A Detachable and Wearable Walking Care(Checking Gait Device) using AHRS Sensor

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Abstract: This study identified the importance of correct walking and proposes a detachable gait detection device considering the user 's convenience and algorithms that can be used for this purpose. Recent research has focused on measuring gait and giving feedback. However, since there is a lack of research on the convenience of the user who intends to use the device, a detachable gait detection device considering the user's view is proposed. Unlike insole type sensors, which can be applied only to existing running shoes, this study makes it possible to apply it to various shoes rather than specific shoes. In particular, we have studied algorithms that can measure various value(gait type, number of steps) that could be measured only by the sensor built in the insole, by using detachable type outside the shoe. It is possible to recognize the problem of walking in daily life without going to the hospital through this device, and it is expected to reduce the cost and psychological burden of consumers further.

Key Words: Detachable type, Gait, Toe-in, Toe-out

1 Introduction

Today, as the quality of living increases, interest in health is increasing. In recent years, the number of patients suffering from diseases of the spine, neck, and legs is increasing. Not only the elderly, but also the workers and the students are sitting in the chair for a long time, so they become the subject of diseases such as scoliosis, which is a big problem in recent modern society. These health problems are related to gait. The wrong gait leads to knee and pelvic swaying, deforming the shape of the feet and legs. Not only unbalance of body shape which doesn’t look good but also from the pelvis to the neck greatly affects the spine and joint health. It is therefore important to remedy the wrong gait.

The purpose of creating a gait therapy system is in people's health and medical care. However, it is costly and psychologically burdensome to actually go to the hospital to fix the gait at the hospital. Therefore, recent research has developed a system that gives gait feedback to correct gait in real life[1,2]. However, before focusing on the feedback system, the sensors used in existing gait-related systems are operated in the insole of the shoes[3,4,5,6].

Shoes and watches for gait and health care are already on the market. In the case of a clock, it is impossible to distinguish whether the user's walking pattern is toe-out walking or toe-in walking. Overall, existing gait analysis systems are only applicable to specific shoes and running shoes. People wear shoes with different sizes and shapes, such as moc, sandals, and slippers. The purpose of this study is to develop a system that gives feedback to the user when taking various footwear. This paper suggests a wearable device that can be attached to the outside of the shoe by detachable type. This wearable device is able to distinguish typical abnormal walking patterns and proposes algorithm of the used sensor.

2 Gait Classification

Typical abnormal walking patterns contain toe-in walking and toe-out walking. Normal walking patterns contain steady-state walking. These gaits are classified by angle. Among the abnormal gait patterns, toe-out walking is a gait pattern that the feet spread outward more than 15.0 degrees from the direction toward which the body moves. Among the abnormal gait patterns, toe-in walking is a gait pattern that the feet spread more than -13.7 degrees from the direction toward which the body moves. The sensor can measure the gait that appears in both stance phase and swing phase. Assuming that the sensor is attached to the only top side of the right shoe, the angle of walking is classified. It is also assumed that the movement of the user's right foot is symmetrical to each other. Toe-in walking was based on standard deviation from Dieter's study[7]. Since toe-out walking was impossible walking posture when Dieter's study's reference was conducted, another study of toe-out walking reference was referred[8].

Table 1: Gait Classification According to Angle

Gait	Toe-in	Safety	Toe-out
Angle(degree)	-13.7	0	15.0

The azimuthal Yaw value is used as the angle-separating value. After storing the initial yaw data, initial yaw data is classified into toe-in walking and toe-out walking by zero point(Safety) according to the table 1. Figure 1 shows the changing picture according to the angle of the sensor.

