Customizable Pressure Sensor Array: Design and Evaluation

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***Abstract*— Pressure senor array is widely used in gait analysis and robotics. To meet the demand on different sizes and reduce the manufacture costs, in this paper, we proposed a design method for customizable pressure sensor array which could be trimmed into different sizes. The customizable pressure sensor array was made of piezo-resistive fabric and flexible circuits, which made it suitable for the sensor array to be trimmed into different sizes. Pressure sensors were uniformly distributed to maintain the resolution of the pressure sensor array when trimmed into different sizes. Wires on the flexible circuits were designed to ensure that all the full/partial sensors remained on the sensor array could be used after trimming the sensor array into a smaller size. To evaluate the design method, we designed insole shaped customizable pressure sensor arrays to analyze gait parameters such as gait cycle and cadence. Spatial and temporal pressure distribution patterns acquired with trimmed and non-trimmed sensor arrays were used for analyzing. Experiment results indicated that the customizable pressure sensor array designed with the method proposed in this paper could be used to acquire spatial and temporal pressure distribution patterns without being influenced by trimming.**

***Index Terms*— Pressure sensor array, trim, customizable, wearable, gait analysis.**

I. Introduction

PRESSURE sensor array is a group of pressure sensors, which usually deployed in a certain geometry pattern, used for recording pressure signals in an area. The advantage of a pressure sensor array over a single pressure sensor is that an array could provide the pressure information of an area with a higher spatial resolution. Pressure sensor arrays nowadays are widely used. For instance, in the field of robotics, to make the robots capable of doing dexterous in-hand manipulation tasks, pressure sensor arrays were used to provide continuous information about the force magnitude and direction at all contact points between robotic hands and the objects they are interacting with [1]. To make the robots sense the touched objects, pressure sensor arrays were also used in artificial skin applications [2]. Pressure sensor arrays also have clinical applications such as the prevention of pressure ulcer. Liu *et al.* [3] proposed a method to automatically monitor the contact pressure between the patient body and bed by using pressure sensor array to help prevent bedsore. In the field of gait analysis, Xu *et al.* [4] used a pair of pressure sensor array worn in shoes to extract important gait parameters like pressure profile, number of steps etc. Cui *et al.* [5] used the plantar pressure signal measured by a pressure sensor array for human balance evaluation. Many other applications also need the pressure signal measured by pressure sensor arrays, such as the risk factors identification for work-related musculoskeletal disorders [6], patient handling activities recognition for at-risk caregivers [7], sitting postures recognition [8], and the fitness testing of prosthetic sockets [9] etc.

In practical applications, there are requirements on different sizes of pressure sensor array. For the sensor array used in robotics, different sizes of pressure sensor array would be necessary for fitting different sizes of robots. For the pressure sensor array used for acquiring plantar pressure distribution patterns, which is an important parameter for gait analysis, tens of different sizes of pressure sensor arrays are necessary to fit different foot sizes. However, using different designs to meet the requirement on different sizes would significantly increase the cost of manufacturing. To reduce the manufacturing cost and meet the requirement on different sizes, designing customizable pressure sensor arrays which could be trimmed into different sizes, is a promising choice.

In this paper, we specified the design method of the customizable pressure sensor array, and detailed the experiments used for evaluating the impact of trimming on the spatial and temporal pressure distribution patterns acquired by the sensor arrays. Contributions of this paper are:

(1) We specified the design method of the customizable pressure sensor array from material selection to circuit design;
(2) We developed an insole shaped customizable pressure sensor array and the corresponding signal processing system for evaluating the design method of the customizable pressure sensor array;
(3) We tested the influence of trimming on the spatial and temporal pressure distribution patterns acquired by the insole shaped customizable pressure sensor array in gait analysis applications.

II. Related Work

As pressure signal is important for research fields like gait analysis and robotics, sensor array, which could provides high

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resolution pressure signals, has become a popular research focus in recent years. In terms of the sensor array structure, there are mainly two kinds of sensor array: one is based on discrete pressure sensors, and the other is based on continuous and consistent pressure sensitive material. Several researches have proposed the sensor arrays consist of discrete pressure sensors. Shu *et al.* [10] proposed a fabric pressure sensor array for in-shoe plantar pressure measurement. Discrete fabric sensors were designed and deployed on six positions at heel and metatarsal areas to form a sensor array. Similarly, Fan *et al.* [11] used four piezo-resistive force sensors to form a sensor array for plantar pressure measurement. The force sensors were attached to the insole areas corresponding to great toe, first metatarsal head, fifth metatarsal head, and center heel. Wertsch *et al.* [12] proposed a pressure sensor array with seven discrete sensors. However, the above pressure sensor arrays were with low resolutions (in this paper, resolution of a pressure sensor array means the number of pressure sensors in a unit area of the pressure sensor array), which make it difficult for them to be used in applications such as abnormal gait diagnosis. Rossi *et al.* [13] proposed a pressure sensor array with a higher resolution. There were 64 pressure sensors deployed on the forefoot and heel areas. However, trimming would damage the sensor structure, then the sensor cannot work as well. Therefore, the sensor arrays based on these sensors are not suitable for trimming.

