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Efficient Placement of Pressure Sensors of a Sitting Cushion Stitched by Conductive Thread for Sitting Position

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***Abstract*— In this paper, efficient placement of pressure sensors is tested for correct posture under sitting cushion using conductive thread to connect the pressure sensors. Conductive thread Ada-641 from the Adafruit industries is used to connect sensors for the sitting cushion. In order to detect the correct sitting postures, an Arduino-based cushion seat with 16 pressure sensors is implemented. A conductive thread connects the sensors to accommodate the comfort of the sitting cushion. In order to test the efficient placement of the pressure sensors, several types of sensor locations are suggested to identify sitting postures. The least number of sensors included for a given type of pressure sensor location is four. Sitting posture detection with 8 and 12 sensors is also tested. The maximum number of sensors included in the experiment is 16. The efficient placement of the sensors is decided by comparing the detection probability of the correct sitting posture for a different number of sensors included in the sitting posture test. It is shown that the correct sitting posture can be detected 100% by using 8 sensors out of 16 sensors. The test results show a guideline for the minimum number of sensors required for reliable, correct posture detection. It is also shown that the performance of the sitting cushion with conductive thread type sensors is as good as the one with the copper wire connection.**

***Keywords*— Conductive thread; pressure sensor; sitting positions.**

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I. INTRODUCTION

Recently, the unified services that provide meaningful health-related data come from various personal devices that emerge to provide health care issues. By spending long hours on the computer with a bent neck and wrong sitting posture can cause chronic skeletal disease. Also, the office workers face more than twice as much spinal disease as the labor workers. The sitting position carries at least three times more load compared to the standing position and seven times more than the lying position. Therefore, the correct sitting position is critically important to a sedentary lifestyle.

Numerous research results recognize sitting postures. A non-wearable sitting cushion with 6 by 6 arrays of pressure sensors has been proposed [1]. The weight load vector is used to analyze the sitting posture. In order to differentiate between the proper sitting posture and improper sitting posture, the 7 senor locations have been proposed [2]. The sensors are placed not only on the bottom but also on the backside of the chair. The machine learning is used to monitor the 9 different sitting postures [3], the Arduino Nano with Wi-Fi transmitter is used in the research. An unconstraint sitting posture monitoring method using a sensitive cushion based on hetero-core fiber optics has been proposed [4]. The advantages of fiber optics, such as single-mode transmission usage, flexibility, and lightweight, are utilized in the proposed research. An IntelliChair has been proposed [5]. The proposed system can discover sitting patterns and predict subsequent activities. The connection material between the force sensors in the cushions used in some previous studies [1]-[5] is a metal wire.

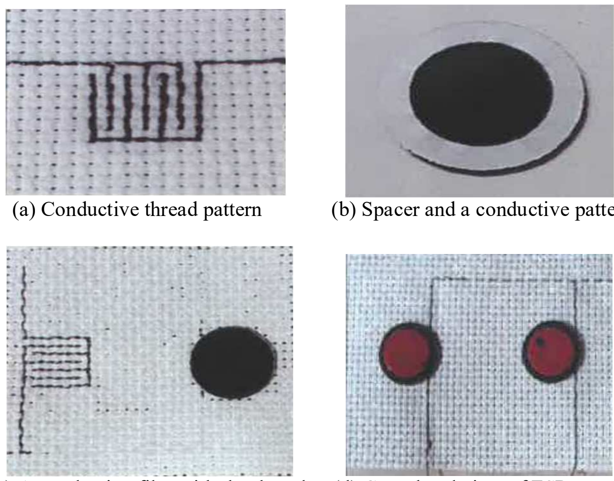
Recently, the conductive thread is emerging as a very promising substitute to copper for various applications that requires flexibility and comfort. Embroidered electrodes for wearable surface electromyography (EMG) is proposed [6]. It is shown that a step-by-step approach to realizing a textile-based surface EMG on the cloth. The conductive thread is used to connect the embroidered electrodes placed inside the sleeve. The comparison of e-threads vs copper wires for electromagnetic applications for a wide range of frequency [7]. It is shown that the transmission lines made of e-thread and copper wire has a good agreement at high frequencies. It is expected that e-textiles can replace copper-wire EM components. A powering scheme for a small wearable device attached to cloth without copper wire connection is proposed [8]. The power transfer device with numerous LEDs is connected with conductive thread. The fabric sheet embroidered with conductive threads can supply power with a capability of the multiplexed on-off control scheme. A power aggregation system that uses small energy harvesting devices on a special cloth embroidered with conductive threads [9], [10]. The power aggregation system is connected from multiple power generation elements to the storage terminal by using conductive thread embroidered fabric. A radiofrequency coil for magnetic resonance imaging application is proposed [11 using conductive thread that is stitched in a zigzag pattern on the athletic fabric to create a single loop receive coil. Conductive thread-based sensors that have the potential to measure body movement and posture are proposed. The conditions of the stitch geometry and physical properties of the threads were examined [12]. A stitched textile-based sensor that measures respiratory rate and monitors breathing pattern is presented [13]. It is shown that a unique pattern stitched into a garment can detect capacitive change. The cyclic capacitance response of the respiration sensor can be used to detect the respiration. Wetness sensing related research are shown in some previous studies [14]-[16] to extract meaningful physiological information. The conductive seamlines detect the presence of fluid by detecting the impedance change. A textile-based sweat detection system is presented in some previous studies [17], [18]. A fully-textile sensor that can simultaneously detect pressure and wetness has been studied [19], [20].