Fig. 1: Using Yaw data of sensor for Gait classification

3 Algorithm for Actual Path Shift

3.1 Recognition of Switching Direction

The user wears the device and turns in the direction of the road. If the device is not reset it after turning it, it will be confirmed as an abnormal gait. Therefore, after turning, the device should be reset. Figure 2 shows the flow chart for switching direction. It is assumed that it takes five seconds for the average person to complete the turn around. Every five seconds, the algorithm was configured to check if a person was turning. Where 't' is the time between 0(sec) and 5(sec), $Y_D(t)$ is yaw data(degree). Y_{D0} is standard yaw data.

$$Y_{D0} = \begin{cases} Y_D(2), & t = 2 \\ Y_D(5), \quad t = 5 \ \ and & |Y_D(5) - Y_{D0}| > 60 \\ Y_{D0}, & otherwise \end{cases} \tag{1}$$

The algorithm of Figure 2 repeats (1).

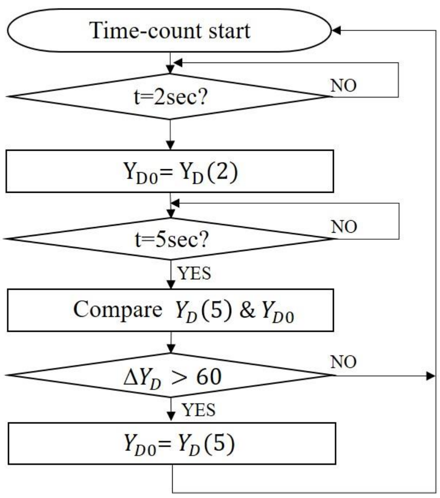

Fig. 2: A algorithm about changing direction

3.2 Measuring the Number of Steps

If the user is walking, movement of the ankle joint axis (transverse axis) occurs. This causes a characteristic change of roll value from the sensor. By using this idea the number of walking steps was measured. Figure 3 shows the roll direction caused by the up-and-down movement of the ankle transverse axis when walking.

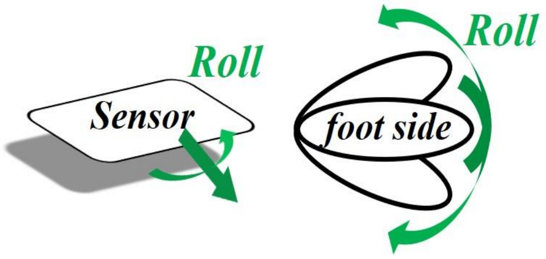

Fig. 3: Using Roll data of sensor for measuring step number.

There is a difference between the foot height and the foot flexion for each user, but since the initial roll value is used as a reference, the problem does not occur. Actually, Figure 4 is a graph that shows the change of Roll value while walking 20 steps with sneakers. An idea has been derived from previous studies that estimate the stride length of a gait using an acceleration sensor[9]. Figure 5 is a graph showing the change in roll value while walking 20 steps with slippers.

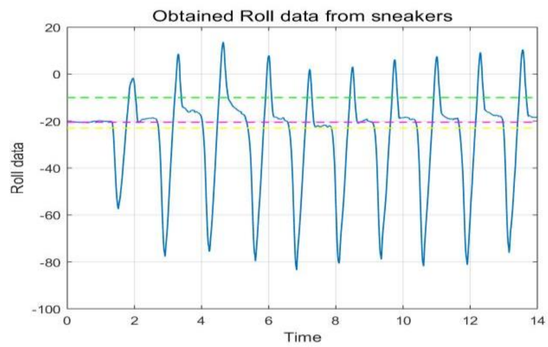

Fig. 4: A variation of Roll data graph about time(Sneakers).

There are three horizontal lines. From the top, the line represents the R_{MAX}, R_{W0}, R_{MIN}. The R_{MAX}, R_{W0}, R_{MIN} lines correspond to mid-stance states' start term, initial roll references and mid-stance state's final term respectively.

