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IoT-Based Sensor Shoes System for Gait Correction

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ABSTRACT- Since the 2000s, diseases that tend to occur in high-age groups such as degenerative arthritis and intervertebral disk has been gradually increasing in low-age groups due to incorrect gait or bad habits. One of the fundamental problems with these results can be found in an indifference to gait. This study aimed at determining the walking styles through pressure sensor. It uses a three-axis accelerometer and a gyro sensor to identify pigeon-toed walking and splay-footed walking. The system can monitor gait using the sensor data stored in the PC and smartphone applications transferred via Bluetooth. This can be visually confirmed through color changes in accordance with the sensor value with the neo-pixels. Research developments can analyze the type of gait as compared to the value for the case of incorrect gait based on normal pace with the acceleration value through the sensor. Through the experiment, the recognition rate capable of distinguishing in toeing gait was 56.25%, and out toeing gait was 81.25%. The system of this paper continuously collects gait data to enable monitoring whenever and wherever users want. It is easy to check when and where users walked with a normal gait or abnormal gait, and it is expected to help users manage their gait. This system may be approached as a precautionary measure by notifying other parts of the body that there is an abnormality in asymmetric walking (walking with differences in speed, angle, and stride of both feet) or when dragging feet.

General Terms: Computer Science**,** IoT Sensor
Keywords: Sensor, Shoes, Gait Correction

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1. INTRODUCTION

Due to advancement in technology, our lives have become more convenient. However, the number of physical activities decreased due to shift to indoor activities and involvement of computers and other gadgets. Since the 2000s, diseases that tend to occur in high-age groups such as degenerative arthritis and intervertebral disk has been gradually increasing in low-age groups because most people's gait is not correct or their bad habits. One of the fundamental problems with these results can be found in an indifference to gait.

In order to solve this problem, we need to be more aware of proper gait. Factors contributing to this includes incorrect walking which leads to adverse effects on the joint health of the spine, pelvis, and lower limbs. If this occurs for a long time, complications may occur. Other factors include the increased use of computers or students wearing a heavy backpack or bags on one shoulder. These can lead to a high possibility that the spine may be deformed from its normal structure [1, 2, 4]. Furthermore, wrong posture affects not only physical health but also psychological health [3, 6, 7]. Daily habits and postures greatly influence the human skeletal structure, thus, it is very important to keep a proper gait. To do this, people should be aware of proper sitting and walking. For example, the spine should be straight and both feet should be moved when walking.

As modern society becomes more prosperous, people's interest on health is increasing, including the use of convergence technologies among the medical field. Examples of convergence technologies in the medical field include the use of IT for medical diagnosis and analysis, micro and nano technology for treatment, and wearable computer technology for health monitoring. Various research are actively conducted to develop relevant technologies on this field.

Another advancement is among communication technology. An example is the ubiquitous health care (U-Health Care), where patients, through smartphones or computers, can receive medical treatment from medical team after being diagnosed with their health condition. Research on gait correction focuses on measuring foot pressure using optics and comparing it with a normal value of foot pressure. However, this type of research is limited [4, 5, 8, 10].

Preceding studies on gait analysis have two major limitations. The first is expensive experimental equipment. Many kinds of assisted device used in research are body-attached, such as pressure sensor carpets and accelerometers, thus, increase the costs of research. The general public struggle with access to this device. Second, it is difficult to measure the experimenter's usual gait. They get psychological burden because it is a controlled environment that is different from daily life, and they are required to wear various device. To address these limitations, efforts to simplify the device and to reduce costs increase. Many studies have been conducted to analyze gait by attaching sensors or device to an inner sole, which is cost-effective and convenient to carry, and wear compared to other devices.

Therefore, efforts to simplify device and reduce costs and researches that may confirm gait patterns are increasing in order to compensate for the limitations. From a medical point of view, gait is a factor that directly or indirectly affects physical health, and it may become a factor that determines impression and personality from a psychological and cultural point of view.