For the sensor array based on continuous and consistent pressure sensitive material, it is convenient to increase its spatial resolution. There are mainly two design methods: one is with a row-column sensor format, the other is based on a discrete format, which is realized by designing discrete sensors on the continuous material. Tan *et al.* [14] designed a sensor array with row-column sensor format for plantar pressure measurement. Although the piezo-resistive rubber and the electrodes of the sensor array could be trimmed, the circuit wires used for connecting the sensor array with the signal processing circuit would be broken if trimming the sensor array into a smaller size. F-Scan in-shoe analysis system produced by Tekscan® addressed this problem by using a circuit wire routing method to make the row-column sensor format sensor array suitable for trimming [15]. However, the row-column sensor format design has a crosstalk problem between adjacent sensors, which would decrease the performance of the sensor array [16]. Although many researches have been done to address the crosstalk problem [17]–[19], the design complexity and cost of the sensor array will be increased. This might be the reason why the pressure sensor arrays with row-column sensor format are not widely used in applications such as gait analysis. The sensor array design method by designing discrete sensors on consistent material is less affected by the crosstalk problem, and it is widely used at present. Lin *et al.* [20] designed an insole shaped sensor array for unobtrusive gait monitoring in daily life. There were 48 discrete sensors designed on a consistent piezo-resistive fabric material. But routing method of the circuit wires made it not suitable for trimming. To overcome this shortcoming, in the following section, we will specify a customizable design method for the sensor array in discrete format.

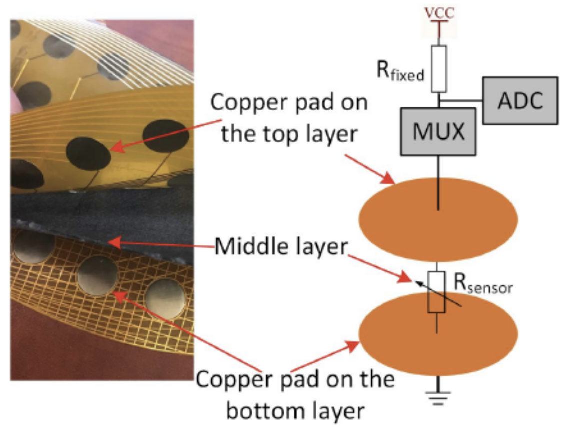

Fig. 1. The mechanism of piezo-resistive pressure sensor array. The figure on the left is a piezo-resistive pressure sensor array that is pulled apart to show its three layers structure. The schematic diagram on the right shows the mechanism of the sensor array.

III. Customizable Design Method

Customizable pressure sensor array consists of continuous and consistent pressure sensitive material and the corresponding circuits, namely Pcircuits in this paper, to construct pressure sensors and to lead out the signal of each pressure sensor. To design a customizable pressure sensor array which could be trimmed into different sizes, special requirements of pressure sensitive material and Pcircuits should be met:

(1) Pressure sensitive material and Pcircuits should be made of trimmable materials. This ensures that the pressure sensor array could be customized into different sizes by trimming;
(2) The pressure sensitive material should be continuous and consistent, which means that pressure sensitivity of the points on the material are similar to each other;
(3) Pcircuits should be designed to make sure that after being cut into different sizes, the sensor array could maintain its original resolution.

A. Pressure Sensitive Material

In this research, a commercial available piezo-resistive fabric material made by EeonTex^{TM} was used for designing the customizable pressure sensor array [21]. Just like normal fabric materials, it is thin (with a thickness of 0.8mm), light weight (with a weight of 170 g/m^2), flexible, and quite easy for trimming. In the “EXPERIMENTS AND RESULTS” section, consistancy of the material was tested.

