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Development of Gait Correction System for Real-Time Gait

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Abstract

Walking is one of the most natural and repetitive actions we do in our daily lives. However, many modern people have problems with shoulders, back and spine due to incorrect walking habits. Therefore, it is becoming important to diagnose and correct wrong walking habits, for example, in-toeing, out-toeing, etc. early, which can be a precursor to various diseases. In this study, we developed the system to diagnose and prevent incorrect gait by grasping and analyzing the angle and muscle activity of the foot according to the typical wrong gait type through MPU 6050 acceleration sensor and the surface EMG sensor. Through a smartphone, numerical and visualization screens based on walking can be used to represent the angle of the feet, real-time EMG values, and even the number of steps. The correction effect was enhanced by improving the cognitive ability through a system that allows individuals to easily diagnose gait through smart devices and improve them according to their own problems.

Keywords: *Gait analysis, In-toeing, Out-toeing, EMG, MPU-6050*

1. Introduction

Our bodies are closely connected organically, and our walking seems to be a movement limited to our feet, but in fact, it is an act that affects the entire body's muscles, bones and nervous system. If you walk in the right posture, walking is exercise of the whole body that is beneficial to your health, but if the walking posture is wrong, it will adversely affect your health through your body [1]. As time goes by, the muscles get used to the wrong gait. Unknowingly, habits continue to repeat and fall into a vicious cycle in which posture spoils health. Quickly, pain occurs all over the body and problems such as body deformation appear. It is important to maintain proper walking because walking is all related to the body's movements, metabolism, immunity, and natural healing power. The types of incorrect gait measured here are as out-toed gait, in-toed gait and heel-walking gait. The out-toed gait refers to a walk like walking with legs apart because the angle at which the toes of two feet open outside is too large. The most common cause of this gait is flat feet, and the effect of germination on gait is very large. Because each person has a different living environment and different muscular strength, so there is a difference in the degree of an out-toed gait. Also, this gait causes chronic pain

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in the calf, buttocks, waist and back [2]. Both in-toed gait and out-toed gait have problems with the rotation of the foot bones [3], mainly related to the femur of the hip joint, the shin bone of the knee joint, and the lumbar bone of the foot of the sole. It can also be said that the effect on health is similar to the out-toed gait. In-toed gait and out-toed gait are common in children with cerebral palsy (CP) who related to the flat foot [4,5]. When the feet are divided into the hindfoot, midfoot, and forefoot, people with flat foot often have hindfoot valgus, dorsiflexed and abducted midfoot, and pronated or externally rotated forefoot. Because these symptoms lead to loss of the medial foot arch. Therefore, this influence makes it difficult to walk normally, and eventually leads to improper gait such as in-toed gait and out-toed gait [6].

The heel-walking gait usually occurs in people with a difference in leg length, and it is a phenomenon that occurs mainly in young children. If this posture persists, it is possible that the calf muscles and Achilles tendon at the back of the calf are tense. This results in tension and pain in the back of the calf. In particular, children usually this walk around 1 to 2 years old, but most of them are corrected and are not big problem. However, if this gait lasts for a long time or is always stepped on each step, it may be a precursor to cerebral palsy. It is important to understand and deal with it in advance.

2. System design

In this study, to use Arduino, the 6-axis acceleration sensor called MPU-6050 is attached to the top of the foot and the Surface electromyography (sEMG) sensor is attached to the outer and inner calf muscles, respectively. We implemented a system that acquires average data according to changes in the X, Y and Z-axis and obtains data on the sEMG that appears. By analyzing this and creating an application, you can inform and correct your gait type to users and control it by sending it to the MCU. Figure 1 shows a rough data flow, and Figure 2 shows a simplified system circuit diagram.

