Development of Textile Proximity Sensor for Medication Adherence Management System

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Abstract

In this study, we developed textile proximity sensor using conductive textile to develop a Medication adherence management system. The textile proximity sensor utilizes the principle of the capacitor, and the ring type sensor used to reduce the fringe-effect. When take medicines, we made a custom PCB that converts the change of the data measured by the sensor into a digital value so that transmitted the PC. In order to compare the performance of the system, we evaluated the correlation between the data variation according to the quantity of pills in the electronic compact scale and the data in this system. As a result, Pearson's correlation coefficient was $0.956 (p<0.01)$, confirmed a good correlation between the scale and our system. Therefore, we concluded that our system evaluated able to whether or not to take medication.

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1. Introduction

Medication adherence is generally indicated by the doctor and pharmacists taking the prescribed amount of medicine and number of times [1]. Adherence to medication compliance is a important act in effectively treating illness and restoring health [2]. However, it does not follow medication adherence as much as doctors and pharmacists expect. This causes problems in the reliability of the doctor and the pharmacist, but more importantly, it can lead to problems in the patient's health. In a study conducted in the United States(US) to determine the importance of medication adherence in terms of the risk of death and the cost of medical care for patients enrolled in the US Medcaid program. As a result, the risk of death among patients with medication adherence below 80% 3 times higher. Also, hospital visits were 86%, and emergency transport visits increased by 50% [3].

In order to solve medication non-adherence, various researches have been conducted on the system that helps the medication adherence. Studies have been conducted to evaluate whether a wearable device is manufactured and adhered to the medication, and it includes a research that uses an inertial sensor to wear on the wrist to detect adherence with medication [4-5]. Also, a study to predict medication adherence using a piezoelectric sensor and a vibration sensor [6]. And a study conducted to measure adherence with an ingestible sensor [7]. In addition, medication adherence studies were conducted include smart pill box using a 3-axis accelerometer sensor [8-9], and using load cell [10].

On the other hand, wearable technology based on conductive textiles has attracted attention in various fields such as medical [11], commercial, military, and aerospace industries. This is because it is technically possible to make the part where the limitations exist only with the exisitng electronic devices. In addition, since conductive textiles are human-friendly materials. There is an advantage that the conductive textiles can be used without discomfort by users. In recent research, a study on healthcare using conductive textile has been conducted [12-17].

Especially, studies on human cyclical behavior and biological activities are underway. As a periodic action, researches are conducted on sitting postures study [18-20] and walking study [21-22] using textile sensors. Research on biometrics [23-29] is also being conducted. With the development of conductive textiles and the use of fibers, human life weill be further imporoved in the future.

In this study, a textile sensor was fabricated by using conductive textile to implement a Medication adherence management system. Previous studies have been many sensors, large, heavy, and mostly mechanical system studies. We propose a system that conductive textiles, which are small, light and human-friendly material, to solve the above problems.

The paper is structured as follows : Section 2 presents the principle and implementation of the conductive textile proximity sensor. Section 3 describes the proposed system. After Section 4 and 5, we describes the experiment and result, discussion respectively. Section 6 summarized about our study.

Fig. 1. Structure of Conductive textile

2. Conductive Textile Proximity Sensor

2.1 Conductive Textile

Conductive textiles are coating a conductive material such as nickel (Ni) or cooper (Cu) on the textiles to allow electricity to pass through the textiles. The structure of the conductive textile is shown in **Fig. 1**. It is have the advantage of having conductive and shielding effect, easy to fabricate the sensor, and can be manufactured in various forms.

In this study, we designed a system for evaluating medication adherence by fabricating a textile proximity sensor using conductive textiles. The conductive textile model was W-290-PCN (Ajin electron, Busan, South Korea) and the properties of the conductive textiles are shown in **Table 1**.