B. Pcircuits Design

Fig. 1 shows the mechanism of the piezo-resistive pressure sensor array. To show the structure of the pressure sensor array clearly, a customizable pressure sensor array was pulled apart. As shown in the left picture of Fig. 1, it is obvious that the pressure sensor array is with a three layers design. The middle layer is made of piezo-resistive material, resistance of which is not stable but related to the pressure applied on it. Therefore, through measuring resistance of the piezo-resistive material, the force applied on it can be estimated. The mechanism of measuring the resistance of the piezo-resistive material is shown in the schematic diagram on the right. One pressure sensor of the sensor array is taken as an example to show the mechanism. As shown in Fig. 1, a pressure sensor is built with one pair of copper pads distributed on the top and bottom layer respectively, and the piezo-resistive material covered by this pair of copper pads. Piezo-resistive material is modeled as a variable resistor, since its resistance is changed with the pressure applied on it. The copper pad on the bottom layer connects the piezo-resistive material to the ground electronic level, and the copper pad on the top layer connects the piezo-resistive material to the source voltage via a fixed resistor. Then a voltage divider circuit is built and the voltage drop on the pressure sensor can be measured by the Analog to Digital Converter (ADC). Finally, resistance of the pressure sensor could be measured by the following equation:

$$R_{sensor} = \frac{V_{sensor} \cdot R_{fixed}}{V_{cc} - V_{sensor}}$$

where R_{sensor} is the resistance of the piezo-resistive material covered by the pair of copper pads on the top and bottom layer; R_{fixed} is the resistance of the fixed resistor used to build the voltage divider circuit; V_{sensor} is the voltage drop on the pressure sensor, which could be measured by ADC; and V_{cc} is the source voltage of the voltage divider circuit. For a sensor array with tens of sensors, multiplexers are needed to connect all the pressure sensors on the sensor array to ADC. By controlling the multiplexer, all the pressure sensors on the sensor array could be scanned one by one and then a pressure distribution map could be acquired.

Circuit material of the pressure senor array is important for customizable design. Currently, there are mainly two kinds of Printed Circuit Board (PCB): flexible PCB and rigid PCB. For most rigid PCB, FR-4 glass epoxy is used as the laminate material, which is difficult for cutting with simple tools like scissor. For flexible PCB, polyimide is usually used as the laminate material, which is a lightweight and flexible polymer. Since the flexible PCB is also very thin (around 0.15mm), it is convenient to customize its size. Therefore, for the customizable pressure sensor array, the flexible circuit was used to designed the top and bottom layers.

For the Pcircuits layout design, it should meet the following two requirements:

(1) Copper pads on the top and bottom layers of the sensor array should be distributed uniformly. Since the location, shape and size of a pressure sensor are determined by the corresponding copper pads on the top and bottom layers, distributing the copper pads uniformly could make sure that the pressure sensors on the sensor array are uniformly distributed;
(2) Wires should be designed to make sure that all the full/partial sensors remained on the sensor array are connected to the FPC connector after cutting the sensor array into different sizes.

Fig. 2 shows the top layer of a customizable sensor array, which is taken as an example to show the customizable design method. There are 36 pressure sensors uniformly distributed on the square sensor array. To make it convenient for customizing the sensor array and to help designers design appropriate circuit wires, green lines that were used to indicate the outline of two smaller sensor arrays were designed on the sensor array. Trimming the sensor array along the corresponding green lines could customize the sensor array into the desired size. In addition, circuit wires were designed according to the outline of each size, and could ensure that all the sensors remained on the array could be connected with the FPC connector after being customized into a smaller size. To make the wires design more efficient, top layer of the sensor array used two layers FPC design: one layer was mainly used for distributing copper pads (round pads in red color), and the other layer was mainly used for the routing wires (wires in blue color).

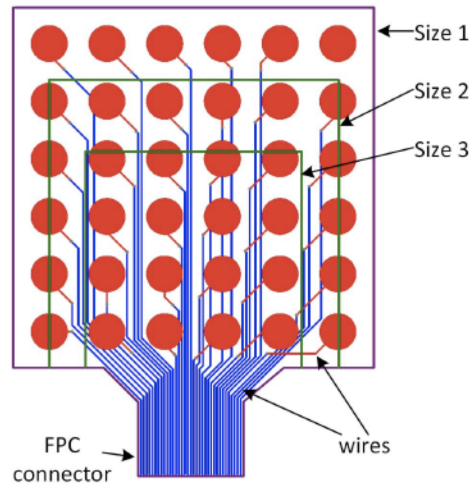

Fig. 2. The top layer of an example design of the customizable pressure sensor array. Green lines indicate the outlines of two smaller sensor array. Circuit wires were designed to make sure that all the remaining sensors could be connected with the FPC connector.

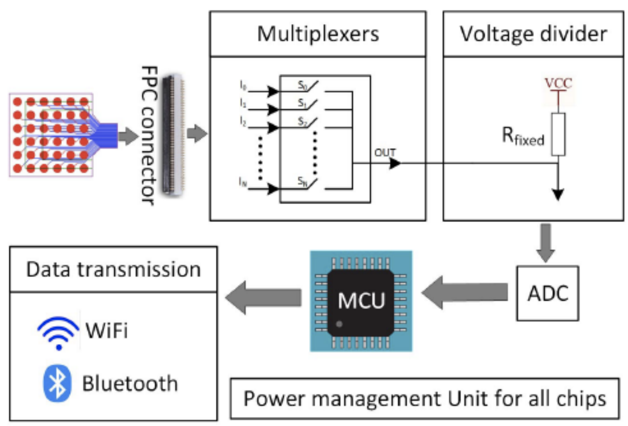

Fig. 3. Architecture of the signal processing circuit.