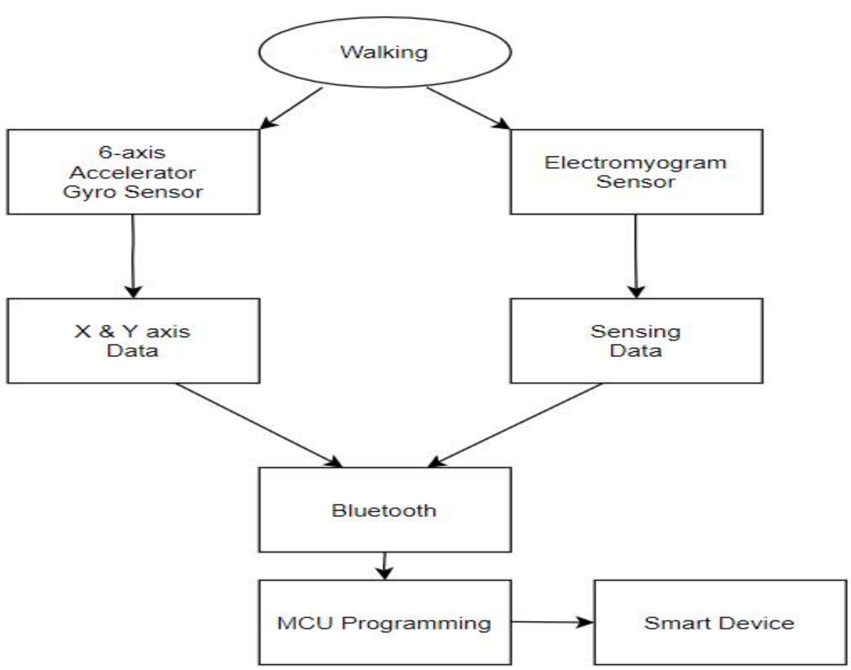

Figure 1. Algorithm for gait measurement

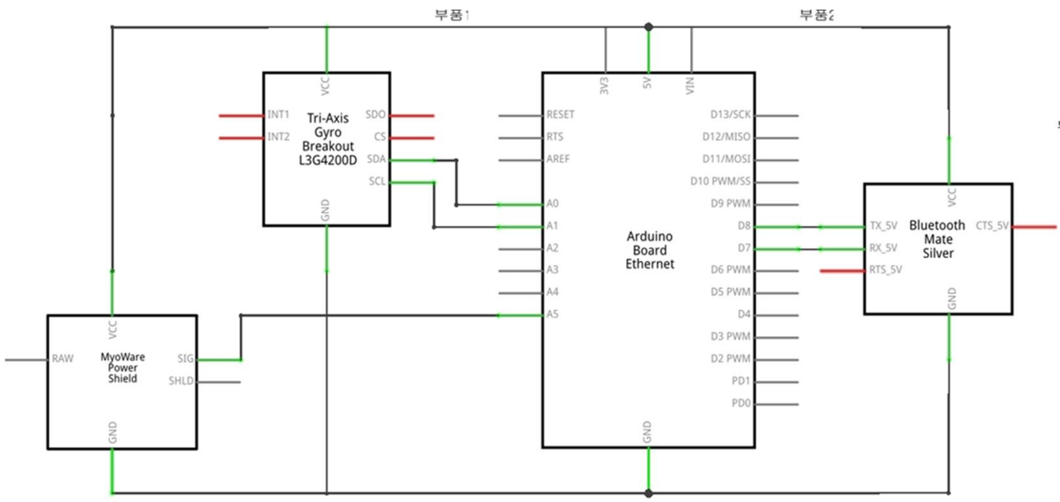

Figure 2. The Block diagram of System circuit

3. Methods

In this experiment, in order to acquire a signal from the MPU-6050 acceleration sensor, the experiment was performed after attaching it to the foot of the shoe and fixing it. As mentioned above, the experiment was carried out by dividing into a normal gait, an in-toed gait, an out-toed gait and a heel-walking gait. Figure 3 is the system design used by attaching an acceleration sensor to the top of the foot for the experiment.

First, if you look at the MPU-6050 used as an acceleration sensor, it can know the degree of tilt and rotation of the foot using the acceleration and gyro sensors. It measures the sensor values of the X and Y axis simultaneously, and outputs these values. At this time, the analog signal is converted into a digital signal through the ADC module that outputs a value of 2 bytes size for each channel, and the communication is performed through the I2C BUS interface. Using this principle, the gait was measured by attaching it to the user's top of the foot. Also, in this experiment, the two values of acceleration and gyro were converted into angles, and the angle change according to the step was examined.