In this paper, a sitting cushion with 16 pressure sensors that are stitched by conductive thread is proposed to identify the types of the sitting posture. Since the force sensors are connected by conductive thread, the sitting cushion has the capability of easy bending and comfort for the people. Thus, the implemented sitting cushion is ergonomically efficient and also cheaper than the conventional cushion with copper wire connections. The final goal of this paper is to find the proper location of the pressure sensors that can efficiently detect the sitting posture. In order to test the efficient location of the sensors, seven types of sensor locations with different numbers of sensors are tested. The least number of the sensors with four and the maximum of 16 are tested to recognize the correct sitting posture to detect the correct sitting posture

II. Material and Method

A. Conductive Thread Type FSR Sensor

As shown in Fig. 1, the conductive thread type FSR sensors are used in the implemented sitting cushion. The thread used in this research is Ada-641 from the Adafruit industries. The structure of the conductive thread type FSR is shown in Fig. 2. The FSR is made of two supporter layers, sensor film, and spacer adhesive. The role of the two supporter layers is to protect the sensor film and to control the sensitivity of the pressure. When the load presses down the sensor film, the sensor film, and the conductive thread contact each other. The sensor's resistance is reduced when the contact between the sensor film and the conductive thread is achieved.



(a) Conductive thread pattern (b) Spacer and a conductive pattern

(c) A conductive film with the thread (d) Completed view of FSR sensor

Fig. 1 Conductive thread FSR sensor pattern and connection

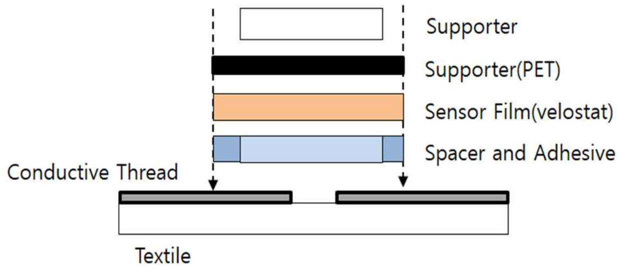


Fig. 2 Structure of the FSR

B. Major Specification of the Posture Detection System

The major specification of the embedded board for posture detection system with conductive thread type FSR system is shown in Table 1. The MCU of an Atmega328 is used for the posture detection system. The block diagram of the implemented posture detection system with the conductive thread FSR type is drawn in Fig. 3. Since the implemented system has 16 pressure sensors, 16 channel MUX(HCT4067) is used to detect the pressure values. As shown in Fig. 4, the cushion stitched by a conductive thread has a smoother surface compared to the conventional sitting cushion with a sensor connected by the wire.