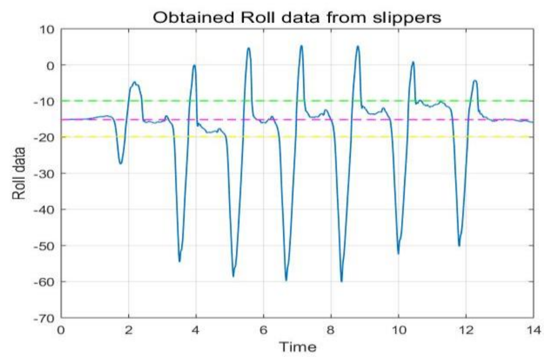

Fig. 5: A variation of Roll data graph about time(Slippers).

$$R_{W0} > R_{MAX} \tag{2}$$

$$R_{W0} < R_{MIN} \tag{3}$$

During a walk, if (2) and (3) are satisfied, the number of steps is accepted.

$$A_{RW} = \frac{\frac{|R_{MAX} - R_{W0}|}{2} + \frac{|R_{MIN} - R_{W0}|}{2}}{2} \quad (4)$$

$$A_{RW} = 6.0, \quad \in \text{ Sneakers} \quad (5)$$

$$A_{RW} = 5.0, \quad \in \text{ Slippers} \quad (6)$$

From (4) to (5) and (6) are obtained. A_{MIN} is defined as 5.0 from (6), which is the minimum value from (5) and (6). This is the value of considering a user having a small angle difference between the horizontal plane and the foot plane while walking. It is recognized as a step when the difference is more than the angle corresponding to A_{MIN} on the basis of R_{W0} (7). S_N is the step number to be measured, and R_{cur} is the current roll data. f is the flag variable used to measure the maximum number of steps per time a section is crossed. Within the section that differs from the initial reference value of R_{W0} by as much as A_{MIN}, it was set to f = 0 so that the walking distance would not be checked until it left the section again. The initial value is S_N=0.

$$S_N = \begin{cases} S_N + 1, f = 0, & (R_{W0} - A_{MIN} < R_{cur} < R_{W0} + A_{MIN}) \\ & and\ f = 1 \\ S_N, \ \ f = 1, & \text{otherwise and } f = 0 \end{cases} \quad (7)$$

Finally, it is possible to measure the number of steps of the individual foot. Figure 6 is a flow chart for measuring the number of steps.

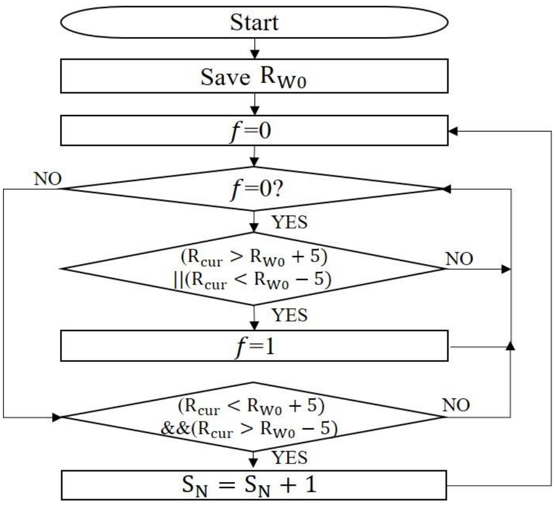

Fig. 6: A algorithm for measuring step number.

3.3 Walk Stop Recognition

Walking stop is based on when the user's walking motion stops. Suspension of walking is detected at fixed time intervals so that vibration and LED feedback do not exist to the user's device. Figure 7 shows the flow chart of the walking mode reset after a certain time when there is no change in the number of steps. S_{Npre} is the stored number of steps when t is 5(sec) and the other variables are defined as above.

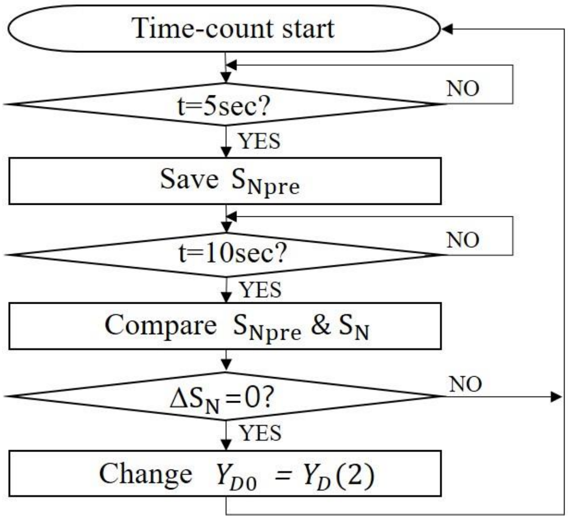

Fig 7: A reset algorithm after 10 seconds for pulling up.