Figure 3. System prototype

First, in the case of acceleration values in each axis, it is necessary to change the angle values of the X, Y, and Z axis through the arc-tangent value.

$$Accel(\angle x) = atan\left(\frac{ay}{\sqrt{y^2+z^2}}\right) \times \frac{180}{\pi} \tag{1}$$

$$Accel(\angle y) = -atan\left(\frac{ax}{\sqrt{y^2+z^2}}\right) \times \frac{180}{\pi} \tag{2}$$

It can be converted to an angle value through the above equation [7], and in the case of a gyro sensor, it should be able to convert it into an angle value. In the case of a gyro sensor, the range of –32768 ~ +32768 is converted to a range of 250 degree/sec. At this time, the gyro value is obtained through process of integrating the value obtained by this equation to obtain the angle value of the gyro sensor. Here, the acceleration sensor detects using gravitational acceleration, but it can't detect rotation about the Z-axis that coincides with the gravitational acceleration direction. Therefore, in the case of the Z-axis, it depends on the only gyro sensor, but since the value of the gyro sensor has a characteristic that accumulative errors occur, an accurate value could not be obtained through the equation without an additional sensor. In addition, since this experiment focuses mainly on the changes in the X and Y axis rather than the changes in the Z-axis, the X and Y axis were measured and analyzed. The amount of change in the X-axis angle was set as θ, and in the case of the normal gait, the value of θ was assumed to be 0. Therefore, when the value of θ is a positive number, it is determined that the out-toed gait, and when the value of θ is a negative number, it is determined that it is an in-toed gait. In the case of the normal gait, it has an angle of –2 ° to 0 °, and the out-toed gait is more than 25 °, and the in-toed gait is less than –20 ° [8].

In the case of the heel-walking gait, it was judged that it was a heel-walking gait if the amount of change in the Y-axis rather than the X-axis of the foot showed a large difference compared to the normal gait. In addition, looking at the principle of the sEMG sensor, the configuration consists of sEMG input, differential amplifier, 60 Hz notch filter, high pass filter, and low pass filter, which controls the sensor and connects +Vs, GND, -Vs to Arduino. And the part +Vs is measured by connecting it to the center or side of the muscle, and the GND part to the bone or non-muscular part of the body. In this experiment, by attaching these sEMG sensors to the inner and outer calf muscle, respectively, the muscle activity in the aforementioned four gaits was examined. The measured sEMG value was expressed in μV by the following equation.

$$Val = \left(\left(val \times \frac{5}{1023}\right) \times 1000 - 2420\right) \div 10 \tag{3}$$

The value of the above formula means the output value, and the formula refers to the ADC process that converts the digital value by dividing 1023 from 0 V to 5 V operating voltage using an analog pin. Also, the muscle activity was indicated by deriving the integral value for the EMG raw data using a Low-Pass Filter. An application was developed so that you can check the foot angle value and EMG data measured above through a smartphone in real time. We can measure X, Y, Z axis, EMG data and the number of steps, and you can intuitively judge your usual gait type through visual data. Ultimately, it figures out their gait and induce them to improve with the correct gait.

