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Comparison of Step Counting Methods according to the Internal Material Molding Methods for the Module of a Smart Shoe

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Abstract

Recently, studies on wearable devices in ubiquitous computing environments have increased and the technology collecting user's activities to provide services has received great attention. We have compared the step counting methods according to sensor molding methods in case of counting steps by using the piezoelectric sensor. We have classified the cases which could result from the course of molding the internal module of a smart shoe as follows: (i) the module is unmolded, (ii) molded but only to the extent that a sensor is fixed or (iii) molded to the extent that a sensor is not moved. Moreover, we have made comparison to verify which algorithm should be used to increase the accuracy of counting steps by the respective cases. Based on the comparison result, we have confirmed that the accuracy of counting steps is higher when using gradient value rather than when using threshold value. In the case of no molding and small molding under the condition of using gradient value, it was turned out to be 100% accuracy for step counting.

Keywords: *Piezoelectric Sensor, Molding, Smart Shoes, Arduino, Step Count*

1. Introduction

The recent major development of computer technology has been based on the human-based technology and the appearance of wearable devices in ubiquitous environments that may be used anywhere anytime [1, 2]. There have been various attempts to quantify behaviors in daily life, and one of those has been to measure the number of steps taken through use of acceleration sensors. These results could have been proved useful in a number of areas [3, 4]. The sensors and systems which monitor and diagnose the state of exercise, health, safety, etc. of a person have been extensively developed [5-7].

Also, the rapid growth of the internet of things demands a wide variety of sensors including acoustic, automotive and navigation, chemical, electric, humidity, optical, pressure, temperature, and proximity sensors that are digitized with high accuracy. The output signals of the sensors are usually analog signals; hence, their analog signals must be digitized for use in the digital world [8]. As smartphones have become common and increasing attention is given to health, the number of systems providing healthcare information with

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smartphones have increased correspondingly [4, 9]. Healthcare information is derived from counting steps to provide information on quantity of motion. Although it is possible to use Global Positioning System (GPS) to estimate distance moved outdoors, it is impossible to estimate moving distance indoors with GPS. However, most of the walking applications in the market rely on simple GPS location trackers to estimate the user's movements and location.

The size of wearable device market is growing rapidly. Wearable devices are combined with various products such as socks, belts, bracelets, rings and shoes that people wear in daily lives, so that the wearable devices may collect information relating to user's activities. The collected information is connected with the user's smart phone or account to provide services and thus, a smart phone is inevitably needed [10]. The wearable computing system is an important system that classifies, analyses and prints data collected based on various types of smart phones.

The developed technology of 3D printers enables to produce personalized products according to the design and size that a person wants, therefore, it is expected that the wearable computing industry may become an industrial dynamic for future growth industries based on flexible manufacturing system(FMS) [10].

Due to the development of mobile industry including smart phones, wearable devices, etc., users in various fields may obtain and use information that they want anywhere anytime. Moreover, the growth of wearable devices and propagation of 3D printers have gained great attention and social needs in regard to relevant areas. These technologies basically measure and display the amount of activity of users [11, 12].

This paper is to verify how the accuracy of counting steps varies according to the three methods of molding internal materials for the module of a shoe as follows: (i) the module is unmolded, (ii) molded but only to the extent that a sensor is fixed and (iii) molded to the extent that a sensor is not moved.

2. Relevant Studies

There are various methods of measuring and displaying user's activity quantity. The most popular methods are to use the number of steps and to use movement distance and time [11]. Based on the experiments on step rate and step length, it can be known that the step length is greatly influenced by the step rate. When measuring step rate with gyroscope/acceleration sensors, there were many cases where the recognition rate was low 87%, depending on the user's stepping pattern. When using gyro/acceleration sensor, it leads to different measuring results depending on the location of the device and the way of carrying it [13]

Human gait is defined as a personal walking pattern using two limbs. Although the definition of human gait is simple, measurement of human gait patterns requires sophisticated techniques to capture the essence of human gait, including natural variations in gait. Many researchers have recognized individual gait patterns as an authentication method [14].