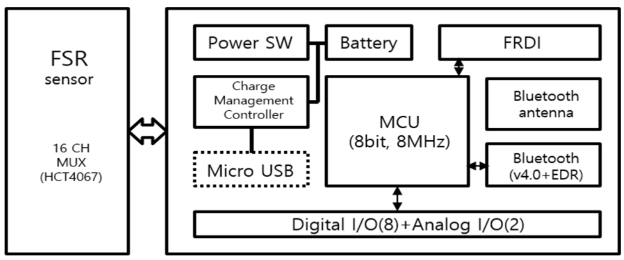


Fig. 3 The block diagram of the implemented posture detection system

TABLE I
MAJOR SPECIFICATION OF THE SYSTEM

Type	Major Specification
MCU	Atmega328
Interface	Digital I/O 8 PIN, ANALOG I/O 2PIN
FTDI Connection	RX, TX, DTR, VCC, GND
Power	3.7V 1 Cell Li-Polymer Battery
Charge function	Micro USB 5PIN
Size (W X H)	20mm x 30mm

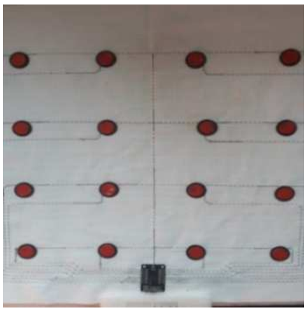
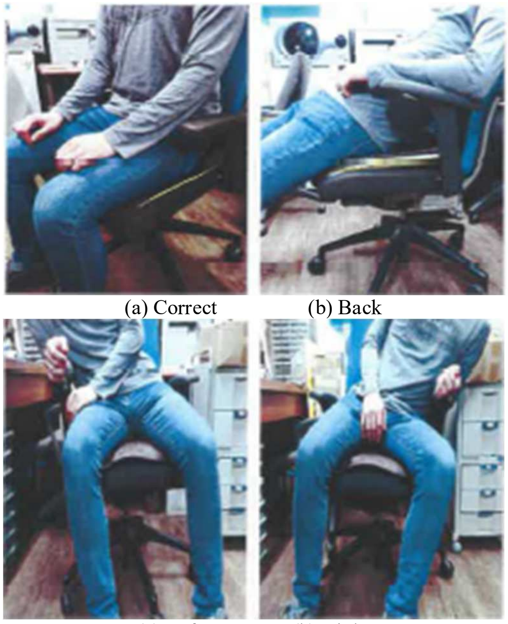


Fig. 4 The implemented posture detection system with conductive thread type FSR sensors

C. Posture Detection Algorithm

The four types of sitting posture are shown in Fig. 5. The four types of the sitting posture are "CORRECT" position, "BACK" position, "LEFT" position and "RIGHT" position. The "CORRECT" position assumes that the person does not lean against the back surface of the chair. Also, the person's posture is vertical toward the surface of the chair such that he does not touch either side of the chair. Therefore, the weight pressure is mainly distributed on the front surface of the chair.



(a) Correct (b) Back

(a) Left (b) Right

Fig. 5 Four types of the sitting postures

The "BACK" posture assumes that the person is leaning against the back of the chair such that the weight pressure is concentrated on the back surface of the chair. Similarly. The "LEFT" and "RIGHT" sitting postures assume that the posture of the person is leaning against the left and right sides of the chair, respectively. Therefore, the weight is tilted toward the left or right side of the chair. The weight pressure will be concentrated on the left or the right side of the sensors.

As shown in Fig. 6, the sensors are labeled as "A" to "P" from the backside of the chair toward the front side of the chair. In order to measure the pressure values of the conductive thread based FSR from the cushion, the sum of the 4 groups of the sensors is defined as shown in Fig. 7. The sum of the pressures from the sensors of A, B, C, D, E, F, G, and H is defined as "UP". As shown in Equation (1) to (4), the "UP", "DOWN", "LT", and "RT" are defined as the sum of the pressure values from the corresponding sensors for the case of the standard-setting sensor location as shown in Fig. 10. Fig. 7 shows the graphical view of the definition of the "UP", "DOWN", "LT" and "RT".

$$UP_{(N)} = \sum(A,B,C,D,E,F,G,H) \tag{1}$$
$$DOWN_{(N)} = \sum(I,J,K,L,M,N,O,P) \tag{2}$$
$$LT_{(N)} = \sum(A,B,E,F,I,J,M,N) \tag{3}$$
$$RT = \sum(C,D,G,H,K,L,O,P) \tag{4}$$