4. Results

4.1 MPU6050 accelerometer and gyroscope

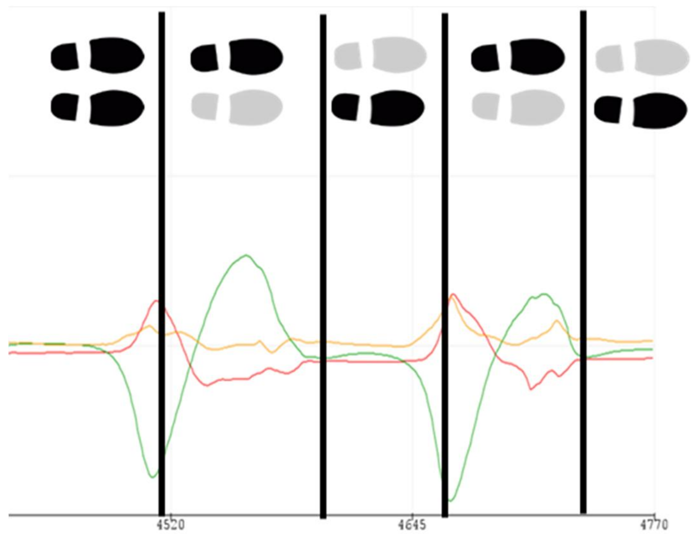

Figure 4. Serial plotter for normal gait

In this experiment, the MPU6050 sensor was attached based on the left foot. The experiment was divided into three processes. First, when the both feet touch the ground, and second, when the right foot is attached on the ground, and last, when the right foot is off and only the left foot is on the ground. Figure 4 is a serial plotter that appears during normal walking, and is the result of the three cases of gait described above.

Table 1. Angle of foot by gait

Foot \ Gait	Normal Gait		Out-toeing Gait		In-toeing gait		Heel-walking gait	
	X axis	Y axis	X axis	Y axis	X axis	Y axis	X axis	Y axis
Both	-2±.3	.99±.2	28.5±.6	.96±.35	-22±.3	-.5±.01	8.4±1.5	-15±.2
Left	-2.8±2	19.1±2	27.4±.3	29.2±2	-25±.9	18.7±2	2.3±.8	-24±8
Right	.08±.58	-.33±.7	31±.12	-3.9±.3	-21±2	-1.6±.2	6±.98	-56±5

The measurement results are shown through Table 1. In the case of normal gait, the experiment was conducted after offsetting the case where both feet were attached to a value of '0'. In the case of an out-toed gait and an in-toed gait, there is little change in the Y-axis, so the X-axis is the center. Since the Y-axis change was larger than the normal step, the analysis was focused on the Y-axis change rather than the X-axis.

First, from the case of normal gait, when the left foot is attached, the X-axis is (-2.8 ± 2) °, and when the right foot is attached, the X axis is (0.08 ± 0.58) ° as when the two feet are attached.

In the case of an out-toed gait, when the left foot is attached, the X-axis result is (27.4 ± 3) °, and the right foot is (31 ± 0.12) °, compared to the normal gait. And the result of comparing an in-toed gait with the normal gait is that the X-axis value when the left foot is attached is about (-25 ± 0.9) °, and in the case of the out-toed gait, it is a positive value on the plotter. In the opposite case, it can be seen that it is measured as a negative value. In addition, the X-axis when the right foot was attached was measured as an average of (-21 ± 2) °.

Finally, looking at the Y-axis change from heel-walking gait, when the state where both feet are properly attached to the ground is 0, the Y-axis value at the start of the heel-walking gait is (-15 ± 0.2) °, and when the left foot is attached (It was found to have a value of -24 ± 8) ° and when the right foot is attached (-56 ± 5) °. In the case of sEMG, as in the case of the MPU6050, when two feet are attached, and when the left and right feet are attached respectively, the measurement was performed.

4.2 Surface electromyography (sEMG)

The surface electromyography (sEMG) sensor was used to compare muscle activity when performing an incorrect gait and normal gait. During the normal gait, about 50% of the power generation of the entire muscle in gait occurs in the soleus muscle and calf muscles [9]. During the gait cycle, the calf muscle showed a statistically significant difference according to the gait method [10]. It was measured by attaching it to the right calf muscle as in the case of using the acceleration sensor. In the case of sEMG, the data values measured through Arduino coding were converted into µV units and expressed. However, compared to the normal gait, the out-toed gait and the in-toed gait were judged to be insignificant because they did not show much difference numerically. And in the case of the heel-walking gait, it was measured that the difference was about 3 times or more compared to the normal gait. Therefore, this sEMG sensor was used only as a sensor to support the angle value through the MPU6050 sensor previously measured, and it was intended to focus only on the comparison value with the heel-walking gait, which showed a significant difference. Also, the RAW data value of the sEMG sensor was difficult to accurately measure due to the motion artifact, so the values were compared with the values through the moving average filter.