There are two ways to measure the number of steps:(i)using the tri-axis gyro/acceleration sensor and (ii) using the piezoelectric sensor. The tri-axis gyro/acceleration sensor for a smart phone is composed of X-axis, Y-axis and Z-axis as shown in Figure 1. X-axis is a horizontal axis of a smart phone, initially based on the right side. Y-axis is a vertical axis of a smart phone, initially based on the upper direction. Z-axis is an axis penetrating the front of a smart phone, initially based on the direction penetrating the liquid crystal from the battery side.

A smart phone measures the number of steps based on the data received in real time from the X, Y and Z values of the tri-axis gyro/acceleration sensor. However, the accuracy of this method varies depending on how to carry the smart phone [3, 11, 15, 16].

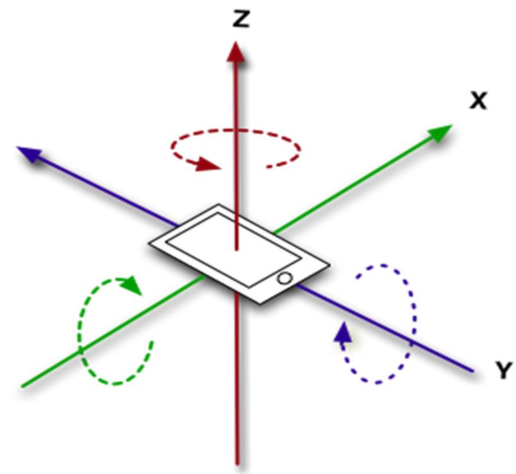

Figure 1. Tri-axis direction of gyro/acceleration sensor

The value of this vertical acceleration depends on how the wearable device is worn, but often a pocket or back-pack, and wrist is not vertical. Mounting wearable device on a belt or backpack, wearing it on the chest, or put in a pocket will cause the forward (roll-axis) and side (pitch-axis) acceleration to be measured rather than the vertical acceleration (yaw-axis) measuring only is likely to produce an incorrect step count, no matter how the wearable device is worn [17].

To use the piezoelectric sensor for measuring the number of steps, sensor value is received in real time and compared with threshold value for determining a step [18]. In this case, the threshold value varies depending on how to mold the surroundings of the sensor if the sensor is located inside the module. In addition, since the restoration time of the sensor varies depending on the type of molding material, problems may be caused in counting steps.

This paper is to compare and experiment the methods of counting steps according to how to mold the internal module of a smart shoe where the piezoelectric sensor is installed.

3. Comparison of Step Counting Methods

The sensor location and how to mold the internal module of a smart shoe may change the method of counting steps or its accuracy. Thus, in this chapter, the unmolded method and the molded method are compared. Moreover, even in case of the molded method, depending on the amount of filling internal material in the surroundings of the internal module, the step counting method may vary. Therefore, this paper compares three methods as follows: (i) unmolded method, (ii) molded method with filling internal material of low density and (iii) molded method with filling internal material of high density.

In order to compare those methods accurately, hardware has been set under the same condition as shown in Figure 2. In Figure 2, PS represents the positive and negative poles of the piezoelectric sensor. Diodes of D1 and D2 prevent the inverse voltage of the piezoelectric sensor. The capacitor of C1 removes noises. If setting hardware like Figure 2, when pressure is put on sensors, sensor data is not measured in real time but when pressure is removed from sensors, sensor data is measured.

