

Analysis Software based on Center of Pressure to Improve Body Balance using Smart Insole

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Abstract

Body balance necessary for ordinary daily activities can be undermined by diverse causes. In this study, as a way to control such a problem, we have produced smart insole as a wearable device in the form of insole and developed analysis software evaluating body balance, which measures ground reaction force applied to each area of sole and Center of Pressure (COP). The software visualized changes in COP positions while a user was moving and average COP positions, and it is also capable of measuring the COP values in the Anterior-Posterior (AP) and Medial-Lateral (ML) areas of feet. Through gait analysis, it can analyze the time of walking, strides, speed, COP trajectory while walking, etc. In addition, we have developed training contents for body balance improvement designed in consideration of Y-Balance Test and Timed Up and Go (TUG) Test. They were established in virtual reality similar to daily living environment so that people can expect more effective training results regardless of places.

Keywords: Body Balance, Center of Pressure, Smart Insole, Training Contents, Virtual Reality, Wearable Device

1. Introduction

Body balance is an ability to maintain the center of gravity on a basal plane in order to keep physical balance. It is an essential ability for ordinary daily life [1]. However, since body balance requires complicated interactions among multiple organs, it is subject to different causes and easily undermined. Examples include any problem in the senses of balance, for instance, - vision, vestibular and somatic senses; cognitive decline due to nerve disorder such as stroke; and reduced motor ability because of insufficient exercise or aging [2]. Such decreased body balancing ability causes spinal muscular asymmetry leading to back pain and scoliosis or disturbing normal walking to increase the risk of fall. For these reasons, it is necessary to develop a method evaluating one's body balance and improving it.

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Commonly utilized tools to evaluate body balance include sitting balance section of the Motor Assessment Scale (MAS), Berg Balance Scale (BBS), and Brunel Balance Assessment (BBA) [3]. These methods, however, are limited in requiring a skilled specialist’s explanation for their implementation and evaluating based on subjective criteria [4]. Evaluation methods under more recent research have been developed to measure body balance easily without a specialist and find objective analysis results. One of the major methods is to assess the degree of body balance by measuring the ground reaction force of one’s body using force plate and examining Center of Pressure (COP) positions, travel area, speed, etc. based on the measurements [5-7]. Since the force plate-based method, however, is implemented in a limited place of measurement, it can hardly collect body balance data from daily activities or rare occasions. Moreover, the method is difficult for an individual to afford for a training purpose as it requires expensive equipment.

To improve this, studies have been conducted on a variety of tools that can be used in everyday life at low cost, replacing force plates [8-11]. In particular, Smart Insole has the advantage of being able to detect foot movements by embedding inertial sensors and measure ground reaction force applied to the feet with pressure sensors attached to the insole so that it can be used at an affordable price available to individuals and at an unrestricted time and place. Compared with the existing balance training methods based on a mirror or monitor, the smart insole method could draw higher user concentration, satisfaction and better training results when connected to virtual reality-based contents [12].

Based on the above, software was established in this study, which can collect and analyze body balance-related data by attaching FSR and inertial sensors to shoe insoles along with training contents for body balance exercise.

2. Materials and Methods

2.1 System Configuration and Scenario

Figure 1 shows the configuration of training system using smart insole proposed in this study. Two smart insoles collect data on pressure in each foot area, feet location and rotational state. The information is transmitted to the Relay Service of analysis software through Bluetooth. The Relay Service, here, connects Bluetooth with smart insoles automatically; synchronizes the pressure, acceleration and rotation data received each from both shoes’ smart insoles; and sends to A and B. A and B are Evaluation and Training modules. Evaluation module includes Total Sway and 12Steps Walking. Training module includes Air Touch and Dynamic Squat. The system also includes a Database (DB) and a Server. The Server is connected to the DB and the Relay Service. The Relay Service is connected to the Evaluation and Training modules. The Statistics module is also connected to the Relay Service.