C. Signal Processing Circuit Design

To measure the sensor resistance and estimate the force applied on it, a signal processing circuit is necessary. Fig. 3 shows the architecture of the signal processing circuit. A FPC

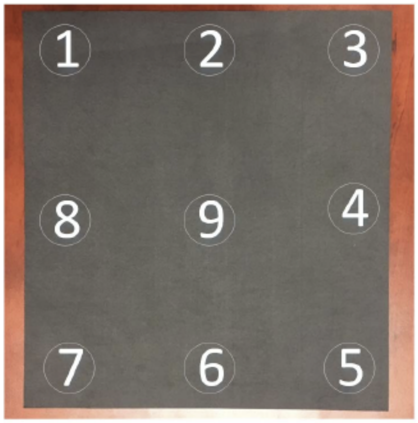

Fig. 4. The consistency test of the piezo-resistive material. The numbers from 1 to 9 indicate the locations of the testing points on the material.

connector was used to connect the pressure sensor array with the signal processing circuit. Multiplexers were used to connect with all the pressure sensors and form a voltage divider circuit by connecting the selected pressure sensor with R_{fixed}, then the voltage drop on the pressure sensor could be digitalized by the ADC. Through controlling the channel selection of the multiplexers, all the pressure sensors on the array could be scanned. The measured data was transmitted through the wireless data transmission unit which consisted of WiFi and Bluetooth. Power management unit was used to supply suitable power to all the components on the circuit. Micro-controller unit (MCU) was used to control the work state of all the function modules.

IV. Experiments and Results

To evaluate the customizable pressure sensor array proposed in this research, two experiments were designed to test: (1) the consistency of the piezo-resistive material; and (2) the influence of trimming on the spatial and temporal pressure distribution patterns acquired by the customizable sensor array.

A. Testing on the Consistency of the Piezo-Resistive Material

In this experiment, a sheet of piezo-resistive material with a dimension of 30.5 × 33 cm was used. As shown in Fig. 4, 9 points on the margin and center areas of the material were randomly selected for testing. A 130Kpa pressure was applied on each test point one by one. The results were shown in table. I. "Variation" was the resistance difference with respect to the mean resistance value of all the nine points. The results showed that there were some differences on the pressure sensitivity between these 9 test points. the largest resistance difference of theses 9 test points was 8.0%. Although the consistency of the material was not perfect, it might be good enough for applications focusing on pressure distribution patterns, rather than accurate pressure values.

B. Testing the Influence of Trimming on the Customizable Pressure Sensor Array

It is well known that sensitivity of a single piezo-resistive pressure sensor is related to the sensor dimension [22]–[24]. Trimming off a part of a pressure sensor would decrease the sensor sensitivity. However, there is few research about the effect of trimming on the sensor array. In this experiment, we focus on the impact of trimming on the spatial and temporal pressure distribution pattern, which is a representative information provided by the pressure sensor array. The procedure of the experiment is shown in Fig. 5. Firstly, insole shaped customizable pressure measurement systems (including sensor array and the corresponding signal processing circuits etc.) were designed for the experiment. Secondly, gait parameters (e.g. gait cycle and cadence) were selected to test the customizable design. Thirdly, the experiment procedure were designed to test the customizable sensor array with gait cycle and cadence. Finally, the impact of trimming on the spatial and temporal pressure distribution patterns acquired by

TABLE I

Results of Consistency Testing

Position number	1	2	3	4	5	6	7	8	9
Resistance(Ω)	50.3	52.0	46.8	50.3	45.9	45.1	48.0	51.8	50.7
Variation(%)	2.7	6.2	4.4	2.7	6.2	8.0	2.0	5.6	3.4

