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Development of smart insole for cycle time measurement in sewing process

Eung Tae Kim[1] and Sungmin Kim[2*]

*Correspondence: sungmin0922@snu.ac.kr
[2] Professor, Research Institute of Human Ecology, Seoul National University, Building 222 Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea
Full list of author information is available at the end of the article

Abstract

A smart insole system consisting of pressure sensors, wireless communication modules, and pressure monitoring software has been developed to measure plantar pressure distribution that appears in sewing process. This system calculates the cycle time of each operation by analyzing the real-time plantar pressure data. The operation cycle time was divided into the time done by machine and by manual and calculated by adding the two types of time. By analyzing the cycle time, it is possible to estimate the type of operation a worker is performing. The ability to calculate accurate cycle time and to manage a large volume of data is the advantage of this system. Establishing an accurate cycle time of all operations would be of great help in improving the production process, capacity planning, line efficiency, and labor cost calculation. The system is expected to be a good alternative to the conventional manual measurement process. It will also be able to meet the high demand from garment manufacturers for automated monitoring systems.

Keywords: Smart insole, Plantar pressure, Sewing process, Cycle time, Remote monitoring system

Introduction

Most garment factories are using linear production systems where garment components are assembled through sequential processes (Rahman et al. 2014). The assembly process known as the sewing operation is the most labor-intensive part of garment manufacturing that constitutes the core of the production system (Maekawa et al. 2016). A worker repetitively performs assigned operations, and the cycle time of each operation should be controlled in order to maximize the efficiency of the assembly line (Dinh et al. 2019). An unbalanced workload along the line can cause a bottleneck and reduce its productivity. Line managers strive hard to keep the balance of the line by assigning operations to each operator as equal as possible based on the task sequence, cycle time required for each operation, and operator rating (Nann et al. 2019). Especially the management of the cycle time of each operation is essential for improving productivity. Cycle time is the key to the competitiveness of a factory as it affects production scheduling and labor costing (Harrell et al. 2004). Currently, there are two ways to measure the average cycle time in the garment industry. First, it can be calculated through observation and time study.

Observation is the process of recognizing and recording the activity of workers (Chisosa and Chipambwa 2018). Time study is a structured process to measure the time required for the completion of work (Hartanti 2016). A stopwatch is the most widely used timing device for time study. This would be a heavy burden for line managers since measured manually. The other way to calculate the average cycle time is to measure the total work time in a day and divide it by the total number of operations. However, this method cannot calculate the average cycle time correctly. An easy and unobtrusive system that automatically measures the time of each operation executed by each operator in real-time is required. With the production time data measured in real-time, it would be easy for a line manager to find which operation is the bottleneck of the line and to estimate the extent to which each worker is habituated to the work (Namioka et al. 2017). In this study, an automatic measurement method for the cycle time of sewing process in real-time using wearable sensors and remote monitoring system is described.

Sewing process requires workers to control fabric direction with their hands and to operate a foot pedal that controls the speed of the sewing machine (Chan et al. 2002). This study is based on the assumption that each sewing operation will exert a specific pressure pattern on the foot pedal. By measuring and analyzing the plantar pressure distribution data obtained from a wearable sensor attached to the worker, it would be possible to figure out which operation a worker is performing and how long does it take. There are several studies on tracking assembly processes in manufacturing using wearable sensors. Koshimaki et al. (2009) tracked what activity the worker was performing at certain time intervals using a single wrist-worn inertial measurement unit. Namioka et al. (2017) estimated the lead time of each period of an operation process by a factory worker using a wrist-worn accelerometer. Ward et al. (2005) focus on the recognition of activities that are characterized by a hand motion and an accompanying sound using microphones and three-axis accelerometers mounted on the user's arms. Most of these studies captured hand motions through wrist-worn devices and analyze operation processes. However, in these cases, reliable recognition of activity is difficult. Non-relevant hand activities often occur between operation activities such as scratching one's body, wiping sweat with hands, or taking something out of the pocket. So far, there is no research on a system that monitors the assembly process using smart insole. The purpose of this study is to monitor the cycle time of each operation automatically in an unobtrusive manner and analyze the operation process. For this, a smart insole system has been developed to measure the plantar pressure distribution during the sewing process in real-time.