Table 1. Characterizes of Conductive textile

Item	W-290-PCN
Textile type	Woven
Base material	Polyester
Width(mm)	1100±5
Weight(g/m^2)	81±5
Thickness(mm)	0.1±0.01
Density(g/cm^3)	188±5

2.2 Textile Proximity Sensor

The textile proximity sensor derives the capacitance value based on capacitor theory. **Fig. 2**. Shows a parallel plate capacitor method that is basic capacitor. The Formula for obtaining the capacitor value in parallel plate capacitors is the equation (1).

$$C = \frac{\varepsilon_r \times \epsilon_0 \times A}{d}$$

(1)

ε_r is the delectric constant of the material placed between the two plates, and ε_0 is the permittivity of free space($8.85 \times 10^{-12} F/m$). A is the Area of the plate (width × length), and

d is the distance between the two plates(in meters). However, in the sensor implementation, the value of ε_r, ε_0, A does not change, so the capacitance value is determined by d.
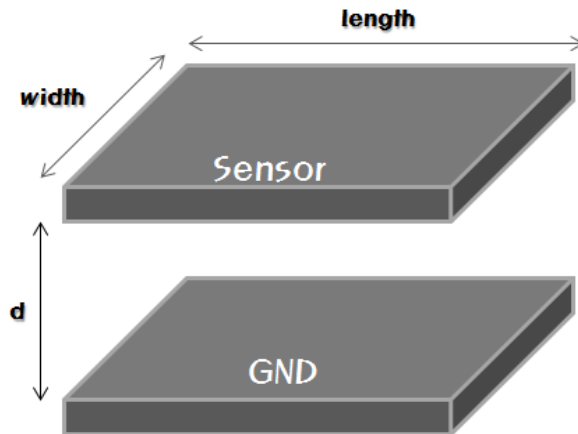

Fig. 2. Parallel Plate Capacitor

For a basic capacitor of two parallel plates in **Fig. 2**, a fringe effect occurs. The fringe effect has a problem affecting the measurement accuracy of the system and occurs near the edge of the plate. Therefore, in this study, a ring-type capacitor sensor was fabricated to minimize the effect of the fringe effect [30].
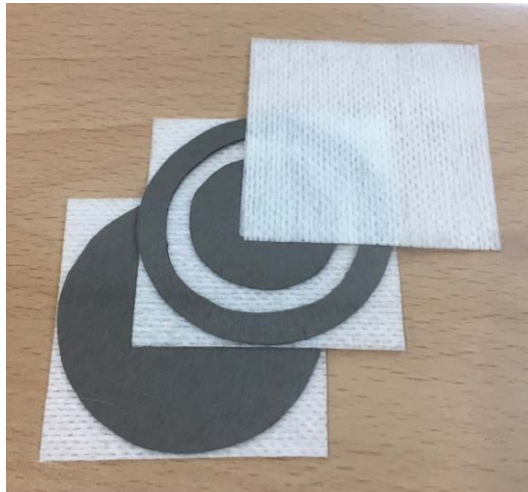

Fig. 3. Ring-type Textile Proximity Sensor

The fabricated sensor consists of a sensor part, a shield part, and a material. A $5\times5cm^2$ square medical textile bandage was used for the material. The sensor part is $3\times3cm^2$ circular size to fit the size of the pill case, and the shield part is made of $5\times5cm^2$ circular size and ring type of width 0.5cm as shown **Fig. 3**.

3. Medication Adherence Management System

We designed overall system based on the textile proximity sensor designed for medication adherence. **Fig. 4** shows the Medication adherence management system.

Fig. 4. Medication Adherence Management System

In order to transmit the capacitance value generated by the textile sensor to Personal Computer(PC), custom Printed Circuit Board (cusotm PCB) was fabricated using MPR 121 chip based on Synchronous Transfer Mode (STM) and BC417 chip providing Bluetooth (BTH) communication. The custom PCB is shown in **Fig. 5**, and the battery able operate for up to 8hours.
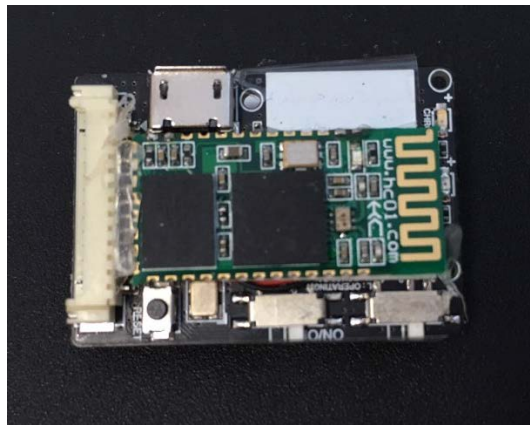