As shown in Fig. 9, the selected location of sensors is used to test the sitting posture by using fewer than 16 sensors for the efficiency of the developed system. For example, the sum of the pressures from the sensors F and G will be defined as "UP" for the case of A1 as shown in Fig. 9 (a) and Equation (5). Similarly, the definition of "DOWN" will be the sum of the pressures from the sensors J, and K. The definitions of "LT are defined as the sum of the pressures from the sensors F and J. The definitions of "RT" is defined as the sum of the pressures from the sensors G and K. The definitions of the "DOWN", "LT", and "RT" for the sensor location type A1 is shown in Equation (6) to (8).

$$UP_{(A1)} = \sum(F,G) \tag{5}$$
$$DOWN_{(A1)} = \sum(J,K) \tag{6}$$
$$LT_{(A1)} = \sum(F,J) \tag{7}$$
$$RT_{(A1)} = \sum(G,K) \tag{8}$$

For the rest cases of sensor locations A2, B1, B2, C1, and C2, the definitions of the "UP", "DOWN", "LT" and "RT" can be modified according to the included sensors of the corresponding location types as indicated in Fig. 9.

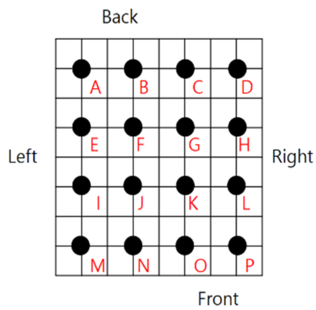


Fig. 6 Location of the 16 sensors of the implemented cushion

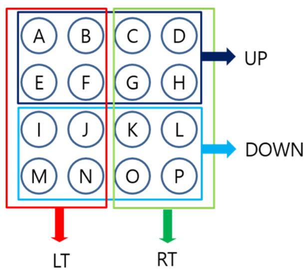


Fig. 7 The definition of the UP, DOWN, LT, and RT

The algorithm to decide one sitting posture out of 4 types of sitting posture is shown in Fig. 8. The algorithm works as follows. The implemented system assumes the sitting posture as "FRONT" when the "UP" value is higher than that of

"DOWN", "LT", and "RT" simultaneously. When the "UP" value the is not higher than the value of "DOWN", "LT", and "RT" simultaneously, the value of "DOWN" is compared with the value of "LT" and "RT". If the value of the "DOWN" is higher than the value of "LT" and "RT" simultaneously, the sitting posture is defined as "BACK". When the value of the "DOWN" is not higher than the value of "LT" and "RT" simultaneously, the value of "RT" is compared with "LT". When the value of the "RT" is higher than "LT", the "RIGHT" sitting posture is declared. Finally, the "LEFT" sitting posture is declared by the algorithm when the value of the "RT" is not higher than the value of "LT".

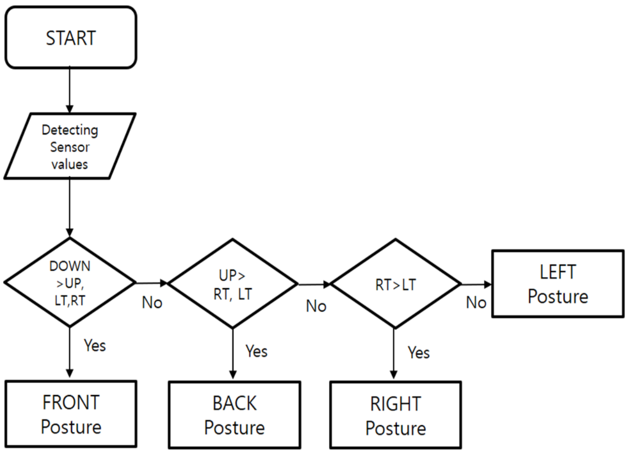
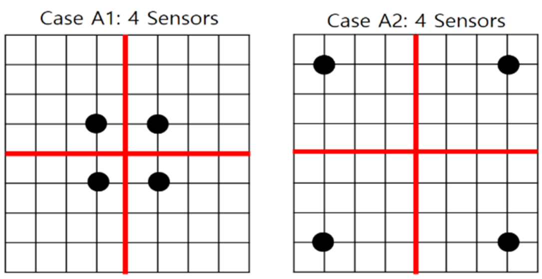