Methods

Preliminary study

During the sewing process, the operator's right foot manipulates the pedal of a sewing machine to control it. In this case, the plantar pressure distribution is changed. A preliminary experiment was conducted to determine where the pressure is concentrated when the foot pedal was pressed. The Kitronyx MP2512 smart sensor insole hardware development kit was used in this experiment as shown in Fig. 1. It is an off-the-shelf product designed for the developers who need an out-of-box solution to build their own sensor insole products (Kitronyx, n.d.).

Fig. 1 MP2512 Smart Insole Development Kit

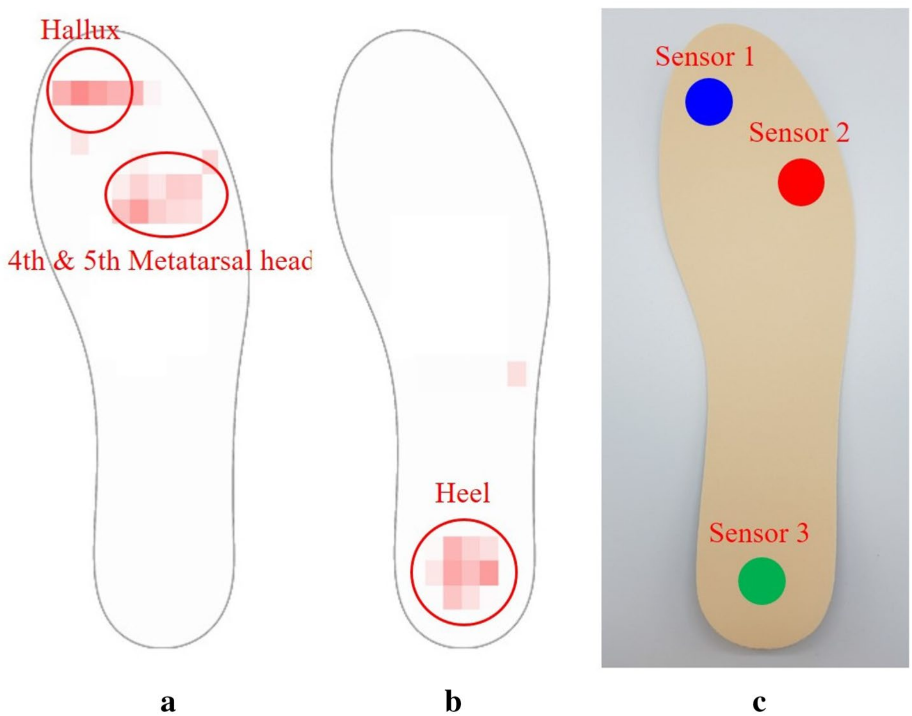

Fig. 2 Plantar pressure distribution. **a** Pedal pressed. **b** Pedal released. **c** Sensor locations

The distribution of plantar pressure on the right foot is shown in Fig. 2. As shown in Fig. 2a, high pressure values were observed at the hallux and 4th and 5th metatarsal heads when the foot pedal was stepped on. When the pedal was released, the pressure was concentrated at the heel area as shown in Fig. 2b. Based on these results, the locations of pressure sensors on the insole were determined as hallux, 4th and 5th metatarsal heads, and heel as shown in Fig. 2c.

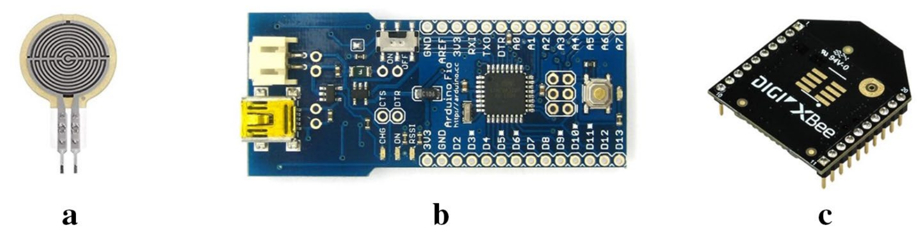

Fig. 3 Components of smart insole hardware. **a** Pressure sensor. **b** Arduino Fio microcontroller. **c** XBee wireless communication module