Fig. 5. Design of custom Printed Circuit Board

In previous study [31], there is a problem that unstable data appeared due to a position where a pill case was placed in a textile sensor, and noise due to the PCB and the battery occured. To solve the problem, Sensor barrier and PCB guard were designed using Replicator 2 (MakerBot, New York City, United States), a 3D printer model. Sensor barrier and PCB guard design are Shown in **Fig. 6**. The sensor barrier was designed with 5cm width, 5cm length and 0.2cm height according to the sensor size. The wall part of the sensor barrier was designed with 3cm width, 3cm length, 1.3cm height accrding to the size of pill case. And the PCB guard is designed to be 4cm width, 3cm length, 1.3cm height according to the size of PCB. And it is possible to power line and sensor connection line were connected through hole of 1.5cm×0.8cm and 2cm×0.5cm, respectively.
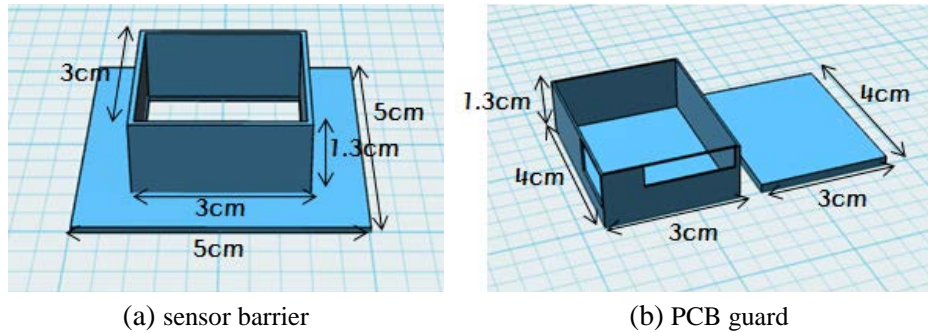
(a) sensor barrier   (b) PCB guard

Fig. 6. 3D printing design

4. Experiments

4.1 Textile Proximity Sensor Evaluation

In the previous study, we measured the capacitance of the LCR meter using LCR-8110G (GW Instek, New Taipei City, Taiwan) to confirm the resolution of the textile sensor [31]. In addition, was measured using an electronic compact scale model SF-400C (Suofei electronic, Jiangsu, China) to confirm the weight data according to the quantity of pills. The properties of the electronic compact scale are shown in **Table 2**. The pill used was 15T (Tablet, 6,000mg×15) multi-vitamin EnerHeim (Nutrilo GmbH, Cuxhaven, Germany). As a result, a graph was shown linearly, as shown in **Fig. 7**, and the average weight of the pill was 6.036g(±0.064). Based on the pill data measured using the electronic compact scale, we acquired the data according to quantity of pills with the textile proximity sensor that we implemented and correlated between the two data to evaluate whether our sensor correlated with the criteria for the electronic compact scale.
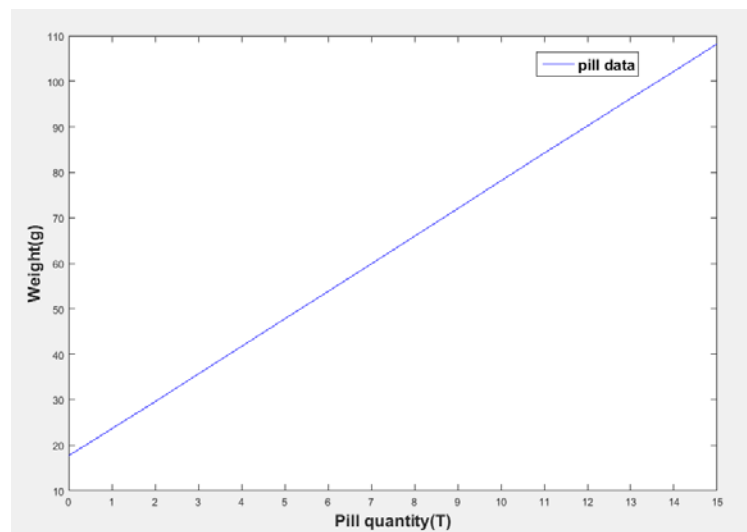