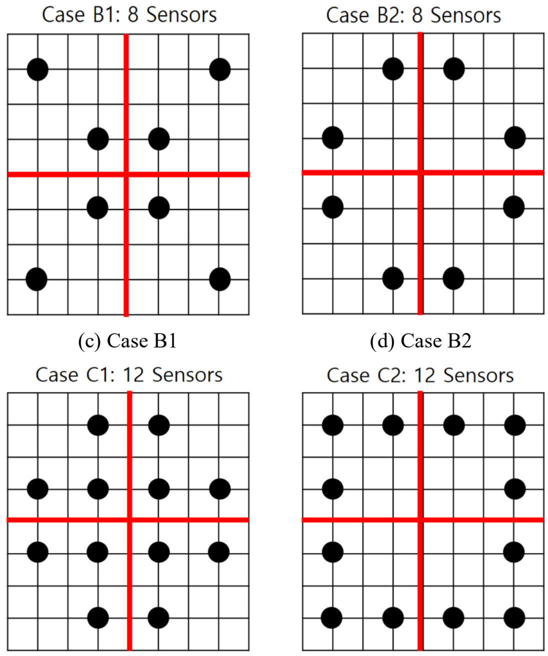
Fig. 8 Sitting posture detection algorithm

D. *Efficient sensor location measurement for sitting posture detection*

In order to find the efficient location of the pressure sensors to determine the sitting posture, the following six cases of pressure sensors are proposed, as shown in Fig. 9. As shown in Fig. 9, the least number of sensors used to measure the pressure is four. The possible locations for the four sensors are represented as A1 and A2. The case of A1 includes sensors located at F, G, J and K, as shown in Fig. 6 (a). For the case of A2, the sensors located at A, D, M, and P are used to measure the pressure to decide the sitting postures. For the case of eight sensors to measure the pressure, sensors located at A, D, E, G, J, K, M and P are included for the case of B1. For the case of B2, sensors located at B, C, D, H, I, L, N, and O are included for pressure measurements. For the case of 12 sensors, cases of C1 and C2 are used. For the case of C1, the sensors located at B, C, E, F, G, H, I, J, K, L, N, and O are utilized to measure the pressures. In the case of C2, the sensors at the edge of the cushion are included, as shown in Fig. 9 (f).



(a) Case A1 (b) Case A2



(c) Case B1 (d) Case B2

(e) Case C1 (f) Case C2

Fig. 9 The six locations of the pressure sensors for measurement

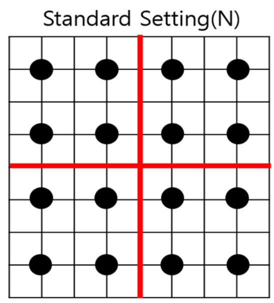


Fig. 10 The standard location of the pressure sensors for measurement

The default setup for 16 pressure sensors is represented as the standard-setting and represented as N, as shown in Fig. 10. The Arduino based sitting posture detection system is shown in Fig. 11. As shown in Fig. 11, the conductive thread-based 16 sensors cushion is connected to the Arduino system through the 16c channel mux to digital input pins. The weight pressure reading from the 16 sensors are tested, and the results are shown in Fig. 12. It is shown that the conductive thread based FSR can efficiently measure the weight pressure. By adapting the conductive thread based FSR, the surface of the cushion is smoother than that of the metal wire connection. Therefore, the developed sitting posture detection system can be considered as somatology efficient and cost-effective.

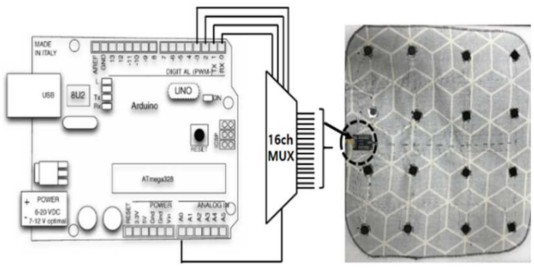


Fig. 11 The Arduino based sitting posture detect system to measure pressure from the conductive thread sensors