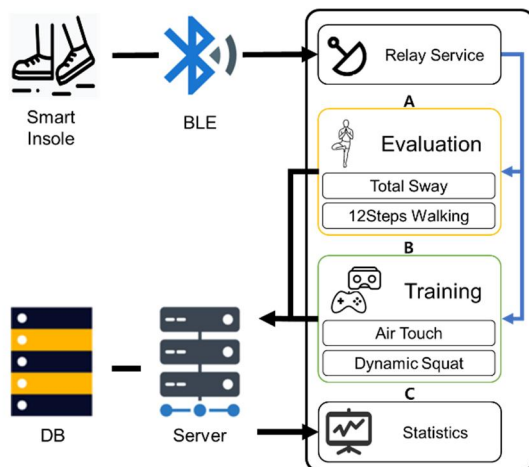


Figure 1. Smart insole-based training system configuration

The synchronized data are utilized to evaluate a user's body balance in the analysis data and to recognize a user's move in the training contents. Evaluation and training results are saved in a server to show the statistical data on pre/post-training improvement and training courses in Figure 1 C.

2.2 Smart Insole Device Production

Smart insole recognizes the distribution of pressure applied to foot, foot movement and rotational status using FSR sensor and inertial sensor and can be utilized to measure a user's static body balance or analyze his or her gait. Generally, body balance is evaluated by observing a subject's behaviors and measuring and analyzing data related to COP, a biodynamic factor. Smart insole assesses body balance by measuring the biodynamic factor and provides the benefit of measuring COP positions, deviations, travel speed, etc. Moreover, smart insole-based gait analysis measures temporal and spatial factors such as stance phase ratio, strides of each foot and walking speed; as well as kinetic factors including foot angle; and kinematic factor of ratio of area-specific max pressure to COP trajectory, etc. Based on the above, this study employed Flexible PCB with FSR sensors as shown in Figure 2 and produced Smart Insole consisting of inertial sensor and Bluetooth Low Energy (BLE) module.

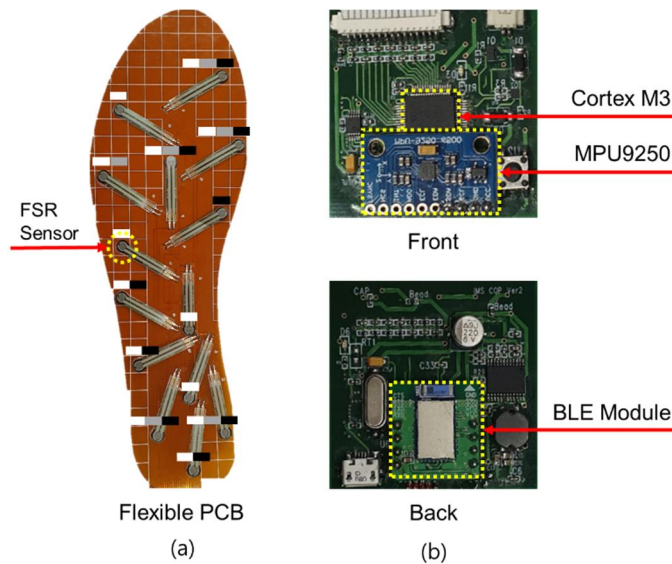


Figure 2. Produced smart insole device

Since foot pressure is to be measured, Flexible PCB was utilized as in Figure 2(a) in order to minimize discomfort while wearing or in the event of destruction. To collect the pressure generated when a foot touches the ground as much as possible, 14 FSR sensors were attached to measure the ground reaction force and COP. The position of each sensor is shown in Figure 2(a) and shown using different colors depending on its characteristics. The position of the most pressure applied to the feet was indicated by black, the white for gait analysis, and the gray for checking the asymmetry of the pressure distribution on both feet [13-15].