Fig. 7. weight for each pill quantity using electronic compact scale

Table 2. Characterizes of Electronic compact scale

Item	SF-400C
Measurement Unit	0.01g
Maximum Measurement	500g
Product Size(mm^3)	225 x 115 x 43

4.2 Take Medication Scenario

In order to evaluate medication adherence, we designed a scenario in which medication patients take pills. At first, the patient measures on the data of sensor before taking the medication. Next, patient takes the medication to take the pill case, and place the pill case on the textile sensor. Finally, measures data of sensor after taking the medication. Take medication scenario step is shown in **Table 3**.

Table 3. Medication Scenario

Step	Action
a	Measures pre-medication data
b	Take the pill case from the sensor
c	Take medication
d	Place the pill case on the textile sensor
e	Measures post-medication data

4.3 Data Communication

Capacitance value was converted into digital value and transmitted to PC to show the capacitance value, which is the data that is generated when the pill case placed on the sensor. To convert a digital value, a custom PCB transfers data through I^{2}C communication and converts the data through an ADC. Then, transmitted data to the PC Through BTH communication. In order to check the transmitted capacitance value, the data of textile proximity sensor can be confirmed and stored in real-time through implement of application using C# language in Visual Studio 2017 as shown in **Fig. 8**.

4.4 Data Acquisition

Based on the constructed system, we acquired data the change of capacitance value every time we take medication. We set the sampling rate of the data to 100Hz, check the data in real-time through C# application, and collect the data through the storage function. The experiment was conducted in total of 7 times experiments according to the take medication scenario from 15T when the pill was full in pill case to 0T when the pill was empty.
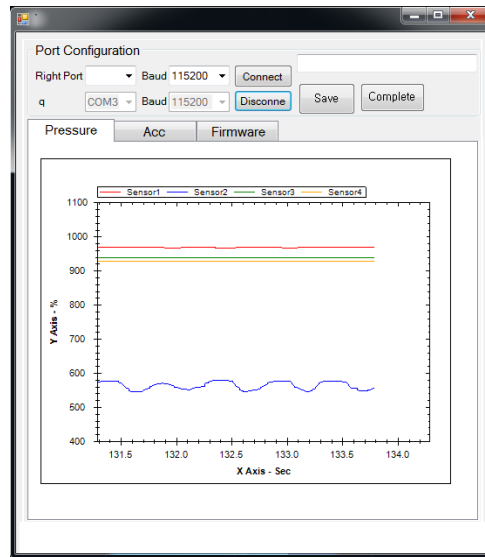
Fig. 8. Application based on C# language.

4.5 Signal Processing

The graph of the raw data acquired through the experiment is shown in **Fig. 9**. **Fig. 9(a)** is a state in which the pill is full in pill case, that is, 15T. **Fig. 9(b)** is a state in which the pill is vacant in pill case by repeating the take medication scenario(**Table 3**). **Fig. 9(c)** shows a series of procedures for take medication that taking pill case and place it down.