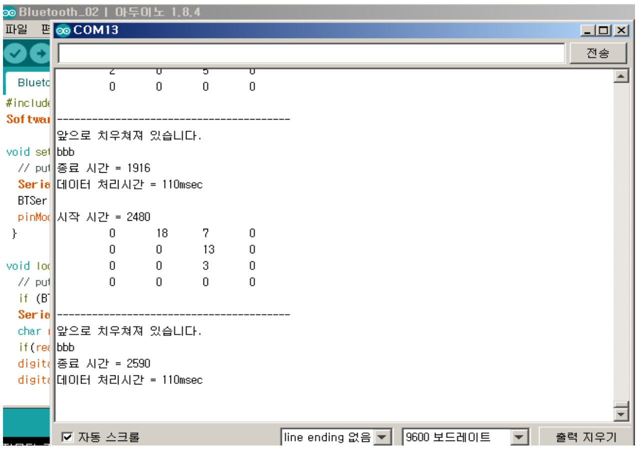


Fig. 12 The measured pressures from the Arduino based posture detect system

III. Results and Discussion

The following tests are performed to measure the effectiveness of the given sensor locations for sitting posture. The implemented sitting cushion measures the weight pressure by inductive thread type FSR. In order to accommodate different weight scenarios, the weight distribution of 5 cases is considered altogether. For the case of the male, three weight cases are considered. For the case of female, two weight cases are considered that weight between 50kg to 60kg and below 50kg. The case M1 represents a man with weight 80Kg and over. The case M2 represents a man with a weight between 60kg and 80 kg. The case M3 represents a man with weight below 60Kg. Similarly, the case W1 represents a woman with a weight between 50Kg and 60Kg. Finally, the case W2 represents a woman with a weight below 50Kg.

As shown in Table II, six different location types of FSR sensors of A1, A2, B1, B2, C1 and C2 are tested for sitting posture detection. For the given weight class and a given sensor location, 100 trials of the sitting posture experiments are performed. Therefore, for a given weight class, a total of 400 sitting posture experiments are performed. That means 100 sitting trials for each sitting posture of LEFT, RIGHT, BACK, and CORRECT posture are tested to detect the given sitting posture. Also, the result of sitting posture for standard sensor location, N, as shown in Fig. 10. The result of the standard sensor location is compared with the result of the rest sensor locations of A1, A2, B1, B2, C1 and C2.

As shown in Table II, the detection probabilities of the CORRECT(C) sitting posture for the case A1 and A2 are 81.4% and 61.4%, respectively. The performance of the correct probability is promising, considering the limited number of sensors to measure the pressures. Moreover, the detection probability of the CORRECT sitting posture for the cases of B1, B2, C1, C2 is higher than 99.2 %. As shown in Fig. 13, the CORRECT detection probability of the sensor location type of B1, B2, C1 and C2 is almost equivalent to the standard type(N). This result means that the least number of sensors to detect the CORRECT sitting posture is 8 sensors out of 16 sensors. The sensor location of B2 showed the highest average probability of sitting posture.

TABLE II
Number of Correct Posture Detection and Probability

Case		M1	M2	M3	W1	W2	SUM	Detection (%)
A1	C	60	100	97	98	52	407	81.4
	L	0	91	0	100	0	191	28.1
	R	96	51	77	100	1	325	65.0
	B	56	100	50	0	0	206	41.2
A2	C	98	100	14	94	0	306	61.2
	L	0	87	2	24	1	114	22.8
	R	45	91	63	2	76	277	45.4
	B	84	99	13	77	0	273	44.6
B1	C	98	100	100	98	100	496	99.2
	L	25	100	6	100	72	303	60.6
	R	86	85	92	100	76	438	87.6
	B	72	100	26	2	0	200	40.0
B2	C	100	100	100	100	100	500	100
	L	0	20	0	57	24	101	20.2
	R	21	100	34	100	94	349	69.8
	B	50	99	13	12	0	174	24.8
C1	C	100	100	100	100	100	500	100
	L	6	60	0	88	73	227	45.4
	R	69	36	61	100	95	361	72.2
	B	67	100	66	4	0	237	45.5
C2	C	100	100	100	100	100	500	100
	L	0	56	0	0	17	73	14.3
	R	35	35	52	100	98	320	64.0
	B	69	100	28	46	0	243	48.6
Standard (N)	C	100	100	100	100	100	500	100
	L	0	79	0	89	54	222	44.4
	R	58	54	70	100	99	381	76.2
	B	74	100	67	12	0	253	50.6

The detection probabilities of the other types of sitting posture except the CORRECT varies from the cases of weight and sensor location. For example, the detection probability of "LEFT" posture varied from the lowest 14.3% to 60.6%. For the case of the "RIGHT" posture detection, the probability is varying from as low as 45.4% to 87.6%.