Furthermore, as exhibited in Figure 2(b), Cortex M3 was utilized as MCU (Micro Controller Unit) for sensor data collection and pre-processing as well as signal correction. InvenSense's MPU-9250 9-axis inertial sensors were employed to acquire feet location and rotational status values to analyze gait pattern. For longer device use by users, low-power Bluetooth was adopted.

3. Results

3.1 Body Balance Analyzing Software

The body balance analyzing software established in this study consisted of Total Sway for quantitative static balancing ability analysis as in Figure 3(a) and 12 Steps Walking Test for gait analysis as exhibited in Figure 3(b). Total Sway can measure the main parameters utilized for static balancing ability – max/min COP values, deviation, mean travel speed, travel speed deviation, and area-specific pressure distribution ratio. Data were measured for 30 seconds each with eyes open and closed to gather more diversified information by distorting information from multiple sense organs. A in Figure 3(a) shows COP position change while a user is moving, and average COP position; and B exhibits the quantitative values of foot AP or ML COP, max COP move to forth, back, left and right, COP change speed, asymmetry of both feet’s pressure, etc. 12 Steps Walking Test is a method using 4 m Walk Test used to analyze gait in limited space. In the 4 m Walk Test, the average number of steps was 7~8, so we added 4 steps in consideration of the pedestrian's acceleration and deceleration [16]. The first and last 2 steps each are excluded from analysis as they may be subject to walking speed change, and the remaining 8 steps were examined. The time taken for walking, strides, walking speed, stance phase ratio and ratio of area-specific max pressure value to COP trajectory can be measured. C in Figure 3(b) shows the time taken to walk 8 steps, stride of 1 step, walking speed and ratio of feet touching the ground during the 8 steps; and D, the distribution of max pressure on left and right feet while walking.

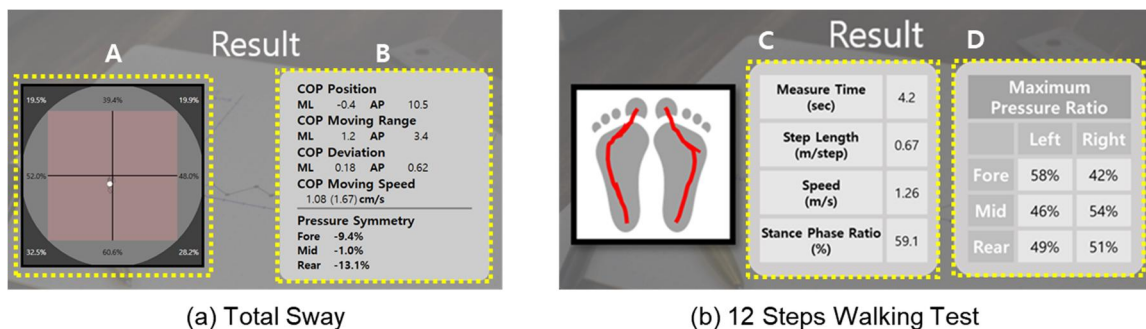


Figure 3. Established body balance analyzing software

3.2 Virtual Reality based Training Contents Designing

In order to improve body balance based on the results analyzed above, Virtual Reality (VR) based training contents were established. The contents were based on the moves utilized in existing body balance measurement but designed for subjects to follow the moves better. Figure 4(a) shows a content to perform Y-Balance move. It measures the distance that a subject can stretch forward and come back as far as possible without feet not touching the ground in the anterior, posterior, medial and lateral sides. A user performs the content by stepping his foot out to the direction indicated by an approaching arrow. The farther the user stretches his foot, the higher the user will score. If the user loses his balance to move his supporting foot or touch outside the center with a lifted foot, or step a foot to the wrong direction, he fails to score. Particularly with respect to foot movement, the actual foot locations were synchronized with the VR content using the embedded inertial sensor so that users can be more absorbed in [17].