Studies related to existing gait have been researched in various ways. It also analyzes gait using multiple camera device, EMG transmitters, and pressure measurement platforms, and specializes in studying the gait of patients with certain diseases. In general, research is conducted in a way that a sensor or device is mounted on a body part to measure motion and analyze it. The body parts that are mainly measured are thighs, calves, ankles, and wrists, however depending on the research, subjects wear device on the waist or head. The sensor can also be mounted on a mat that subjects can walk on, such as on the ground, to measure their gait [9, 11, 14, 18].

In line with this, the stud aimed at determining the walking styles are either classified or incorrect gait is recognized then corrected. The final purpose of most studies on gait is related to medical treatment or health. Therefore, this study measured subject's gait status and monitored the wrong gait through an application or PC referring to data analysis. Through the pressure sensor, it is possible to check the correct order in which the soles of the feet touch the ground. This output value may be measured by the LED flickering through neo-pixel. In addition, unlike existing products, the three-axis acceleration and Gyro sensor are used to correct the shape of the gait by classifying it as in toeing gait and out toeing gait.

2. RELATED WORKS

2.1 Gait Correction

The gait of a person may be largely divided into three types of gaits. There is 'out toeing gait' in which the front of the foot with the toes points outward, 'in toeing gait' in which the forefoot crosses inward with each step, and an ideal 'normal gait' in which the forefoot is stepped following the direction of walking.

The joint movement pattern, force, kinetic energy, potential energy, and surface touching the ground vary according to the gait type. Gait can be checked with the naked eye, but this may be inaccurate. Measuring the gait accurately requires expensive device, which takes a lot of time and money.

One study showed an advantage because the device was portable and in a shape of a shoe insert and there is no time-based and spatial limitation. However, the disadvantage is the cost because one shoe has more than 90 sensors installed. Therefore, in this study, a small system is manufactured that determines gait to keep the right posture and live a healthy life, and it is confirmed that gait may be easily and simply measured by this system [10, 12, 14, 17].

In general, in toeing gait looks ugly because the foot goes inward, causing the femur to twist inward. On the other hand, out toeing gait is a walking step in which both feet walk outward, causing the leg bone to twist outward and adversely influence the spinal joint, and there is possibility of increasing back pain.

The normal gait is the healthiest step, making your body straight and touching the ground from your heels to the center of your feet and toes, so even if you walk for a long time, the pain in your feet will not be severe, but well-balanced because you walk straight.

Most of the people are walking out toeing gait, and some people are walking with in toeing gait or normal gait. Those who walk out toeing gait or in toeing gait have become habitual from a young age and often do not realize that it is a wrong gait. If this gait is treated as insignificant, it will become habitual and when you walk in the same shape for a long time, the skeletal structure of the body may be affected and the spine may curve. This may lead to poor posture or spinal-related diseases.

There are methods to measure a person's gait measuring the movement of the center of gravity that the foot touches the ground when walking, to measure the period of gait with kinematics, such as the movement of the ankle bone, and to measure the angle of movement when feet is moving according to the starting point of taking off the foot. There is a study on identifying a person using human body measurement and gait information of a sensor. In this study, subjects were divided through individual gait habits by accurately measuring a person's gait condition.

2.2 IoT-Based Sensor Shoe System

This study confirmed whether the correct value may be measured through the Kinect sensor. Gait is analyzed through machine learning algorithms KNN (K-Nearest Neighbor), SVM (Support Vector Machine), and MLP (Multi-Layer Perception) to find which algorithm is effective for gait analysis.

When researching about analysis of the relationship between the degree of back pain and the disability index according to the gait type of normal people, back pain was focused by analyzing the gait of normal people. We found properties to determine the problem related to the waist and analyzed what kind of gait style causes problems to the waist. The study was conducted by setting the width of the stride, the width of both feet, arch of foot, the angle at which the foot goes out of straight direction, and the weight as attribute values [6, 9, 10, 13].