The number of steps is stored every 5 seconds and compared with the number of steps every 10 seconds. If there is no difference in value, proceed to the resetting mode.

4 Experiment

4.1 Experimental Environment

Based on the algorithm designed in the previous section, a wearable identification device (hereinafter referred to as device) is designed for checking the gait. The EBIMU-9DOFV3 AHRS sensor was used as the sensor for measuring the yaw and roll data of the algorithm. We used Neo Pixel Led which can use various colors to get visual feedback from the sensor. Led shows different 3 color according to the gait. Figure 8 shows that the device can be attached to a variety of shoes. Figure 9 shows the color classification according to the gaits.

Fig. 8: Detachable device on various shoe type

(a) (b) (c)

Fig. 9: Color classification of a device according to gait.

(a) is the green light for a steady walk, (b) is the blue light for toe-in gait and (c) is the red light for toe-out gait

4.2 Measuring Accuracy of Gait Classification

For the gait classification of the male and female participants, three types of shoes were used to measure accuracy. The size of the shoes was usually chosen to fit the size of the participants. The speed of the step was 4 km / h. Table 2 provides information and results for experiments. The table below shows the average value of 35 measurements in 40 steps according to the shoe. For accurate results, each movement of the left foot and right foot was calculated as an independent step count. The measured value is the frequency at which the light of the sensor is changed during 40 steps. Average (8) was applied.

$$\text{Average} = \left(\frac{\sum^{35} \textit{frequency of user'sgait in 40 steps}}{35 \times 40} \right) \times 100 \quad (8)$$

Table 2: Accuracy of Device According to Wearing Various Shoe Type

Walk as usual	The Average (%) of the Usual Gait When Walking 40 Steps		
	Sneakers	Moc	Slippers
Toe-out walking (male)	87.29	80.76	88.29
Toe-out walking (female)	97.00	94.29	96.00

The frequency of specific gait between shoes was similar. The two users showed toe-out walking only in the swing phase. Therefore, this study shows that it is not a gait classification system that can be applied only in running shoes, but a system that can be applied even when people wear various shoes.

4.3 Step Count Measurement Accuracy

Experiments on step count measurement accuracy were carried out by comparing the actual number of walking, healthcare application, and device. A woman with a 250mm foot size experimented with a 250mm size slippers. Table 3 and Table 4 show the experimental results. Since the measurement error of the device varies depending on the speed of the stepping, the measurement is made based on the standard step and the slow step. For accurate results, each movement of the left foot and right foot was calculated as an independent step count. The average value of 30 measurements was applied. For accuracy, (9) was applied.

$$\text{Accuracy} = 100 - \left(\frac{|\textit{Step number} - \textit{test number}|}{\textit{Step number}} \times 100 \right) \quad (9)$$

Table 3: Step Number Accuracy of Device When Walking Slowly(1km/h)

The Number of Steps Measured by the Number of Steps			
The number of steps	Device Measurements Average	Accuracy (%)	Average (%)
10	10.1	99.0	99.17
20	19.97	99.85	
30	29.87	99.57	
50	50.87	98.26	

Table 4: Step Number Accuracy of Device When Walking as Usual(4km/h)

The Number of Steps Measured by the Number of Steps			
The number of steps	Device Measurements Average	Accuracy (%)	Average (%)
10	10.17	98.3	99.17
20	20.07	99.65	
30	29.9	99.67	
50	50.47	99.06	

Compare it to the Samsung Health application of mobile phone with the same conditions. The experiment was conducted with a mobile phone in a pocket. Table 5 shows the number of steps measured by the healthcare application. The table below shows the average value of 30 measurements.