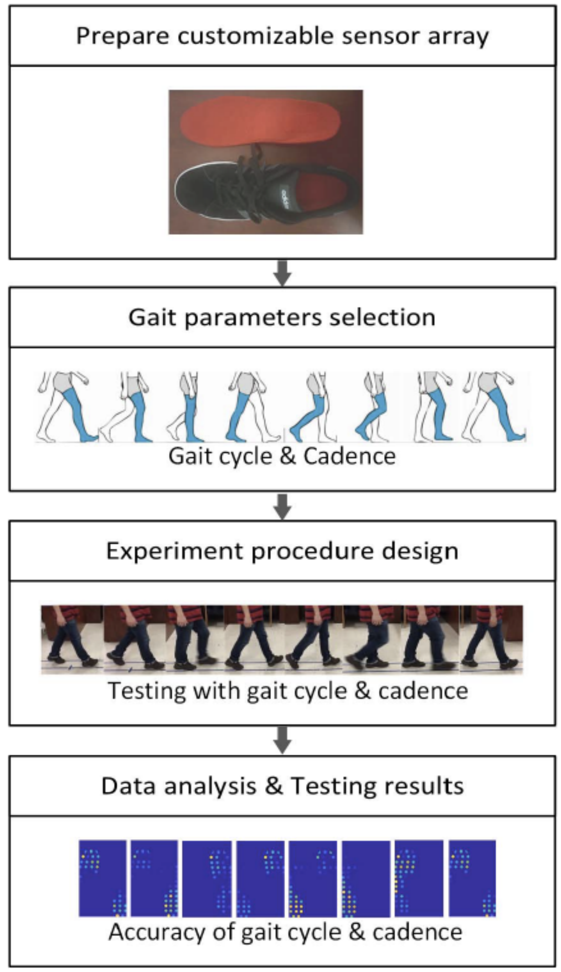

Fig. 5. Flowchart of the experiment about testing the influence of trimming on the customizable pressure sensor array.

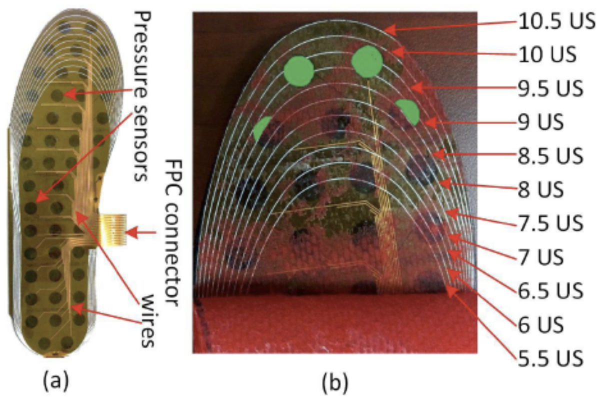

Fig. 6. Insole shaped customizable pressure sensor array. White lines indicate the outlines corresponding to different foot sizes (from 5.5 to 10.5 US). The green areas in subfigure "(b)" indicate the sensor areas that will be cut off if cutting the pressure array into 8.5 US size.

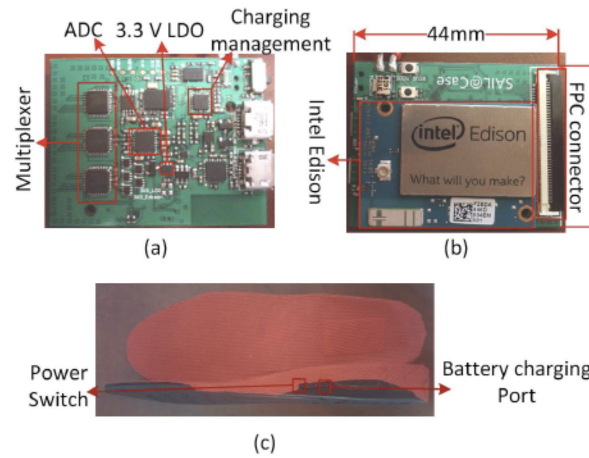

Fig. 7. Both sides of the signal processing circuit and the system prototype.

customizable pressure sensor arrays were analyzed based on the accuracy of the acquired gait cycle and cadence.

1) Insole Shaped Customizable Pressure Measurement System: The insole shaped customizable pressure measurement system consisted of the insole shaped customizable pressure sensor array and the corresponding signal processing system. Fig. 6 shows details of the insole shaped customizable pressure sensor array used in the experiment. As shown in Fig. 6 (b), white lines indicates outlines of different foot sizes (from 5.5 to 10.5 US). When cutting the sensor array along the white lines, parts of several sensors on the edge would be cut off. For instance, when cutting the sensor array into 8.5 US size, green areas, as shown in Fig. 6 (b), indicates the sensor areas that would be cut off. But wires on the sensor array could connect all the full/partial sensors remained on the sensor array to the PFC connector, and ensure the resolution of the sensor array.