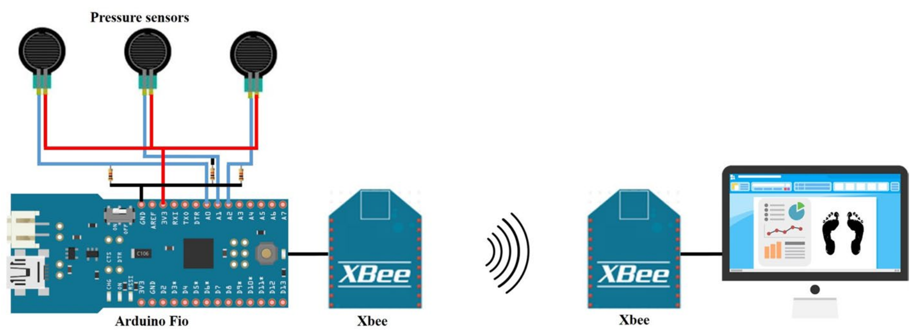

Fig. 4 Overall architecture of smart insole system

Design of smart insole system

The MP2512 sensor kit used in the preliminary experiment has several limitations for practical use. It is very expensive (over $600) and too big to be fit in a shoe. Moreover, it must be wired to a computer. Therefore it is unsuitable to be used to monitor the sewing process. In this study, a low cost as well as easy-to-use smart insole system has been developed.

Hardware design

The smart insole hardware developed in this study consists of pressure sensor, microcontroller, and wireless communication module as shown in Fig. 3.

Three force sensitive resistors (RP-C18.3-ST thin film pressure sensor; Film Sensor Technology Co., LTD, Shenzhen, China) were used to measure the plantar pressure distribution. Each sensor can measure the pressure ranging from 20 g to 6 kg. The resistance of a force sensitive resistor tends to decrease when the pressure is applied and it produces a corresponding voltage change (Manupibul et al. 2014). Each sensor was connected to an analog input terminal of the microcontroller (Arduino Fio; Sparkfun Electronics, Boulder, CO, USA) to transmit the data. Then a wireless communication module (XBee; Digi International Inc., Minnesota, MN, USA) was attached to the microcontroller to send the measured data to the monitoring computer. The XBee module is a popular inexpensive wireless communication device with low power consumption (Manupibul et al. 2014). The transmitter module is paired

Fig. 5 Circuit design using embroidery CAD software

with the receiver module which is connected to the client computer. The overall schematic of the smart insole system is as shown in Fig. 4.

A circuit connecting the sensors to the microcontroller was embroidered using conductive thread on the non-conductive fabric. Embroidery technique is expected to automate the textile based circuit production due to its flexibility (Briedis et al. 2017). The circuit was designed using an embroidery CAD software (Brother PE Design) as shown in Fig. 5. To prevent the short circuit, zigzag stitches with non-conductive thread were made to completely cover the conductive traces.

Then, a Brother NV2600 computerized embroidery machine was used to make the circuit as shown in Fig. 6.

The prototype of a smart insole developed in this study is as shown in Fig. 7. After placing pressure sensors on the insole, everything was covered with the fabric for further insulation. An enclosure for the microcontroller and a lithium-polymer battery was made using a 3-D printer and was attached to the test shoe.

Software design

A dedicated monitoring software program was developed using Embarcadero C++Builder 10.2 (Embarcadero, USA) to visualize and analyze the plantar pressure data transmitted from the smart insole. The software displays the plantar pressure distribution on the right insole image in real-time and shows the time-pressure relationship graph. Users can save the pressure data as a CSV (Comma Separated Value) format file for further analysis. The overview of the pressure monitoring software is as shown in Fig. 8.