Figure 5 shows the difference between the normal gait and the heel-walking gait in the outer calf muscle through a serial plotter. First, A in Figure 5 shows the gait cycle and sequence, and the marked part in the picture is the period to compare with normal gait. which represents the walking sequence when the standard right leg touches the ground. Namely, it represents the gait cycle when the right leg touches the ground. The part marked in A is marked in the same part in B and C. In Figure 5, B represents the muscle activity during the normal gait, and C represents the muscle activity during heel-walking gait. In the case of a normal gait, when the right leg touches the ground, the average value is about 2 ㎶, but in the case of the heel-walking gait, a value of 8-9 ㎶ was measured. Also, in Figure 6, the normal gait in the inner calf muscle and the heel-walking gait are compared. As in the picture above, part A represents the gait cycle to be measured, B is normal gait, and C is the heel-walking gait. As for the normal gait, the value of 2 ㎶ was similar to the Figure 5, but the value of 9-10 ㎶ was measured in the case of the heel-walking gait. In other words, there was a difference of about 4-4.5 times in both the inner and outer calf muscles compared to the normal gait, and through this, when maintaining the heel-walking gait, many changes in muscle activity were shown compared to the normal gait.

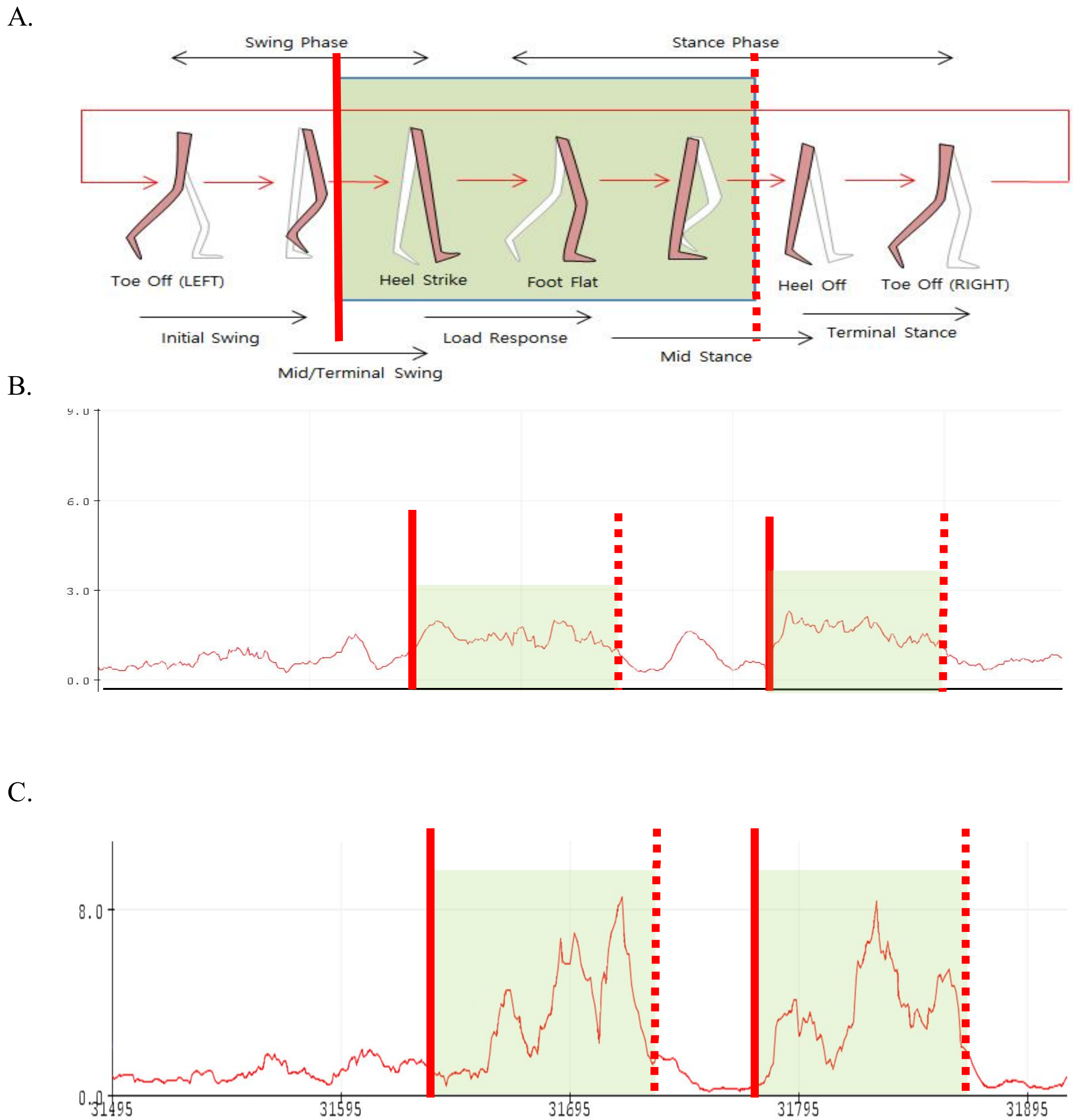

Figure 5. Comparison at the outer calf muscle

(A : Gait cycle and sequence B : Normal gait, C : Heel-walking gait)