As a result of the study, it is found that problems related to the waist occurred when the values of patients deviated from the standard value. And in the visual feedback system design study for gait management, visual feedback system design was researched. Recently, many studies have been conducted in which gait measurement and feedback may be obtained in real time at a low cost using wearable computing platform technology [2, 15, 16, 17, 18, 19]

The structure of this visual feedback system allows the user to directly wear the wearable device to analyze the result value that is obtained by walking through the smartphone application. As to attributes of analyzing the gait, the degree of widen tiptoe, the number of steps taken in out toeing gait, the number of steps taken in toeing gait, and the total number of steps were calculated. In addition, as per disease prediction according to gait, we measured the hip joint with a Kinect, then analyzed and predicted whether there is a problem with the hip area caused

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by gait habit. The slope was calculated using the joint coordinates of both hips with Kinect, and about 30 people were measured to determine whether they had a problem with 93% accuracy.

Sensors are directly mounted on shoe soles or shoes and data is transmitted through wireless communication or Bluetooth. The user receives feedback of the analyzed data through the application. There are studies that provided feedback with stimulation of auditory, visual, and vibration, and some of the studies showed the pressure distribution of the soles through pictures and graphs. There was also a study on providing feedback that the gait status as a character's facial expression to add interest.

3. SYSTEM DESIGN

Figure 1 shows the whole circuit diagram based on IoT. When the user is walking, the pressure sensor and the 3-axis acceleration/Gyro sensor detect the walking status and receive the input value. The control unit allows the analog-to-digital conversion received from the pressure sensor so that it can be checked as digital values 1 and 0. Since the 3-axis acceleration/gyro sensor requires analog values, thus A/D process was not required.

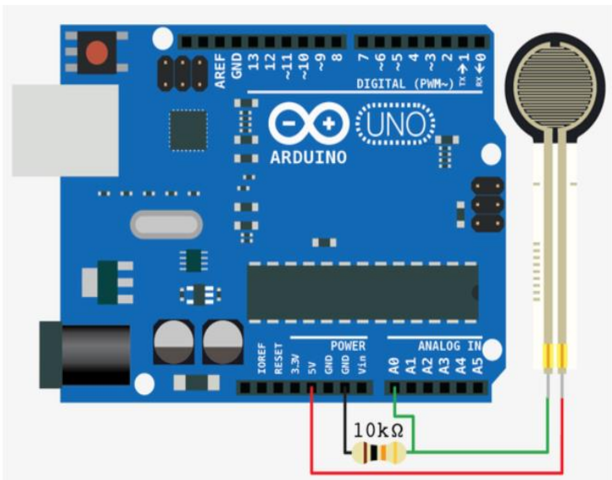


Figure 1: Circuit Diagram

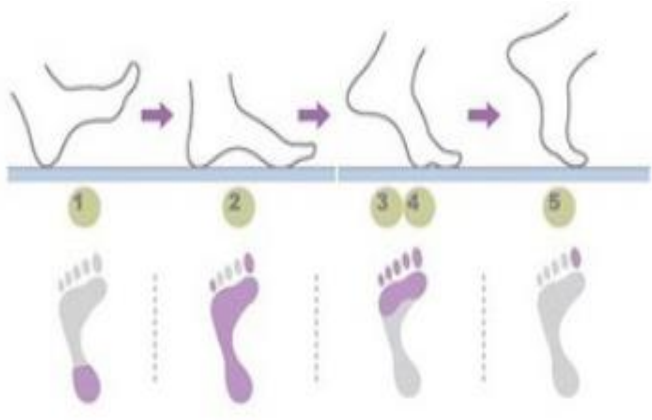
The received input value transmits and receives the data value wirelessly to or from the PC using Bluetooth. Through PC, it may check the output value with a waveform after saving the data value in the Excel using the serial monitor value of the Arduino program. When the pressure sensor is pressed in order using Neo Pixel, the output can be checked through the LED.