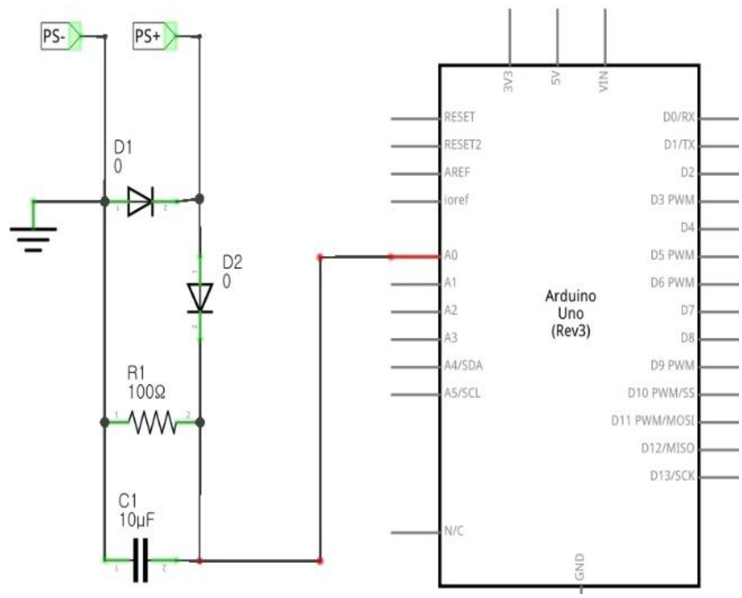

Figure 2. Hardware setting

3.1. Unmolded Method

The unmolded method is to install the piezoelectric sensor on the shoe insole without any treatment on the sensor. If walking with a shoe where the piezoelectric sensor is installed, a graph is made as shown in Figure 3. In the graph, X-axis stands for time and Y-axis for sensor value.

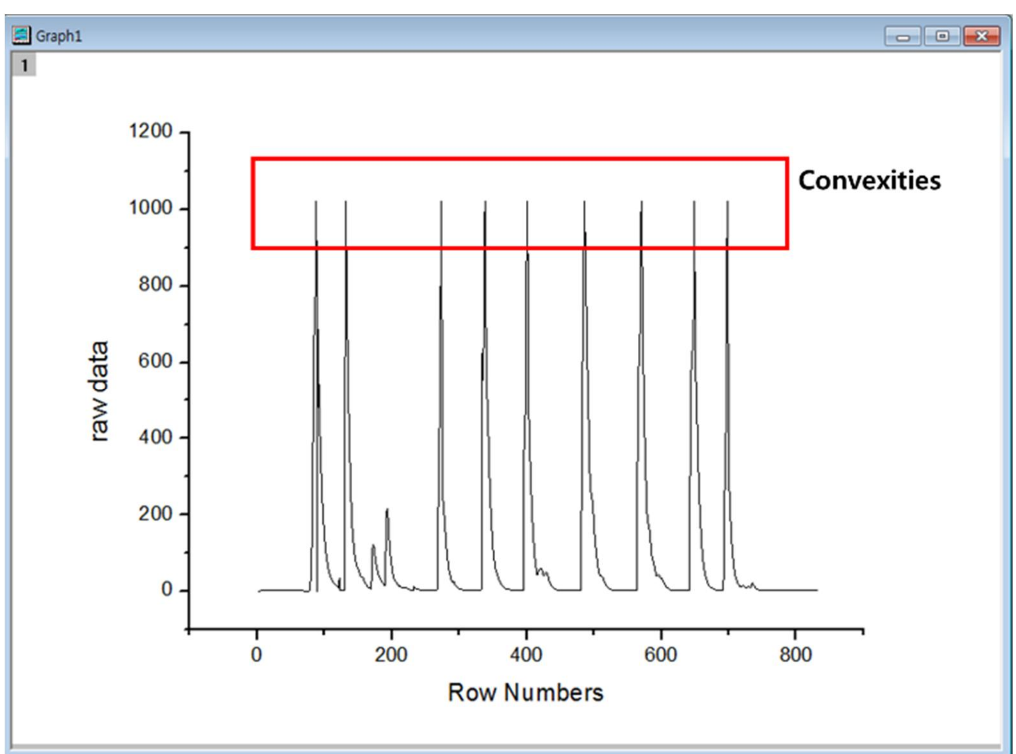

Figure 3. Graph of unmolded piezoelectric sensor

If sensor value is continuously printed out as in Figure 3, steps are counted based on threshold value. The threshold value is relative, so if the graph shows uneven convexities as shown in Figure 4, a value which is less than the lowest point among other convexities of the graph is set as threshold value. After setting threshold value, when a variable is greater than the initial threshold value, the variable value becomes TRUE and a step is counted. When sensor value becomes lower than the threshold value, state is changed to FALSE.