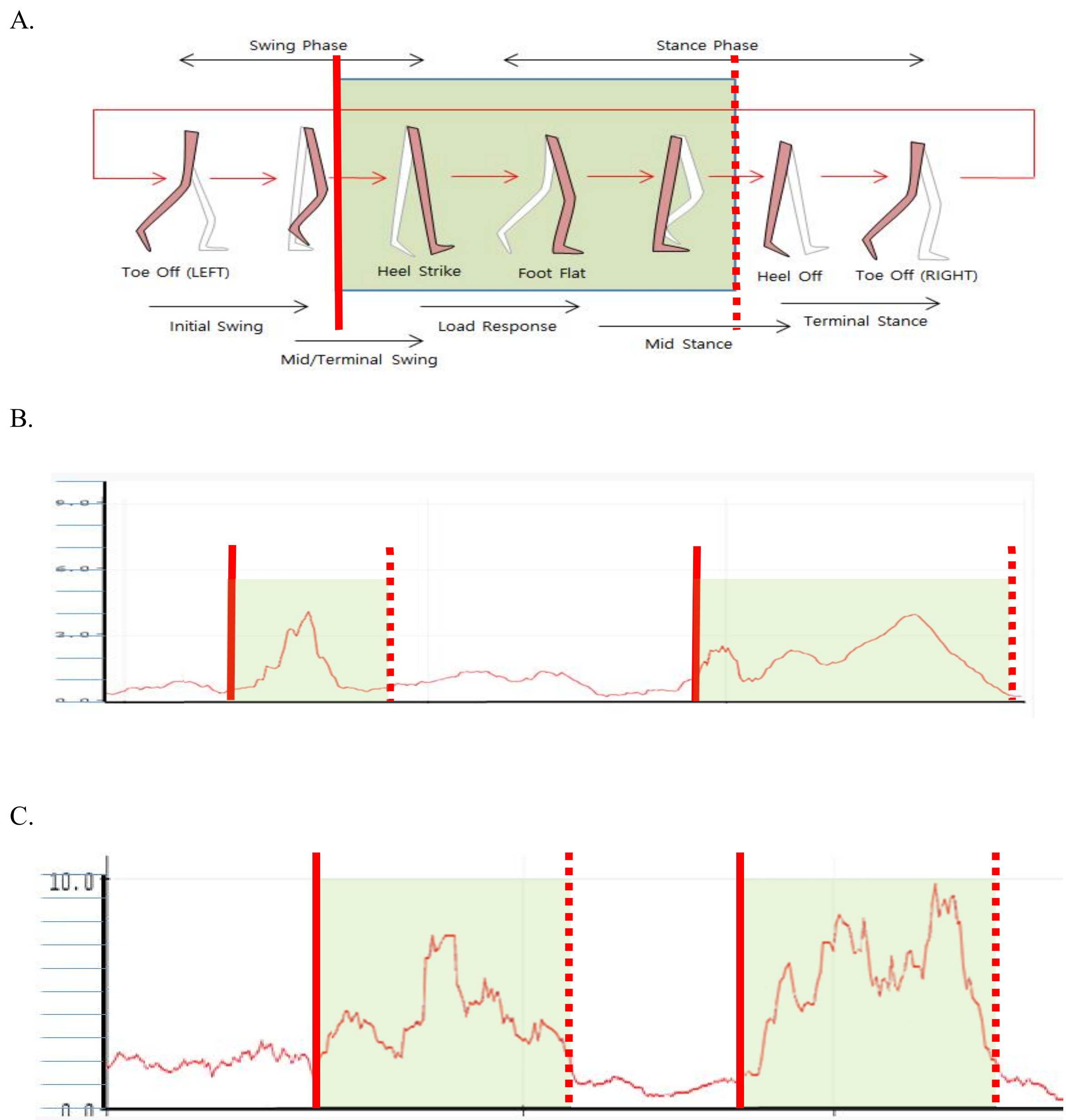

Figure 6. Comparison at the inner calf muscle

(A : Gait cycle and sequence B : Normal gait, C : Heel-walking gait)

The goal of the gait measurement system to be presented in this study is to diagnose and prevent people's wrong gait. Previous studies have shown that in the case of treatment in a hospital or home without specialized equipment, lack of data can lead to difficulty in correction. To this end, the current foot angle and sEMG value were displayed on a smartphone through the App Inventor to easily grasp the person's current gait. According to a previous study, when information was presented as numbers and analyzed as a graph, visualization was performed to enhance the user's understanding of information. Numerical values and visualization screens according to gait were configured to show the angle of the foot according to gait, real-time sEMG values, and even the number of steps.

Figure 7. Screen when using the app

The circle indicated in Figure 7 represents the gait type ratio. Also, through the above numerical values, you can know the values related to your current gait in real time. It was designed to start from the beginning again by pressing the step reset button. In the production of these applications, it was mainly composed through "IF" statement. First, the coding part related to connection in the Bluetooth client and "IF" statement to receive data values from the time the timer is activated were composed. At this time, if certain data is not received, the process of setting so that output is not performed. In this, the data value consists of a code statement to receive the sEMG value and the angle values of the X, Y and Z axis. Also, since you need to use it every day, you can measure from the beginning by pressing the 'Reset number of steps' button as shown in Figure 7. When you press the 'Final diagnosis' button, the current gait state is classified according to the foot angle. It was shown and made to be confirmed by type.