Fig. 7 (a) and (b) show the details of signal processing circuit. Three 16 to 1 multiplexers, which have 48 channels in total, were used to connect all the 48 pressure sensors to the voltage divider circuits, then voltage drop on the pressure sensor could be digitalized by 3 ADC channels. Through controlling these three multiplexers, all the 48 pressure sensors could be scanned, and then the plantar pressure distribution map could be acquired. Intel Edison was responsible for wireless communication, data storage and system control. A red LED was used to indicate the working status of the system. Battery charging management unit and the 3.3V low dropout regulator (LDO) were used to manage the power of the system. A fully charged Lithium-ion battery with a capacity of 1000 mAh could power the system for about 5.5 hours. To make it comfortable for wear, the circuit board was designed in a small size (34 × 44 × 6mm), which made it easy to be integrated into a normal insole. Fig. 7 (c) shows the prototype of the customizable plantar pressure measurement system. In this prototype, all the hardware system (i.e. signal processing circuit, customizable pressure sensor array and Li-ion battery) were packed into a normal insole which not only makes it convenient for using, but also helps protect the hardware system from being damaged.

2) Gait Parameters Selection: Two gait parameters: gait cycle and cadence, were selected to evaluate the customizable pressure sensor array. Gait cycle is defined as the time interval between two successive occurrences of one of the repetitive phases of walking [25]. It was subdivided into eight gait phases (as shown in Fig. 8) by the Rancho Los Amigos gait analysis committee [26]. According to the research of Kong and Tomizuka [27], gait phases could be detected based on plantar pressure distribution patterns. But to discriminate these eight gait phases from the plantar pressure distribution patterns only, the pressure sensor array used should be with high resolution and sensitivity to sense the pressure change under foot. Therefore, gait cycle could be a suitable gait parameter for testing whether or not trimming the sensor array into smaller sizes would influence the sensor array performance. Cadence is another gait parameter used for evaluating the customizable design. It is the number of steps taken in a given time (e.g. steps per minute). Cadence could be calculated with step cycle:

$$Cadence(steps/min) = 60/StepCycle(s)$$

where *Step Cycle* is the duration time between the appearance of the same gait phase on both feet. For instance, time duration of the appearance of "initial contact" on the left foot and the next "initial contact" gait phase on the right foot is one step cycle. Since, in our design, trimming mainly influenced the sensors on the forefoot area, the cadence calculated with the "pre-swing" phase of each foot was used to evaluate the customizable design.

3) Experiment Process Design: Two experiments were designed: one was about gait cycle and the other was related to step cadence. For the experiment about gait cycle, two subjects with normal gait were involved. The one with a foot size of 10.5 US used the full size pressure sensor array. The other subject with a foot size of 8.5 US used a smaller pressure sensor array trimmed from the full size array. During the experiments, each subject wear the corresponding pair of insoles for plantar pressure recording. Each subject walked normally for five steps. During the experiment, one camera was used to tape the walking activities, from which eight gait phases of one gait cycle would be extracted. And the other camera was used to record both the activity of the subject and the timestamp of the real-time plantar pressure data. This was used to realize the time synchronization between the taped activity video and plantar pressure data. After time synchronization, the plantar pressure distribution map of each posture in the taped video could be localized.

In the experiment about cadence, five subjects with a foot size of 10.5 US, 10.0 US, 9.5 US, 8.5 US, 6.5 US, respectively, were involved. Each subject wear the corresponding size of insoles and walked in three different cadences: 50, 60 and 70 beat per minute (BMP), respectively. Beep sound was used in the experiment to help the subject walk in the correct cadence. Before each experiment, the subject would walk with the beep sound for three minutes to be adaptive to that walking cadence. During the experiment, the subject would walk for 30 seconds with the beep sound.

4) Data Analysis Method: For gait cycle, firstly, all the eight gait phases were found in the tapped videos according to the standard postures(as shown in the left column of Fig. 8). Then the plantar pressure distribution map corresponding to each gait phase was extracted. To evaluate the plantar pressure distribution map acquired by the customizable sensor array, a standard plantar pressure distribution map of each gait phase is necessary. For normal walking, the standard plantar pressure could be acquired by analyzing the posture in each gait phase [27]. Taking the "Initial contact" phase for example, heel of the shaded foot in Fig. 8 starts to contact the ground. At this gait phase, plantar pressure of the shaded foot should concentrate on the heel area. On the contrary, plantar pressure of the contralateral foot should concentrate on the forefoot area. Finally, through comparing the measured plantar pressure distribution map with the standard plantar pressure distribution map, the performance of the customizable pressure sensor array could be evaluated.

For the experiment about cadence, the step cycle was calculated as the time difference between the "pre-swing" phase of one foot and the successive "pre-swing" phase of the other foot. Since the subject might need time to walk in a stable cadence, 10 successive steps in the middle (from 10s to 20s) of each experiment were used to calculate the mean step cycle and then cadence.