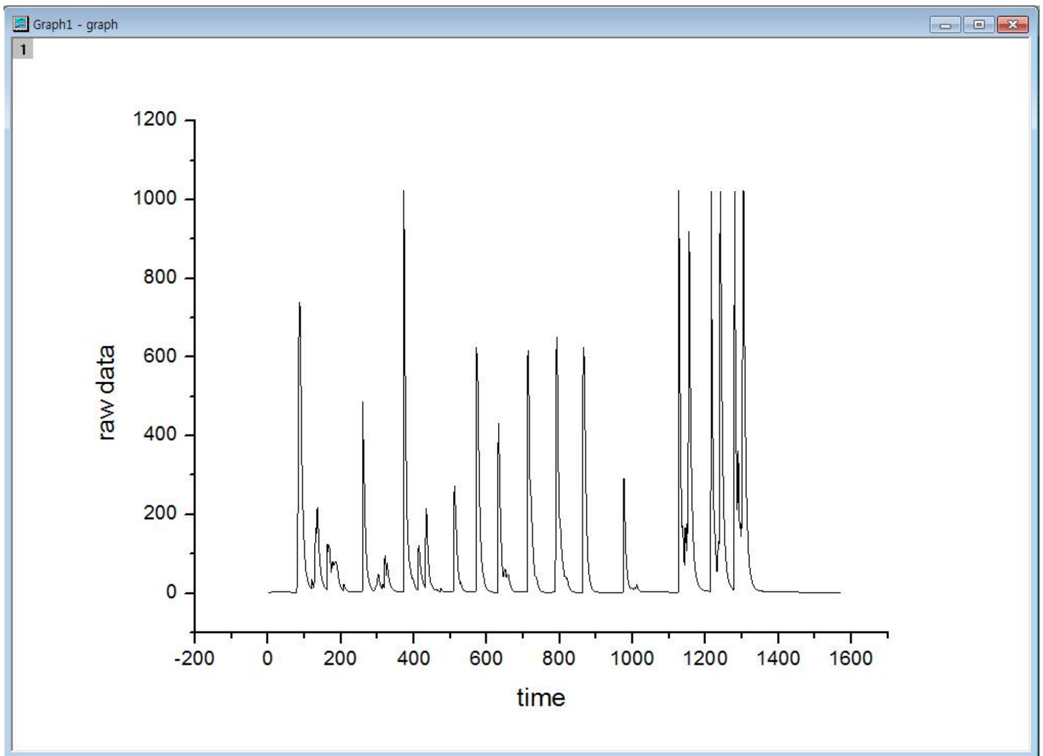

Figure 4. Graph of molded piezoelectric sensor

The reason for counting steps by using a variable together, instead of using threshold value only, is to prevent the number of steps from increasing continuously from the moment when sensor value becomes greater than threshold value to the moment when it becomes lower than that.

3.2. Molded Method

There are various types of material including plastics, silicon, urethane, etc. which are used for molding in the course of producing a module. This paper has used silicon-type material which can be easily obtained by ordinary persons and easy to use. When producing a module, depending on the amount of filling internal material, the basic distortion degree of the piezoelectric sensor varies. Therefore, whenever producing a sensor, the threshold value for counting steps varies, it should be set again and again, which is inconvenient. Moreover, if the internal material is soft, sensor value slowly increases or decreases and if solidity increases as time goes on, sensor value quickly increases or decreases.

For this reason, it is highly possible that the algorithms proposed by the existing studies may not be applied. Therefore, this paper presents and compares algorithms for two cases such as fast restoration and slow restoration.

3.2.1. Third-order Headings

Restoration becomes fast when silicon becomes stiff and intensity increases when the piezoelectric sensor of the module is fixed. In case of fast restoration, the overall waveform of the sensor is shown as Figure 4 and similar to Figure 3. However, the maximum value of the waveform is definitely different from that of the unmolded module. This is because silicon-type material is used, so the shocks given to the piezoelectric sensor are absorbed and dispersed.

In that case, when counting steps only with threshold value, which is the existing method, accuracy often decreases. Therefore, a new method is needed to take measures against various circumstances and to increase accuracy.

The piezoelectric sensor value increases or decreases depending on the strength of pressure. Based on such characteristic, gradient values are obtained for the respective sections by using the formula (1). In the formula (1), “g” means gradient value.

$$g = \frac{y_2 - y_1}{x_2 - x_1} \tag{1}$$

Figure 5 shows a graph for the results of the formula (1) in regard to the data of Figure 4. If determining a step based on gradient, a step is counted on the point where the value corresponding to zero changes from positive number to negative number.