In addition, you can check the step count using the application, the calories burned after receiving the exercise time, and your weight. The following figure shows the pressure sensor (FSR-402) applied in this study. When pressure is applied to the sensor, the resistance of the sensor decreases, and the signal may be changed.

Figure 2 : Pressure Sensor (FSR-402)

Therefore, the intensity of the pressure at each point of the sole may be found through the pressure sensor. The position of the pressure sensor was placed on the part where the weight is most carried when a person walked in shoes.

Figure 3(a) shows the distribution of the load on the soles of the feet and the five stages of normal walking motion. The pressure sensor was arranged as shown in *Figure 3(b)* based on the load distribution diagram.



(a) Distribution of Load on the Floor

(b) Pressure sensor arrangement

Figure 3 : Pressure Sensor Positioning

The user may designate the number for each pressure sensor to confirm that the pressure sensor is sequentially pressed while the user is walking. This study used 3-axis acceleration/Gyro sensor (MPU-6050). It is possible to classify the shape of gait through x, y, and z axes of the sensor.

In order to correct the gait, the wrong gait was classified into in toeing gait and out toeing gait. Out toeing gait was classified into a form in which the tiptoes were widen outward, and in

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toeing gait was classified into a form in which the feet are curved inward. This classification criterion was determined with an angle at which the tiptoes were widen in a normal gait status.

The following figure shows the algorithm of a 3-axis acceleration. We set an arbitrary angle, and the standard value of the angle between them to distinguish in toeing gait, out toeing gait, and normal gait by finding them whether they are larger or smaller than the angle.

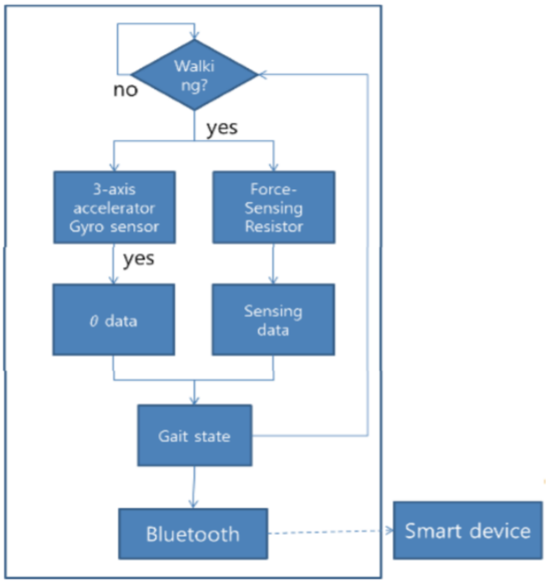

Figure 4 : Device Sensing Algorithm

For A/D converter device, ADC0808CCN was used. The following figure shows the data sheet of ADC0808CCN. This study used ADC IC device to convert the analog input value of the pressure sensor to digital.

```
void setup() {
#if defined (__AVR_ATtiny85__)
if (F_CPU == 16000000) clock_prescale_set(clock_div_1);
#endif
strip.begin();
strip.show(); // Initialize all pixels to 'off'
}
void loop() {
// Some example procedures showing how to display to the pixels:
colorWipe(strip.Color(255, 0, 0), 50); // Red
colorWipe(strip.Color(0, 255, 0), 50); // Green
colorWipe(strip.Color(0, 0, 255), 50); // Blue
// Send a theater pixel chase in...
theaterChase(strip.Color(127, 127, 127), 50); // White
theaterChase(strip.Color(127, 0, 0), 50); // Red
theaterChase(strip.Color(0, 0, 127), 50); // Blue
rainbow(20);
rainbowCycle(20);
theaterChaseRainbow(50);
}
```