The main reason for the drastic change in sitting posture detection probability comes from the ambiguity of a person's sitting pattern. Also, collecting uniform test results is not easy since the size of the person is varying drastically. It is not easy to sit on a cushion uniformly from one sitting event to the next sitting event.

As a result, the "CORRECT" sitting posture can be detected almost perfect for the locations of the pressure sensors of B1, B2, C1, C2. The average sitting posture detection probabilities of the sensor location type of B1, B2, C1, and C2 are 71.9%, 53.7%, 65.8% and 56.7%, respectively. Finally, the average sitting posture detection probability of the standard case(N) is given by 67.8%. It is shown that at the sensor location of B1 gives the most promising posture detection probability out of 7 sensor location types.

The detection probability of the left, right and the back sitting posture is shown in Fig. 14. As shown in Fig. 14, the detection probability of the LEFT sitting posture is close to 70% except for the sensor location of A2. The detection probability of the RIGHT and BACK sitting posture is below 50%. According to the different test persons, the poor performance of the detection probability of the sitting posture of LEFT, RIGHT, and BACK posture comes from the incorrect and ambiguous sitting position and weight distribution. The ambiguous sitting position comes from the body size difference of the persons who are participating in the sitting test. Also, there exists a large weight gap between the persons who are participating in the sitting test. The precise sitting position can vary from sitting trails can also cause poor detection probability.

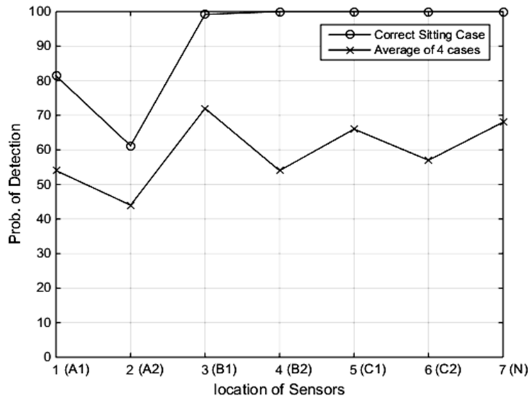


Fig. 13 Probability of correct sitting posture detection for different location of sensors

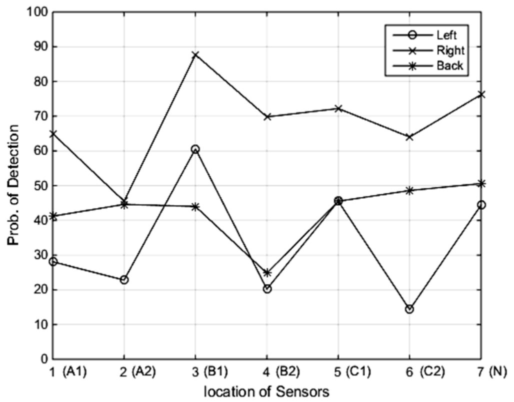


Fig. 14 Probability of Left, Right, and Back sitting posture detection for different location of sensors

IV. CONCLUSIONS

In this paper, a posture detection system with a conductive thread based FSR system is proposed and implemented. Since the implemented system is based on the thread based FSR system, the surface of the sitting cushion is smoother than that with a copper wire connection. Thus, the system is somatology-friendly and cost-effective. Also, the implemented system can detect weight pressure as good as the one with the copper wire-connected system.

In order to test the performance of sitting posture detection, six types of the different sensor locations are tested to compare the probability of correct sitting posture detection. The least number of sensors included for a given location is 4. The sitting posture detection location type with 8, 12 and 16 sensors is tested for comparison. It is shown that the location type B1, which includes 8 sensors, resulted in the highest average detection probability of 71.9%. Also, type B1 could detect the "CORRECT" posture almost correctly with 8 sensors.

The difficulty of the performance measurement in the test is to obtain a uniform sitting environment. Since the weight of the test person varies drastically from 50kg to over 80Kg, an algorithm that gives uniform sitting posture conditions is not easy to find. Also, the size of the test person varies drastically, and the area of pressing the sitting cushion also varies from person to person. Thus, an algorithm that satisfies all the test environments seems impossible. Further research on the test person's various conditions is necessary to find the importance of the sensor locations for the sitting cushion with the conductive thread based FSR.

ACKNOWLEDGMENT

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