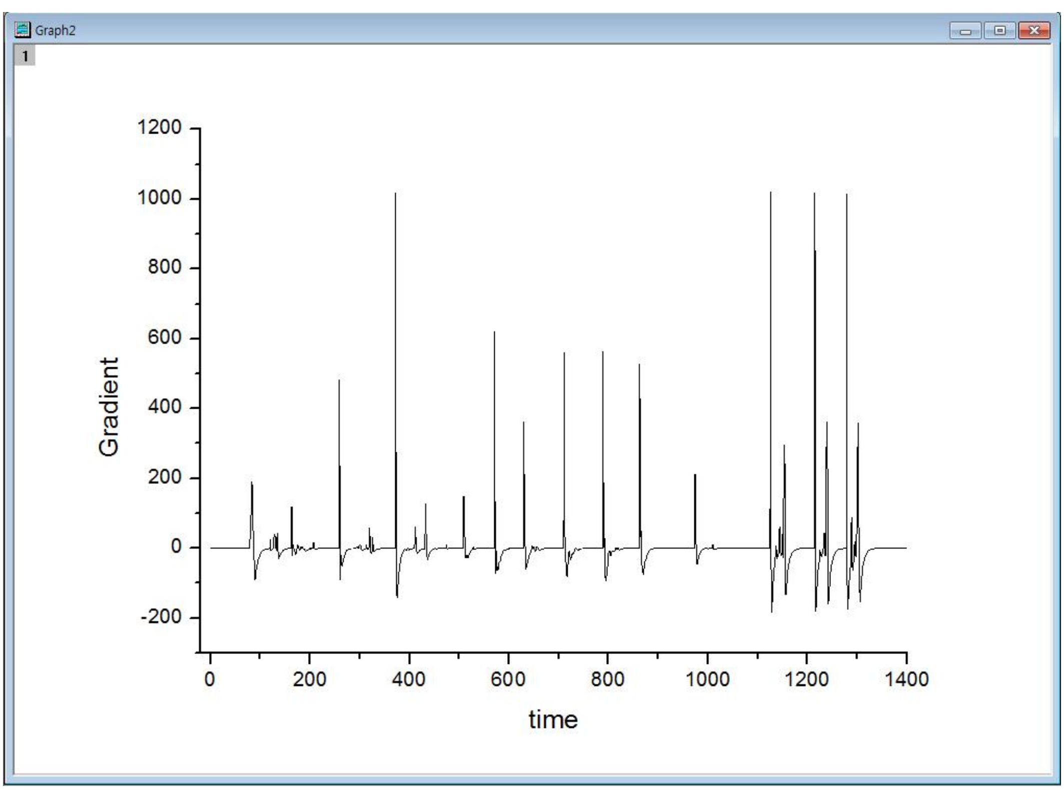

Figure 5. Graph of gradient for figure 4 Using formula (1)

3.2.2. Third-order Headings

Restoration becomes slow in case that silicon has not been stiff and intensity become low when the piezoelectric sensor of the module is fixed. The silicon-type internal material tends to become stiff as time goes on but in early stage, silicon is soft and restoration is slow.

In such case, the data waveform is obtained as shown Figure 6. The data waveform of Figure 6 shows that data increases slowly in the form of stairs. The value increases because pressure is put on the sensor and before the sensor is restored to its original condition, pressure is put again. If failing to press the sensor more strongly than before, the sensor cannot make any recognition.