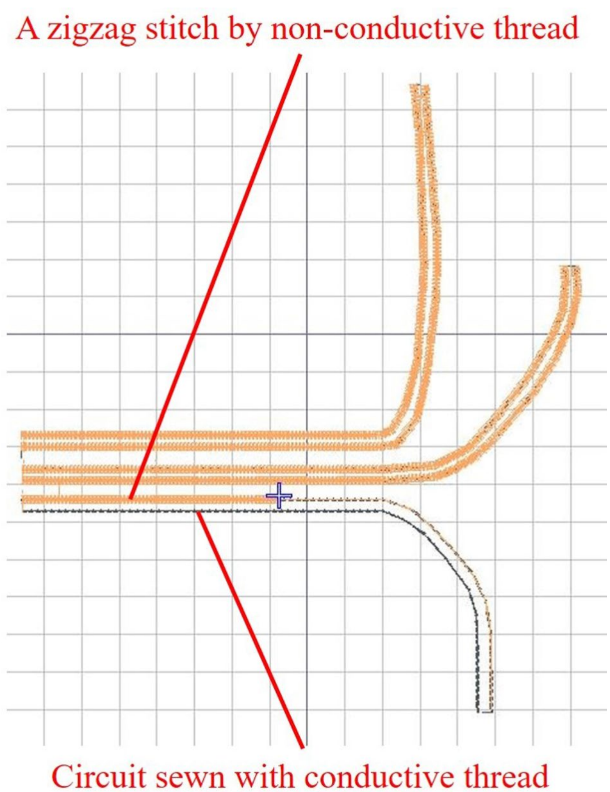

Fig. 6 Circuit production using computerized embroidery machine

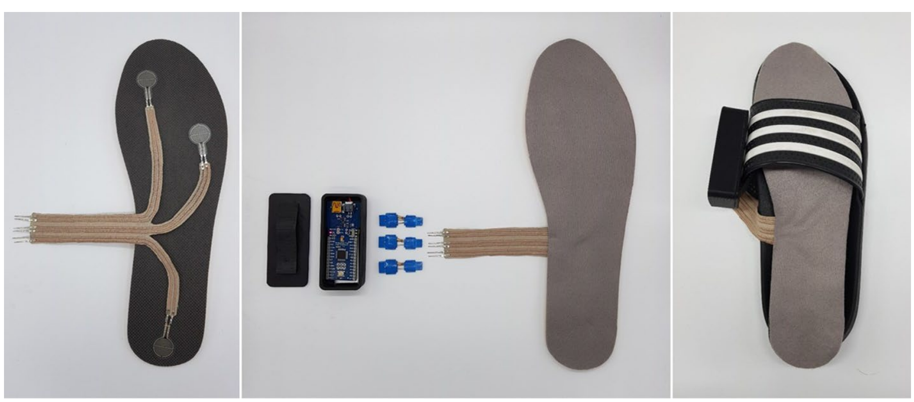

Fig. 7 Prototype of smart insole

Cycle time

A sewing operation goes through the following processes; A worker first takes over the patterns that need to be sewn and puts them into the sewing machine. Then the worker steps on the foot pedal to start sewing. When the sewing is finished, the sewing thread is cut and the assembled part is transferred to the next process. The time taken during this cycle is called the operation cycle time. A sewing operation consists of machine type

