for each sitting posture.

Finally, the sitting posture detection/correction program was simulated as shown in Fig. 8. The textile pressure sensors detect the signals caused by changing postures and the values are analyzed by the proposed classification algorithm. In the list of the recognized postures, one posture that is related to an actual posture was determined and displayed the posture type on a computer monitor. The simulation results clearly show that the proposed sensor system is highly useful in the real-time monitoring and self-awareness of incorrect sitting postures.

5. Conclusions

A highly durable and washable textile pressure sensor was simply fabricated by weaving polyurethane-coated Ni-Ti alloy fibers. It was confirmed that even after 1000 times of repeated sit-down measurements and washing with detergent, the performance of the textile pressure sensor was perfectly maintained. We developed measurement of sitting pressures from a woven fabric pressure sensor arrays which were directly contacted the surface of the hips, thighs, and back of a chair. Posture imbalance was successfully analyzed through the information of the left and right unbalanced states.

The in-situ sitting posture detection/correction program was successfully simulated. It is expected that when the sensor is made into a large cushion or a single chair, the system will provide more convenience to the users who need to sit and work for a long time

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi: https://doi.org/10.1016/j.sna.2017.11.054

References

[1] S. Reinecke, R. Hazard, K. Coleman, M. Pope, A continuous passive lumbar motion device to relieve back pain in prolonged sitting, in: Advances in Industrial Ergonomics and Safety IV, Taylor and Francis, London, 2002, pp. 971–976.

[2] D.D. Harrison, S.O. Harrison, A.C. Croft, D.E. Harrison, S.J. Troyanovich, Sitting biomechanics part I: review of the literature, J. Manip. Physiol. Ther. 22 (1999) 594–609.

[3] A.P. Claus, J.A. Hides, G.L. Moseley, P.W. Hodges, Thoracic and lumbar posture behaviour in sitting tasks and standing: progressing the biomechanics from observations to measurements, Appl. Ergon. 53 (2016) 161–168.

[4] I.Y. Cho, S.Y. Park, J.H. Park, T.K. Kim, T.W. Jung, H.M. Lee, The effect of standing and different sitting positions on lumbar lordosis: radiographic study of 30 healthy volunteers, Asian Spine J. 9 (2015) 762–769.

[5] C.-F. Juang, C.-M. Chang, Human body posture classification by a neural fuzzy network and home care system application, IEEE Trans. Syst. Man Cybern. Part A Syst. Hum. 37 (2007) 984–994.

[6] R. Cucchiara, C. Grana, A. Prati, R. Vezzani, Probabilistic posture classification for human-behavior analysis, IEEE Trans. Syst. Man Cybern. Part A Syst. Hum. 35 (2005) 42–54.

[7] Y. Zheng, J.B. Morrell, A vibrotactile feedback approach to posture guidance, IEEE, Haptics Symposium, 2010 IEEE (2010) 351–358.

[8] K. Kamiya, M. Kudo, H. Nonaka, J. Toyama, Sitting posture analysis by pressure sensors, IEEE, Pattern Recognition, 2008 ICPR 2008 19th International Conference on (2008) 1–4.

[9] B.W. Lee, H. Shin, Feasibility study of sitting posture monitoring based on piezoresistive conductive film-based flexible force sensor, IEEE Sens. J. 16 (2016) 15–16.

[10] M. Shimojo, A. Namiki, M. Ishikawa, R. Makino, K. Mabuchi, A tactile sensor sheet using pressure conductive rubber with electrical-wires stitched method, IEEE Sens. J. 4 (2004) 589–596.

[11] W. Xu, M.-C. Huang, N. Amini, L. He, M. Sarrafzadeh, Ecushion: A textile pressure sensor array design and calibration for sitting posture analysis, IEEE Sens. J. 13 (2013) 3926–3934.

[12] J. Lee, H. Kwon, J. Seo, S. Shin, J.H. Koo, C. Pang, et al., Conductive fiber-based ultrasensitive textile pressure sensor for wearable electronics, Adv. Mater. 27 (2015) 2433–2439.

[13] Y. Wang, T. Hua, B. Zhu, Q. Li, W. Yi, X. Tao, Novel fabric pressure sensors: design, fabrication, and characterization, Smart Mater. Struct. 20 (2011) 065015.

[14] J. Meyer, B. Arnrich, J. Schumm, G. Troster, Design and modeling of a textile pressure sensor for sitting posture classification, IEEE Sens. J. 10 (2010) 1391–1398.

[15] C. Wayman, T. Duerig, An introduction to martensite and shape memory, in: Engineering Aspects of Shape Memory Alloys, Butterworth-Heinemann, UK), 1990, pp. 3–20.

[16] Y.-R. Huang, X.-F. Ouyang, Sitting posture detection and recognition using force sensor, IEEE, 2012 5th International Conference on Biomedical Engineering and Informatics (BMEI) (2012) 1117–1121.

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Jinwoo Park received his B.S. in electronics engineering from Korea University in 1979 and his Ph.D. degree in electrical engineering from Virginia Tech in 1987. He is currently a professor with the School of Electrical Engineering at Korea University. His research interests are mobile service management in integrated wireless and wired networks, context-aware networking, content delivery networks, and software-defined networking.

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Min-Chul Park received the Ph.D. degree in information and communication engineering from Tokyo University in 2000. He was an Associate Professor at Tokyo University of Science in 2005 and a Visiting Researcher to Qualcomm in 2009. He is currently a Principal Research Scientist at Korea Institute of Science and Technology, Seoul, Korea and a Professor at KIST School. His research focuses on 3D image processing, 3D human factors, and HCI.

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