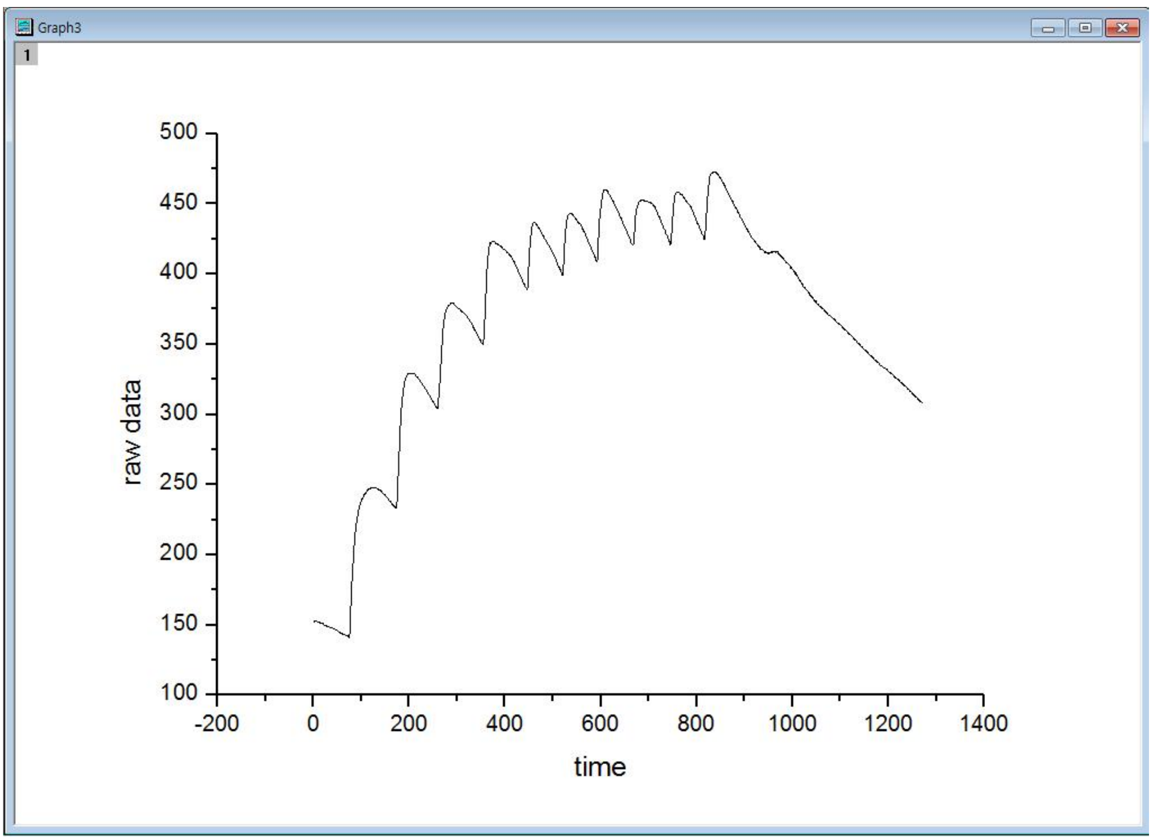

Figure 6. Graph of slow restoration with molding

Figure 7 displays the gradient obtained through Formula (1) for Figure 6 in diagram form. In general, when checking a step with gradient, a step is counted on the point where gradient value changes from positive to negative based on the point where gradient becomes zero.

Moreover, when using threshold value to recognize a step, sensor value does not change greater or lower than a certain value as shown in Figure 6. Since sensor value changes as the overall average value increases, it is impossible to count steps by setting threshold value. Therefore, in case of slow restoration, steps are counted by using gradient indicating variations as shown in Figure 7.