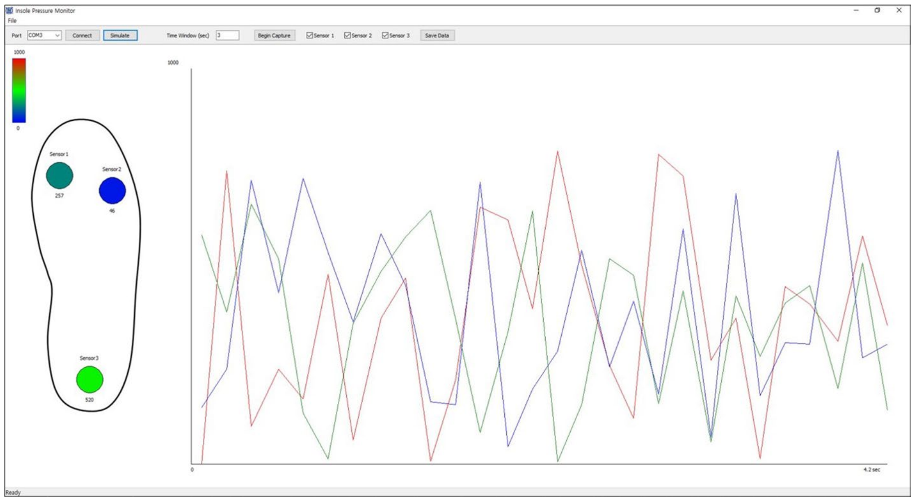

Fig. 8 Overview of insole pressure monitoring software

(e.g. sewing) and manual type (e.g. material handling) action. A worker always uses a foot pedal to do the machine type action and therefore it is possible to estimate the type of action the worker is performing by monitoring the worker's pedaling activity.

A line manager can check the status of the assembly line by observing the ratio of time required for machine type and manual type action. When the time for machine type action suddenly exceeds the average value, the manager can suspect a product defection or a mechanical problem. When the time for manual type action exceeds the average value, the manager can suspect a workflow problem such as bottleneck. Furthermore, if a specific worker's time for machine type action exceeds the standard value, the manager can determine that the worker does not have appropriate skills for the operation. However, a little number of garment manufacturers divide cycle time into the two types described above and calculate each. In this research, the operation cycle time was divided into the time done by machine and by manual and calculated by adding the two types of time. An extra time needed for an operation such as the time to change thread spool, replace empty bobbin, and change the needle were not considered in this study. In fact, these times should be considered to calculate more accurate cycle time.

Experiment

An experiment was designed to see whether it is possible or not to estimate the type of operation a worker is performing and the cycle time of that operation by analyzing the plantar pressure data measured by the smart insole system developed in this study. A skilled subject wore a shoe with the smart insole in it and performed two kinds of sewing operations repetitively. The schematic diagram of those operations is as shown in Fig. 9. Each operation was performed 10 times separately on a single needle sewing machine. Plantar pressure data acquisition was carried out by the insole pressure monitoring software. This experiment was also video recorded to obtain the reference data.

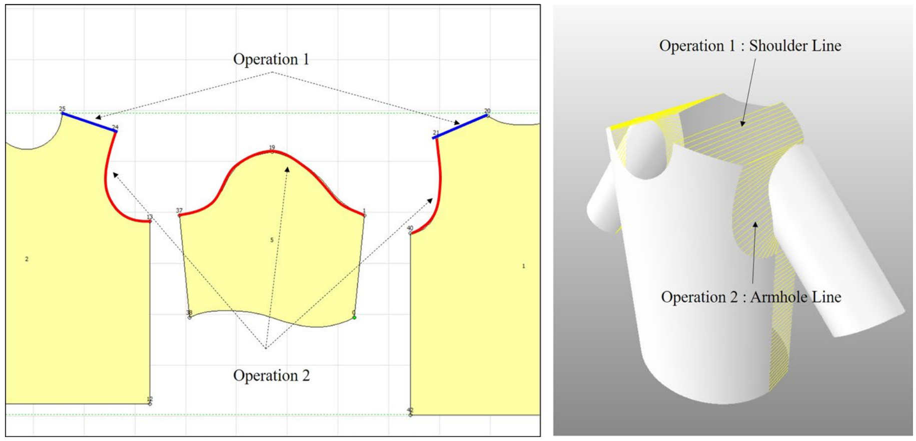

Fig. 9 Schematic diagram of two sewing operations

Results and discussion

As shown in Fig. 10, variation in plantar pressure could be observed during the given sewing operations.