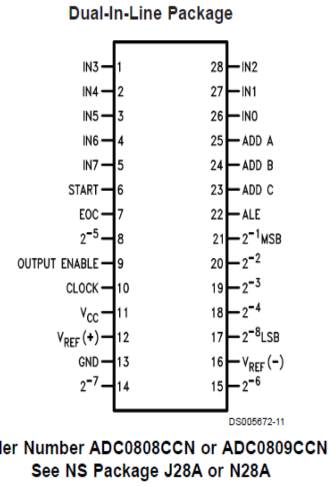

Figure 5 : ADC0808CCN Data Sheet

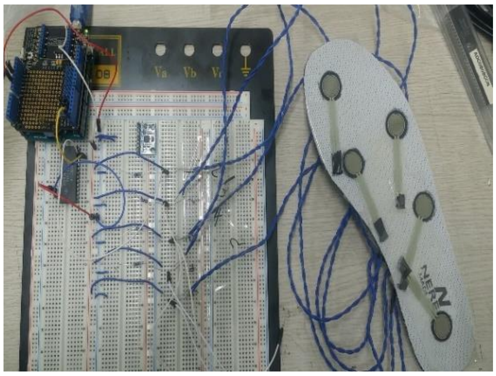

Figure 6 : System Connection

```
#include <Adafruit_NeoPixel.h>
#ifdef __AVR__
#include <avr/power.h>
#endif
#define PIN 6
Adafruit_NeoPixel strip = Adafruit_NeoPixel(10, PIN, NEO_GRB + NEO_KHZ800);
```

Figure 7 shows the Neo-pixel. It was applied in the study to receive input from the pressure sensor and directly check with the naked eyes when pressed in order. In addition, Neopixels was attached around the shoe, used input voltage of 5V, and set the time and color of LED blinking by interlocking with the pressure sensor through Arduino programming. The output value of Arduino was possible to be confirmed with a smartphone. The output value of the sensor may be confirmed through application of Bluetooth wireless communication after receiving input from sensors attached to the shoe.

Figure 7 : Neo-pixel Strip

4. ENVIRONMENT AND RESULT

The following figure shows the operation of the shoe that the pressure sensor is connected to LED. The circuit was composed of the pressure sensor, resistor, and diode on the breadboard, and the output was confirmed by LED lighting when pressure is applied.

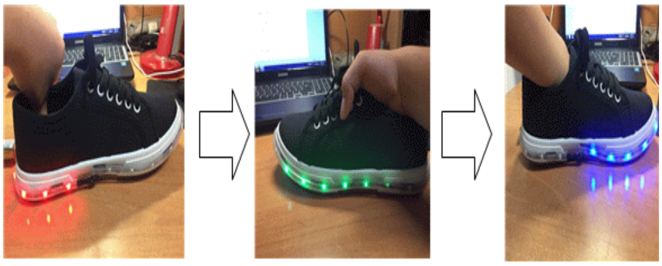

Figure 8 : Operation of the Shoes

As shown in *Table 1*, an experiment was conducted to confirm whether the pressure sensor is operating. As a result of the experiment, we confirmed that the LED, which is connected just above the tip of the shoes, did not light up with an 80% probability among the pressure sensors located at the designated number.

Table 1. Pressure Sensor Experiment

Sensor Number	1	2	3	4	5
1	O	O	O	X	O
2	X	O	X	X	O
3	O	O	O	X	O
4	O	O	O	O	O
5	O	X	O	X	O
6	X	O	O	X	O
7	O	O	O	X	O
8	O	O	X	X	O
9	O	O	O	O	O
10	O	X	O	X	O
Error rate (%)	20	20	20	80	0

Table 2 shows the analog output value based on the subject's different body weight. The output value is the sensor value of the serial monitor that shoes the pressure sensor value using the Arduino program, which means the ADC conversion value.

Table 2. Pressure Sensor Analog Output Value

Weight	50kg	55kg	60kg	80kg
1	966	965	967	966
2	968	967	968	971
3	965	969	968	970

In addition, the correct gait was visually confirmed by flickering according to the order in which the pressure sensor is pressed using neo-fixel. If only the pressure sensor on the heel is pressed or only the pressure sensor on the front of the foot is pressed, it is set that no lights on, and LED is programmed to light up only when pressed sequentially from the heel to the front. We checked whether the soles of the feet touched the ground in the correct order. In order to measure the user's gait, x-axis of the 3-axis acceleration sensor was attached to the front of the shoe so that the x-axis may be perpendicular to the direction of progress and the y-axis may be parallel to the direction of progress.