Table 5: Step Number Accuracy of Health Application of Phone When Walking as Usual(4km/h)

The Number of Steps Measured by the Number of Steps			
The number of steps	Application Measurements Average	Accuracy (%)	Average (%)
10	9.1613	91.61	95.36
20	18.9677	94.84	
30	28.9355	96.45	
50	49.1613	98.32	

At a normal pace (4 km / h), the accuracy of the device was an average of 3.81 percent higher than the health applications. At a slow pace (1 km / h), the health applications were not measurable.

5 Conclusion

In this study, this algorithm was proposed to classify gait by solving the problem of gait analysis using sensors located in the insole. In addition, by developing the device based on it, it is possible to grasp the gait of the person who is usually walking by attaching to various shoes without measuring the gait by confining to the only specific shoe.

The angle of toe-out walking is specified by foot angle. The angle of feet will change the appearance of walking. In the previous experiments, gait classification was carried out including swing phase and stance phase. Instead of this case, if the angle is checked only by the stance phase, it is expected to satisfy the gait classification criteria and show higher accuracy. In our following study, we will continue to modify the algorithm based on the paper, which will be accurate data on the angle of foot and gait[10].

In addition, the device will be developed and improved as a device considering the user's view through the miniaturization and advanced design of the proposed device. This will reduce the resistance of users to wear on the surface of the shoe.

On the other hand, additional applications are developed to allow doctors and rehabilitation therapists to provide statistical data and give feedback on the patient's gait. Since the gait is digitized, the patient will be able to take care of the gait in everyday life and will proceed in a direction to help the quick correction. Also, if the proposed device is developed for children, the LEDs of the device will be interesting to children's gait and can be worn constantly, so that a gait corrective treatment can be performed in the form of a game.

References

[1] JuYoung Shin, HyeYeon Lee, SeongYeon Kim, ByungChull Bae, JunDong Cho, Visual feedback system design for gait management, The HCI Society of Korea, 2014.12, 286-291.

[2] Garam Lee, Gwangrae Yeom, Jeonghoon Rhee, Dayoung Jeong, Jundong Cho, Auditory feedback interface design for real-time gait management," The HCI Society of Korea, 2017.2, 458-461.

[3] Se-Dong Min, Chun-Ki Kwon, Step counts and posture monitoring system using insole type textile capacitive pressure sensor for smart gait analysis, The Korean Society Of Computer And Information 17(8), 2012.8, 107-114.

[4] Seoljun Yoon, Seokhyun Yoon, A study on gait pattern using a smart insole, The Korean Institute of Electrical Engineers, 2017.7, 1402-1403.

[5] HyeongSeok Kim, WonWoo Park, NaHyun Seo, Development of smart insole and mobile application for healthcare, Proceedings of Symposium of the Korean Institute of communications and Information Sciences, 2014.11, 321-322.

[6] Seong-Min Kim, Dong-Hyeon Kim, ByongHyeon Lee, DongHyun Koo, DoHoon Lee, mSiS : mobile smart insole system using pressure, gyroscope sensor, KOREA INFORMATION SCIENCE SOCIETY, 2015.12, 1651-1652.

[7] Dieter Rosenbum, Foot loading patterns can be changed by deliberately walking with intoeing or out-toeing gait modifications, Gait & Posture 38, 2013, 1067-1069.

[8] Oh – Bok Kwon, Kinematic and kinetic analysis of the out-toeing gait pattern, Master Thesis, Department of Physical Education, Graduate School, Hallym University, 2001. 6.

[9] Hwy-Kuen Kwak, Sang-Hoon Park, Choon-Woo Lee, Design and Implementation of Pedestrian Position Information System in GPS-disabled Area, Journal of the Korea Academia-Industrial cooperation Society 13(9), 2012, 4131-4138.

[10] Jae-min Kim, The analysis of walking variables in normal and out-toed pedestrian according to height of shoe insole, Master's Thesis, Department of Physical Education, Kongju National University, 2014.12