The first operation was to sew a 19.5 cm long straight line. As shown in Fig. 10a, a specific pressure distribution pattern that occurs in each operation can be observed. It is also easy to confirm that the operation has been performed 10 times. The second operation was to sew a 52.4 cm long curved line. As shown in Fig. 10b, the shape of the data segment that appears repeatedly in every operation period is not as regular as that of the first operation. It may be because of the fact that sewing a curved line is harder than sewing a straight line. It is difficult to sew a long curved line with one continuous pedaling and the operator should pedal several times, which makes it difficult to find the pressure data pattern. To solve this problem, a moving average filter (MAF) was used to identify the pressure sensor data pattern of the second sewing operation. MAF is one of the most popular and widely used signal filtering techniques because of its simplicity and effectiveness (Golestan et al. 2013). The filtered data can be obtained using Eq. 1.

$$\bar{x}(k) = \frac{1}{N}\sum_{i=0}^{N-1} x(k-i) \quad (1)$$

where $x(k)$ is a single data and N is the subset size. Even though this filter gives a good response, the filtered data is continuously lagging behind the real-time data (Nirmal et al. 2016). However, it is still applicable because the purpose of MAF in this study is just to find the segment of the operation period. The performance of the MAF ($N = 100$) is as shown in Fig. 11. The operation period can be identified visually.

The operation cycle time and the net time taken by the sewing machine can be easily calculated from the sensor data segment. When the foot pedal is stepped on, pressure values from sensor 1 and 2 rise rapidly, and when the sewing is completed, these values drop sharply. The data from sensor 3 changes in the opposite direction to the sensor 1 and 2 data. Because of this repetitive regularity, it is easy to distinguish the time taken by machine type and manual type action. Table 1 shows the cycle time of two sewing