We also determined the angle between the heel and the tiptoe, so that the standard of the gait can be set. After determining the standard angle of a normal gait, we checked the difference between out toeing gait and in toeing gait. The value was used as a reference point for each gait.

In the case of correct gait, the angle from the heel to the tiptoes does not extend more than 15 to 20 degrees. If the value is positive, it may be identified by out toeing gait but if it is negative, it may be identified by in toeing gait. A 3-axis acceleration sensor (MPU-6050) was used to check the shape and accuracy of each step.

This acceleration sensor occurs a large error value therefore, it was verified through several experiments. The angle was measured for the reference line and the acceleration sensor was attached by distinguishing in toeing gait, out toeing gait, and normal gait. After wearing shoes with the acceleration sensor to set the initial reference value, subjects took a normal step. We compared incorrect gait based on the waveform for normal gait shown in the figure. Through these graphs, out toeing gait and in toeing gait were distinguished.

The normal gait was marked with a dotted line, then the x-axis and y-axis acceleration values for out toeing gait were designated as solid lines to distinguish them. It is confirmed that the waveform that appears in the case of out toeing gait is generally located higher than the waveform that appears in the case of normal gait. *Table 3* show the recognition rate for in toeing gait and out toeing gait.

5. CONCLUSION

To keep a healthy and correct posture, walking in ordinary times is important. Human gait can be largely divided into in toeing gait, out toeing gait, and normal gait and in toeing gait or out toeing gait may have a bad effect on the skeletal structure. In this study, we developed a shoe that can analyze the gait shape using a strain sensor. When walking with the developed shoes on, the signal sizes of the three sensors mounted on the shoes appear differently, we could confirm that human walking patterns can be read by analyzing this sensor signal.

This system may be approached as a precautionary measure by notifying other parts of the body where there is an abnormality in asymmetric walking (walking with differences in speed, angle, and stride of both feet) and when dragging feet. It is also expected to be useful on rehabilitation and tele-healthcare for specific patient groups such as those with cerebral palsy or Parkinson's disease. The shoes developed in this study were intended for children’s gait correction for those who have an open growth plate and muscles are less developed. The system can improve foot deformation and can be used regularly by adding fun features on the shoes such as sounds and lights.

In addition, a Bluetooth-based communication system was connected. In other words, information on gait is automatically saved wirelessly based on the application, and users can receive feedback on various walking information real time, such as gait status or running situations, and distortion of posture through the recorded information. Rephrase. The wearable device developed in this study measures the wrong gait using a pressure sensor and 3-axis acceleration sensor so that users could walk correctly. Through this program, the correct order was checked in which the sole of the foot touches the ground with the pressure sensor, and the gait shape was checked using the 3-axis acceleration sensor. Therefore, it is possible to distinguish a normal gait from out toeing gait or in toeing gait by analyzing the user’s gait status. The change value of the acceleration sensor can be monitored through a waveform. It was confirmed as an output value of 1 and 0 by converting the analog value of the pressure sensor into a digital value.

Users can also visually check whether the soles of their feet properly touched the ground by designating the color of neo-fixel through programming so that they can know whether they are taking the right step when the pressure sensor is pressed. Accordingly, it is possible to increase the accuracy of the gait correction. The experiment was conducted by setting the normal gait as 15° to 20° using the 3-axis acceleration sensor and when it was wider than the standard angle, it was deemed as out toeing gait and when it was narrower than the standard angle, it was deemed as in toeing gait. Through the experiment, the recognition rate capable of distinguishing in toeing gait was 56.25%, and out toeing gait was 81.25%. The result values were based on the waveform for normal gait and the specific point was set to compare the accuracy of the graph to induce correct gait habits.

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