5) Testing Results About Trimmed Sensor Array: Fig. 8 shows eight gait phases of each subject and the corresponding plantar pressure distribution maps. Through comparing the standard plantar pressure distribution map with the pressure map acquired by the customizable pressure sensor array, it is obvious that the pressure distribution maps acquired with trimmed and non-trimmed sensor arrays are both correct for different gait phases. Taking the "Pre-swing" phase for example, only toes of the shaded foot touch the ground, and forefoot and heel of the contralateral foot starts to contact the ground. At this gait phase, there would be a little pressure on the toe area of the shaded foot, while on the contralateral foot, the pressure would be distributed on both forefoot and heel, but more pressure on heel. This is the same as the pressure distribution map acquired with both customizable sensor arrays: there is a little pressure on the right forefoot and a little pressure on the left forefoot, and more pressure is concentrated on the left heel. Table II shows the results of cadence experiment. The results show that all these five sizes of insoles (i.e. 10.5 US, 10.0 US, 9.5 US, 8.5 US, 6.5 US) could acquire cadence with high accuracy. The errors might be caused by the variance of walking cadence when the subjects were doing the experiment. Testing results indicate that trimming has no influence on the spatial and temporal pressure distribution patterns acquired by the customizable pressure sensor array.

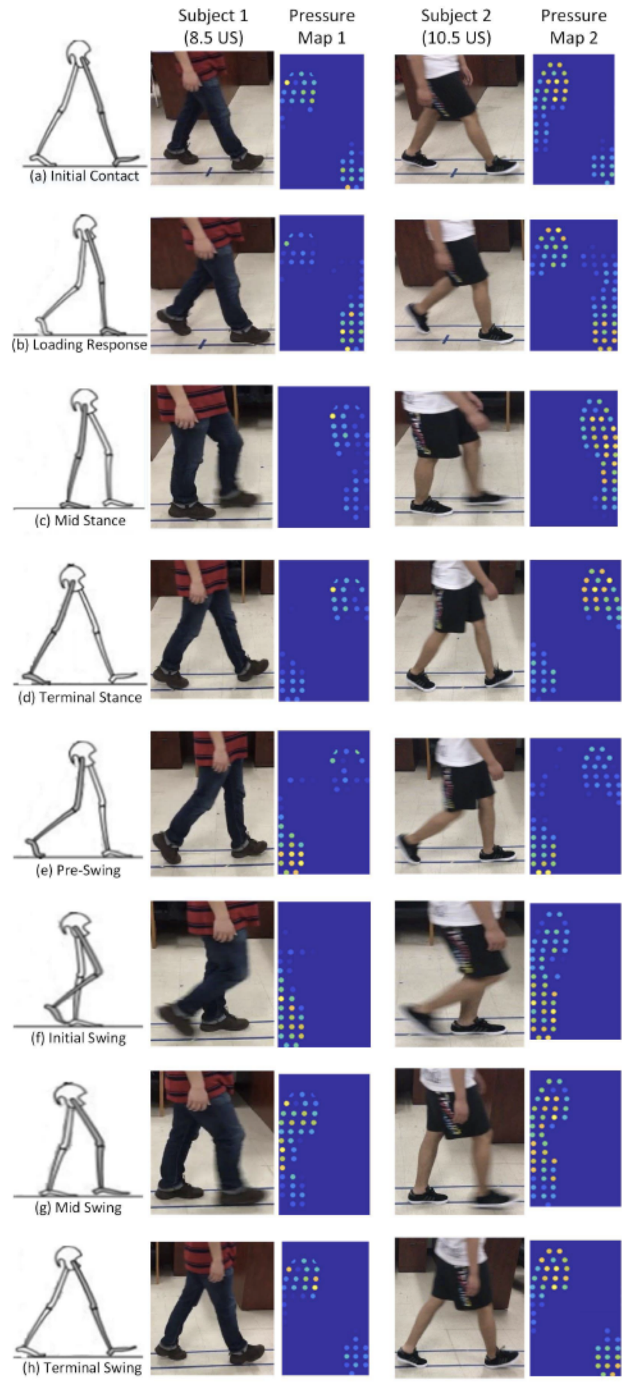

Fig. 8. Eight gait phases of each subject and the corresponding plantar pressure distribution map.

TABLE II
RESULTS OF CADENCE EXPERIMENT

	50 BPM	60 BPM	70 BPM
10.5 US	49.1	59.8	69.6
10.0 US	50.2	59.6	70.2
9.5 US	49.3	60.5	70.8
8.5 US	50.3	59.0	70.5
6.5 US	50.7	60.2	69.6

V. DISCUSSION

Experiment results show that the customizable pressure sensor array proposed in this paper is suitable for acquiring the spatial and temporal pressure distribution patterns even if being trimmed into a smaller size. It is noteworthy that the trimmed sensors are helpful to reveal the pressure distribution patterns, although the sensor sensitivity would be decreased by trimming. As illustrated in Fig. 6, parts of those two sensors corresponding to the toe area of the 8.5 US sized sensor array were cut off. As shown in the "Pressure Map 1" of Fig. 8, it is obvious that the remaining parts of those two sensors could give useful pressure information to build the spatial and temporal pressure distribution pattern. This reflects an advantage of the sensor array based on continuous materials over the sensor array based on discrete sensors which would be broken by trimming.