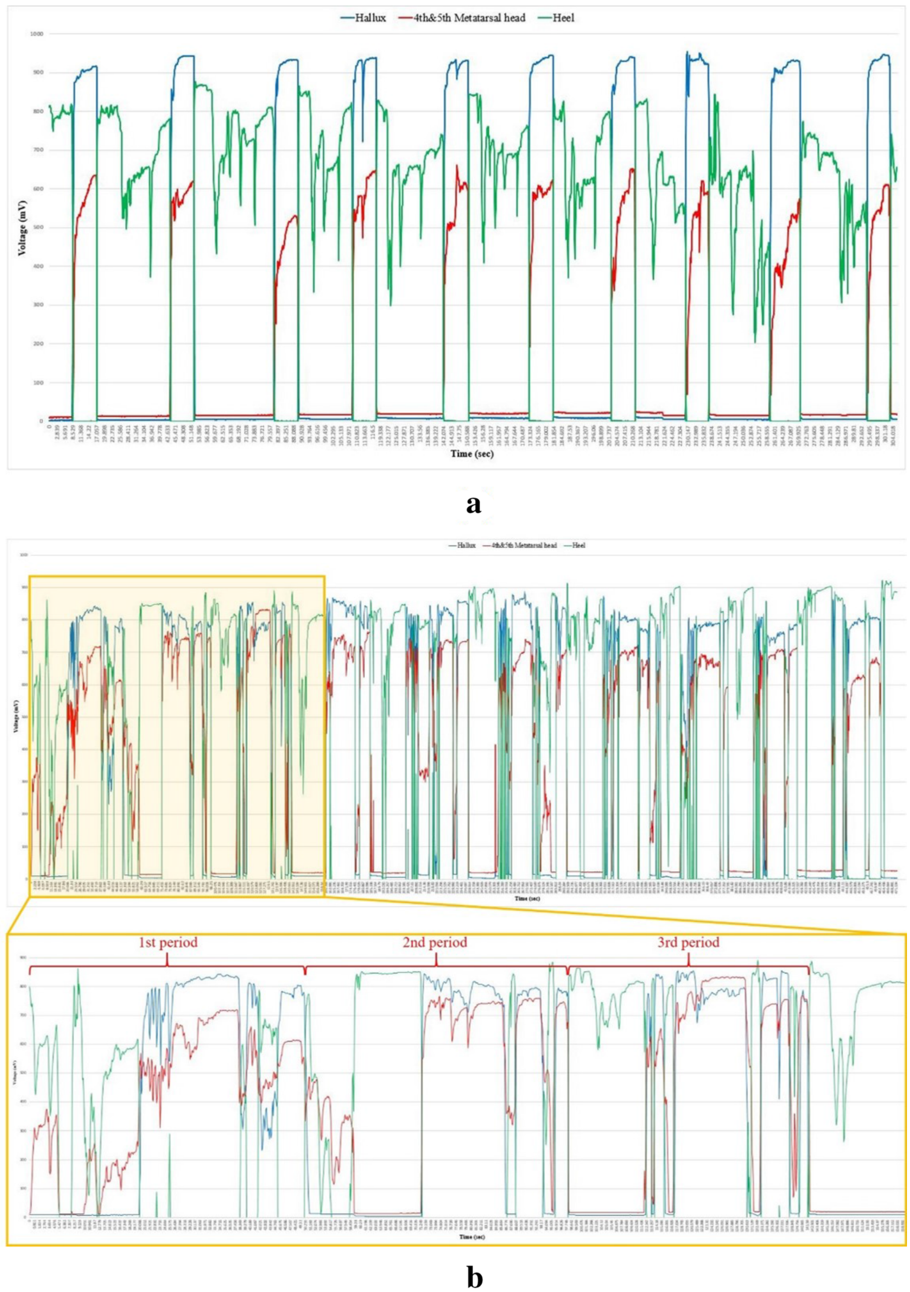

Fig. 10 Plantar pressure data of sewing operations **a** Operation 1 **b** Operation 2

operations. The operation cycle time was measured by averaging the observed 10 cycle times.

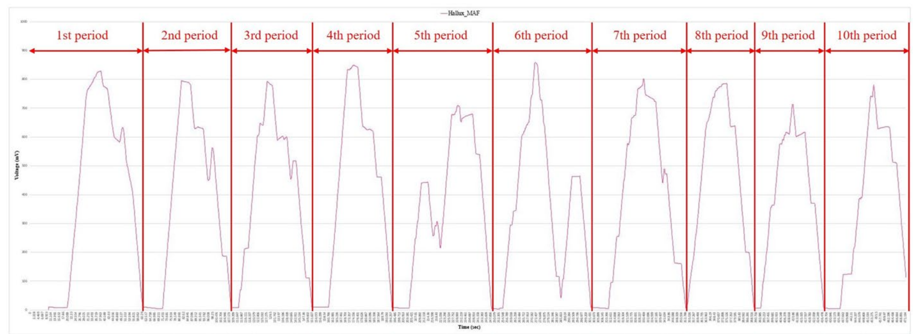

Fig. 11 Performance of MAF **a** Data from sensor 1, 2, and 3 **b** Data from sensor 1

Table 1 Average cycle time of two sewing operations

Sewing operation	Average cycle time		
	Manual (sec)	Machine (sec)	Total (sec)
Operation 1	22.818	8.944	31.762
Operation 2	16.849	28.879	45.728

Conclusion

This study aimed to develop a smart insole system consisting of pressure sensors, wireless communication modules, and pressure monitoring software. It is an unobtrusive system to calculate the cycle time of each operation by analyzing the plantar pressure distribution. As the garment production process cannot be completely automated, arrangement of worker in the assembly line is the important task for increasing productivity. The first task in managing production line is to measure the operation cycle time. This system could solve the challenging task of establishing cycle times of all assembly operations. This would reduce the heavy burden imposed on the line manager. Furthermore, by analyzing the operation time, it is possible to estimate the type and duration of the operation a worker is performing.

A revolution is taking place in the field of the garment industry through data digitization, IoT, and automation. To keep up with this change, garment manufacturers need to adopt a novel system that can automatically estimate the average cycle time of the sewing process. Establishing an accurate cycle time of all operations can be of great help in improving the production process, capacity planning, line efficiency, and labor cost calculation. The smart insole system developed in this study is expected to be a good alternative to the conventional manual measurement process.

Abbreviation
MAF: Moving average filter.

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Not applicable.

Authors' contributions
ETK have done the literature study, product development, experiment, and manuscript drafting. SK developed software for analyzing data, and supervised the research. Both authors read and approved the final manuscript.

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Availability of data and materials
The datasets generated and analysed during the current study and the software used are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

Author details
[1] Ph.D Candidate, Department of Textiles, Merchandising and Fashion Design, Seoul National University, Building 222 Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea. [2] Professor, Research Institute of Human Ecology, Seoul National University, Building 222 Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea.

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