We apply the Moving Average Filter (MAF, N=15) to reduce the noise and staircase phenomena because the data can affect the result by the influence of the staircase phenomenon and noise in the acquired data**.** And **Fig. 9(c)** was detected using the peak detection algorithm. After peak detection, the time required to stabilize the data was 1 second, and the data values for 1.5 seconds after stabilization were extracted as Region of Interst (ROI). The average value was acquired from the extracted ROI data and used as the evaluation index of the medication adherence.
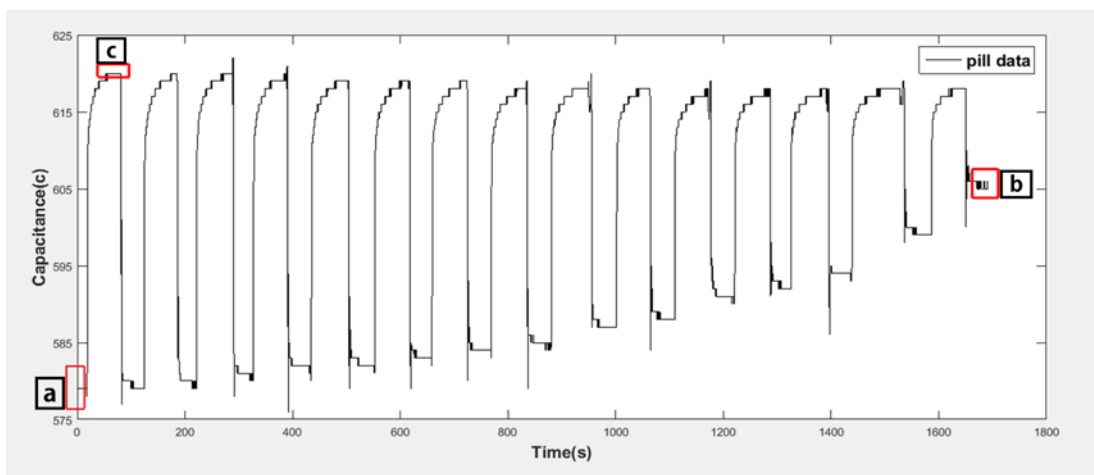

Fig. 9. Raw data for pill quantity when take medication

4.6 Statistical Analysis

In order to confirm the correlation between the pill data of electronic compact scale and the textile proximity sensor based on conductive textile. We used Pearson's correlation between two groups of data using SPSS Statistics version 18.0 (IBM, New York City, United States) to evaluate the correlation between the two group's data.

5. Results and Discussion

We conducted an experiment to evaluate whether there is a change in data at the time of medication adherence according to the medication scenario.

Table 4. Result data of each experiment

Pill quantity	Experiments							Ave.
	1	2	3	4	5	6	7	
15T	605.74	593.07	594.00	586.94	588.06	584.00	585.00	590.97
14T	599.49	588.00	589.74	581.94	584.00	579.88	581.00	586.29
13T	594.00	585.80	586.00	581.00	582.00	577.00	578.97	583.53
12T	592.58	583.96	585.00	579.00	580.00	576.00	577.00	581.93
11	591.00	582.02	582.76	578.00	579.00	575.00	576.00	580.54
10	588.00	580.00	581.00	576.00	577.00	574.00	575.00	578.71
9T	587.00	579.00	580.00	575.00	576.00	572.82	573.20	577.57
8T	585.00	578.12	579.00	574.93	575.98	571.00	572.42	576.63
7T	584.00	577.96	578.00	574.00	573.00	570.00	571.65	575.51
6t	583.00	576.01	576.99	572.98	573.15	569.01	571.00	574.59
5T	582.58	575.97	575.00	572.00	573.02	569.00	571.00	574.08
4T	582.00	575.00	575.06	571.00	571.89	568.00	569.00	573.13
3T	581.01	574.00	574.00	571.00	571.48	567.01	568.93	572.49
2t	580.00	573.00	574.00	571.00	571.00	567.00	568.50	572.07
1T	579.63	573.00	574.00	569.00	570.00	566.19	568.00	571.40
0T	579.00	571.76	573.00	567.99	569.00	566.00	566.50	570.46