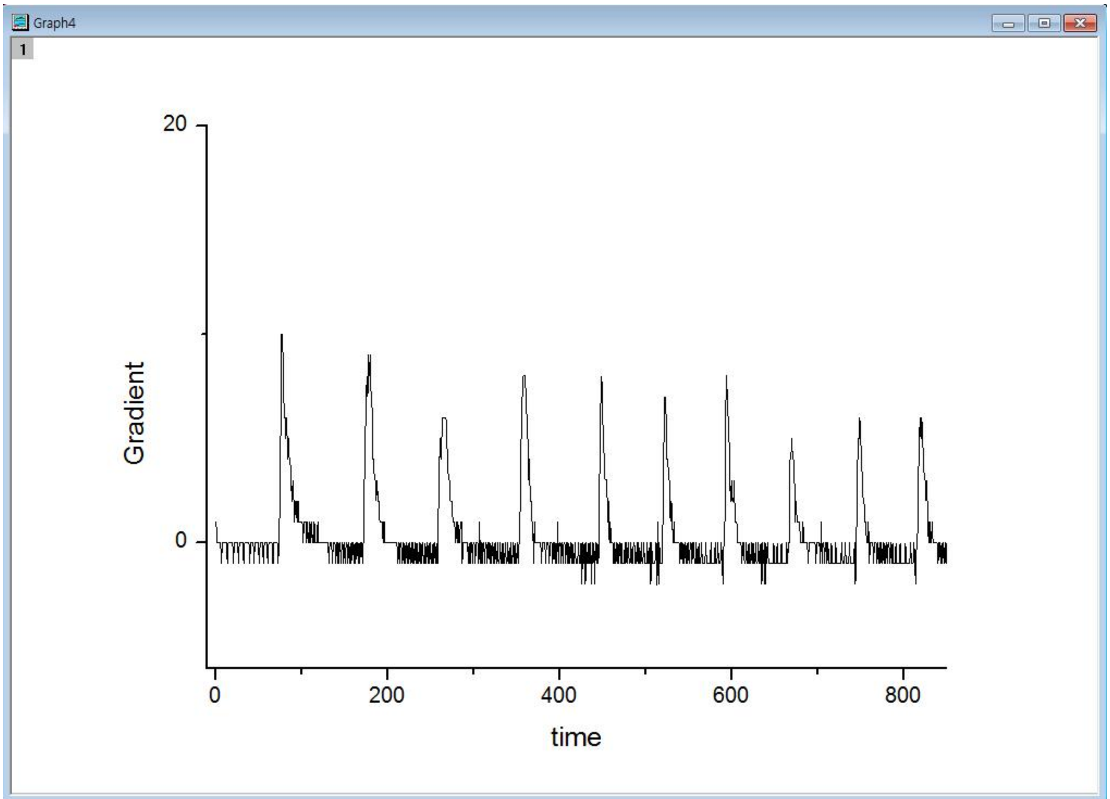

Figure 7. Graph of gradient for figure 6 using formula (1)

4. Comparison Results

The difference between molding and unmolding is that sensor value varies according to the amount and strength of molding. In case of molded module, internal material absorbs shocks and the sensor bears a less burden and restoration is slow. In case of unmolded module, restoration is fast for no shock is absorbed.

Table 1 shows the result of step recognition rates according to molding methods using threshold value or gradient value. In case of no molding and small molding, if using threshold value only, accuracy decreases due to noise value. Noise occurs in the condition that shoes do not fit a user, so feet hit the sensor many times while walking. Therefore a step has been often counted since sensor value is greater than threshold value, even though sensor value is lower than the actual step value.

Table 1. Result of step recognition rates according to molding methods

	No Molding	Small Molding	Large Molding
Threshold Value	96%	98%	30%
Gradient Value	100%	100%	68%

In case of large molding, average value could be measured to some extent based on threshold value but when sensor value became over the threshold, measurement was impossible, so only gradient value was used.

In the case of no molding and small molding, the step count using the threshold value showed 96% ~ 98% accuracy, while when using the gradient value, 100% accuracy. No molding and small molding are turned out to be a useful method for step count. However, in the case of using large molding, the accuracy of 60% was found even when using the gradient value, so it is turned out that large molding cannot be used for step counting.

5. Conclusion

We have compared the step counting methods according to sensor molding methods in case of counting steps by using the piezoelectric sensor. There was a little difference between cases but it turned out that the method using gradient value was more desirable than the method using both.

In case of the method using threshold value, exception can be applied for low noise value but when the noise value was measured similar to the general step value, it was counted as a step. In other words, counting steps with the gradient value obtained through Formula (1), without threshold value, is expected to have high accuracy in any circumstances.

However, if sensor's restoration becomes slow due to large molding on module, consecutive pressure or similar pressure cannot be recognized. In that case, the type of internal material for sensor needs to be changed or the quantity of silicon needs to be adjusted properly.

Moreover, we have made comparison to verify which algorithm should be used to increase the accuracy of counting steps by the respective cases. Based on the comparison result, we have confirmed that the accuracy of counting steps is higher when using gradient value rather than when using threshold value.

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