For different applications, there might be different requirements on sensor array resolution and sensor shape and size. This kind of requirements could be met by configuring the distribution density, shape and size of the copper pads on the top and bottom layers. This is another advantage of the sensor array based on continuous and consistent pressure sensitive material.

The requirement for the circuit material of the top and bottom layers of the sensor array is that it should be suitable for customizing into different sizes. In this paper, we used flexible PCB to design the sensor array circuit. With the development of material technology, commercial available conductive fabric [28], thread [29], ink [30] etc. are available in these years, which could also be used for designing customizable sensor array. For example, conductive fabric could be used to replace the copper pads on the sensor array, and conductive thread could be used as the wires to connect each pressure sensor with the signal processing board. General fabric with high electronic resistance could be used as the substrate of the sensor array circuit. By inserting the piezo-resistive fabric material in the middle layer, the whole sensor array could be made of fabric material. In recent years, integrating sensors to fabric clothes is a new trend in the research field about wearable sensing. Compared with the polyimide based flexible circuit, the sensor array made of fabric is more suitable to be seamed on clothes and has many applications. For example, to analyze the risk of work-related musculoskeletal disorders of a worker who usually uses knees as a support for the whole body, the force distribution on knees is an important parameter [6]. Through seaming the fabric pressure sensor array to the knee area of the trousers, the pressure on knees could be recorded. While compared to flexible PCB, fabric is not that durable. Conductive ink could also be used to design the sensor array circuit by printing the sensor pads and wires on high electronic resistive substrate like paper and plastic. The sensor array designed with conductive ink is economics, but the disadvantage is that the printed ink wears off easily. Conductive tape could also be used for designing the sensor array circuit with low cost. But the stickiness of most tapes might not be strong enough to keep the sensor pads and wires still during frequent use. Therefore, material selection for the circuit material of the top and bottom layers of the sensor array should take the application requirements into consideration.

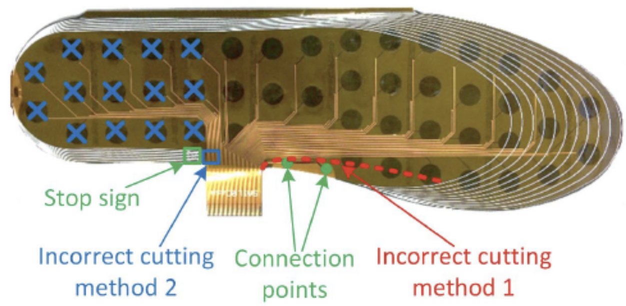

Fig. 9. Examples used to show that incorrect trimming methods would destroy the customizable sensor array.

The customizable pressure sensor array proposed in this research could be customized into different sizes, but it is necessary to note that when cutting the sensor array into a smaller size, important instructions should be followed, otherwise the sensor array might be broken. Taking the insole shaped customizable pressure sensor array for example, Fig. 9 shows two kinds of incorrect trimming methods that would destroy the customizable sensor array. As shown in Fig. 9, white lines are used to indicate the outline of different sizes of insoles, and the user should follow the trace of white lines to customize the insole shaped sensor array. However, if a user cut the sensor array along the red dashed line shown in Fig. 9, then connection points for connecting the bottom layer to ground electronic level would be cut off, and all the sensors on the sensor array would be broken. The second incorrect trimming method shown in Fig. 9 is that the user does not stop cutting at the stop sign but cut into the blue rectangular area. This trimming method would break the wires that connect the sensors on the heel area (indicated with blue cross signs) to the FPC connector and then those sensors will not work normally. Therefore, when customizing the customizable pressure sensor array the user should follow the corresponding instructions.

VI. CONCLUSION

In this paper, we specified the design of a customizable pressure sensor array, which could be trimmed to meet the requirement on different sizes. Experiments involved gait cycle and cadence were designed to test the influence of trimming on the sensor array. The results indicated that trimming did not influence the spatial and temporal pressure distribution patterns acquired by customizable pressure sensor array.

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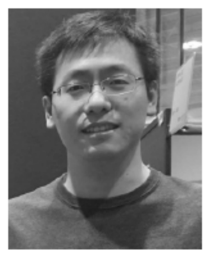

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