Unit: Capacitance value (pF)
T: Tablet, Ave.: Average

The experiment has seven times in total, and a result of experiment as shown in **Table 4**. The data value for each experiment in **Table 4** represenst the capacitance value(pF), and the capacitance value decreases gradually as the quantity of pill decreases. However, although quantity of pills in **Table 4** is reduced, the section where the data value is same or the section where the data is increased have been confirmed. In this problem, we considered that the data of the y-axis in the program code of the C# application is set to be too insensitive. This problem will be resolved by checking and correcting the problems of the code.
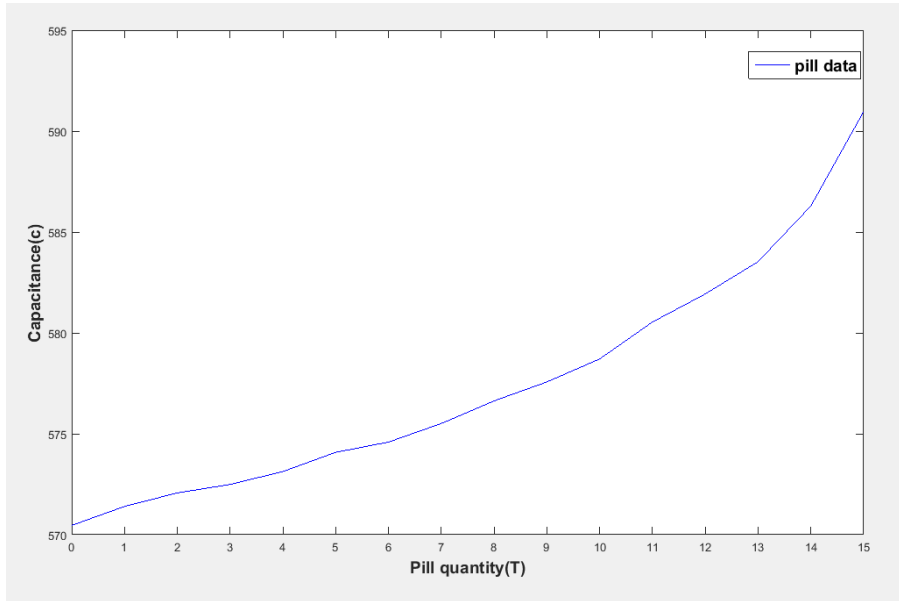
Fig. 10. Pill average data for pill quantity

The data measured with proposed system in **Table 4**. each experiment data value were averaged to evaluate the overall system stability. The average value of the capacitance value by each quantity of pill was derived. The change of the data is expressed by a graph as shown **Fig. 10**.

Table 5. Pearson's correlation coefficient of experiment data and electronic scale data

Experiments	Pearson' r
1	0.932^{**}
2	0.956^{**}
3	0.950^{**}
4	0.963^{**}
5	0.960^{**}
6	0.960^{**}
7	0.962^{**}
Ave.	0.956^{**}

Ave.: Average $^{**}p < 0.01$

Fig. 10 shows that the capacitance value gradually increases with the increase of the pill. Then, we evaluated the correlation between proposed system and electronic compact scale through Pearson's correlation. The Pearson's correlation result of experiment data and electronic scale data as shown in **Table 5.**

The results showed that the lowest correlation coefficient was 0.932 and the highest correlation coefficient was 0.963 for each of the seven experiments. Moreover, for the average data, a correlation coefficient of 0.956, and the results were statistically significant for all experiments [32]. As a result, we concluded that our system able evaluate drug compliance when taking medication.

6. Conclusion

In this study, a textile proximity sensor using conductive textile fabricated to propose a Medication adherence management system. The findings of the studies suggest that we concluded that it is possible to evaluate in our system for the quantity of pills that decrease every time they take medication. However, we have found that small problem that needs to be more sensitive to the resolution of the system. Further study is after solving the resolution problem of the system, we will add a service function that will help the medication adherence patient to maintain adherence with the medication in cooperation with the smart device in android application. In addition, we are trying to experiment our system using in real-life. Finally, we expect that proposed system using textile proximity sensor to be utilized various studies.

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