As the setting value, when the angle of the Y axis is less than '-20 °', if the value of the X axis is less than '-5 ° to 20 °', it is 'Normal gait', if it is more than 20 °, it is 'Out-toed gait', and if it is less than –5 ° , it is 'In-toed gait". If it is more than –30 °, it was set as 'heel-walking gait'. Through this process, the code of App Inventor was written, and as a result, an application system capable of measuring gait by type as shown in Figure 7 was built.

5. Conclusion

Currently, many people who have not corrected their wrong gait have a lot of problems with the joints and spine, or the risk of various diseases is increasing. In general, it can be said that out-toed gait, in-toed gait and heel-walking gait are typical false gait. Therefore, in order to analyze this and arouse awareness, a system was implemented that allows individuals to easily diagnose their gait through smart devices and improve them according to their own problems. First, when using the acceleration sensor and using based on the right foot, the result of comparing the angles of the X-axis and Y-axis coming out of the wrong gait when compared with the normal step, in the case of out-toed gait and in-toed gait, on average |15~20 °| It was confirmed that it had a degree of angular change. In heel-walking gait, on average in the Y axis rather than the X axis |28~30 °| It was found that it brought about a change in degree. In addition, by attaching sEMG electrodes to the inner and outer calf muscles, it was possible to diagnose through the change in muscle mass when comparing the heel-walking gait and normal gait. The difference in sEMG signals was measured through a serial plotter. Using this, at the end, through an application of a smart device, a system for diagnosing the change in muscle activity occurring in the current calf muscle was implemented through the real-time sEMG value' shown in Figure 7.

However, in the case of the heel-walking gait, it was difficult to express numerically when compared to the stance phase and swing phase patterns of normal gait to represent as an application. Furthermore, other service models for personal health management through diagnosis of such smart devices and gait are expected to be studied.

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