Figure 4(b) was designed in consideration of the walking movement of Tandem Gait and sit-down and stand-up movements of Timed Up and Go (TUG) Test. Tandem Walk measures how stably and fast one can walk in

a way of stepping as if the heel of the front foot touches the toes of the back foot in a narrowed space disturbing the maintenance of center of gravity. TUG Test measures the time taken by a subject to stand up from a sedentary position, walk along, come back and sit down again. For the up and go and come back moves of TUG Test, the subjects walked across a single log bridge so that they could increase tension, concentration and absorption. In the event of applying to VR training, instead of sitting on a chair and standing up which has a risk of accident, the subjects were made to do squats so that they could train their lower limb and core muscles necessary for balance maintenance. If squats are done incorrectly, however, it could increase the risk of injury. Thus, the normal range was visually provided for users not to lose their balance and COP changes, lowering the risk of injury while helping for better performance. Scoring was based on the TUG Test measurement criterion, time. The faster the subject implemented the content, the higher the person scored. Difficulty was increased by narrowing down the width of the single log bridge to induce them to walk like Tandem Gait and train both aspects.

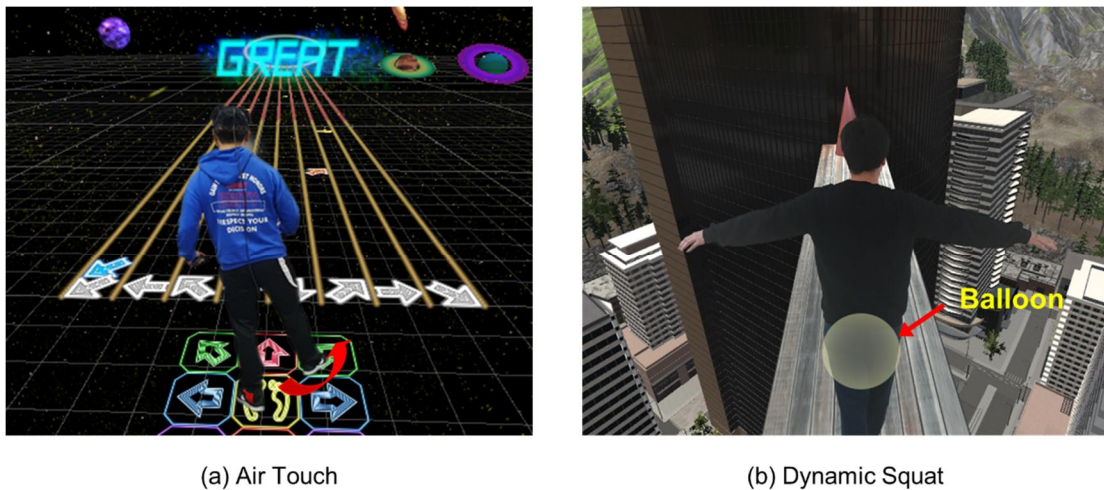


Figure 4. VR-based training contents

4. Conclusion

In this study, the software was established to evaluate body balance quantitatively by collecting diverse data, other than the existing way of evaluation based on the subjective experience of specialists. In addition to this, smart insole was produced, which is a wearable device to acquire body balance data in environment similar to our daily living space. To provide safer and stronger training effect, the training contents were designed in VR environment.

The body balance analysis software visualized changing COP positions while a user was moving and average COP positions and analyzed not only the foot anterior-posterior but also medial-lateral COP values. Gait analysis also examined the time during walking, strides, speed, COP trajectory while walking, etc.

The training contents utilizing the data related to body balance as above train the conventional moves for body balancing evaluation and present the pre/post-train changes in body balance for individual participants to visually check the effect of repeated training.

Still, it is necessary to see, through more experiments, if body balance could be actually enhanced by employing the smart insole and VR contents produced in this study and the ability to quickly and correctly perform the moves for body balance evaluation. Unlike the force plate-based method, smart insole utilizes

inertial sensors and measures each foot separately in body balance analysis; thus, the algorithm needs to be improved for higher data accuracy of rotation values.

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