Development of a Multi-purpose Test Device for Measuring Mechanical Properties of Shoes

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Abstract: This paper concerns on developing a multi-purpose test device for measuring mechanical properties of shoes. The device was modified from a commercial robot manipulator, with which impact, bending, and pronation tests were suggested to evaluate performances of shoes. From several experiments, the developed device could produce repetitive and consistent results corresponding to the different material of shoes. In the shoe industry, it is expected that the device could contribute to developing a better shoe for comfort of costumers.

Keywords: Measuring Device, Mechanical Property, Shoe, Robot, heel impact, bending, pronation.

1. INTRODUCTION

There have been many studies for analyzing human walking motion to make a better shoe for a given purpose. A. Gefen.(2000) and F. C. Anderson.(2001) and presented studies about the posture and kinetics of walking. On the other hand, there are many commercial measurement devices that can measure variety of mechanical properties of shoes. AMTI and Satra are the well-known companies that commercialize devices measuring mechanical property of shoes. Some mechanical properties measured by those devices however sometimes were failing to give consistent results due to inconsistency in human motion.

This paper concerns on developing a multi-purpose test device to measure mechanical properties of shoes by using a commercial robot system as well as on introducing a new approach to evaluate performance of shoes by using the test device. In the shoe industry, it is required to develop a better shoe for costumers. The better shoe could be determined based on softness of heel part that supports costumer's weight and reduces impact on walking depending on a given purpose. The other factors could be the bending stiffness of forefoot and stability in roll motion of heel (so called pronation). When those factors are measured while a human wearing on the shoe, reliable test results can be hardly expected due to lack of repeatability in human walking. Hence, experimental results from human walking cannot be used to compare performances of two or more different shoes. In order to resolve such difficulty, a human walking simulator is considered and developed here as the multi-purpose device.

The goal of this research is to develop a device to measure mechanical properties such as cushioning, flexibility, stability, and traction of shoe. When we try to measure such mechanical properties of a shoe, it can be a good start to develop a robot system as a test device for shoes. Although this study is only covered three items for checking the performance of shoes, it could be further extended to other items not only for shoes but also for other products after more researches.

2. SYSTEM CONFIGURATION OF THE DEVICE

In the device FARA AT2 robot with 6 degrees of freedom (d.o.f.) made by the Samsung Electronics is the main manipulator, where a passive foot model as the end-effecter is added. The Robot is then modified so that the base is hanged at a linear trailer underneath the ceiling of a main frame to perform the translation of the human hip while walking as shown in Fig. 1.

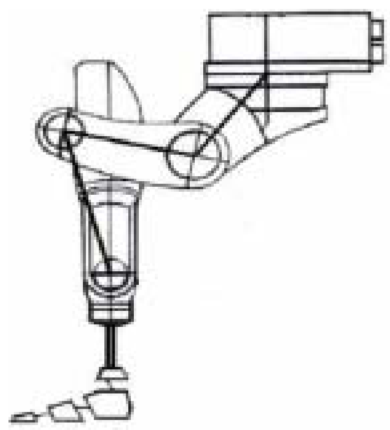

Fig.1 Schematic diagram of the system.

Table 1 Specification of the robot system

ROBOT TYPE	FARA AT2 by Samsung
Degrees of Freedom	6
Pay load	3kg
Repeat Precision	±0.04mm
Length of arm	720mm
Motor Type	AC servo motor
Position detect type	Absolute encoder
Controller type	SRCP Series

For the ankle joint motion of the foot, we first considered an actuator that could rotate the foot against the tibia (knee). However, it was hard to find a proper motor that makes the ankle joint to sustain the body weight with enough power and space. Hence, we developed the passive type of a foot model with carbon steel panels shown in the Fig. 1 which is made out of a shoe last of 265mm size. After we put specimen shoes on the foot model, several experiments have been performed. Here we took some tests with 6 kinds of shoes which are assembled with different hardness of outsole.

On the floor, we placed Force Platform made by AMTI and connected it to a PC. The Force Platform has sensors inside to measure the ground reaction forces that are composed of 6 components F_x, F_y, F_z, M_x, M_y, and M_z corresponding to 6 d.o.f. of a 3D space. Then we could extract necessary mechanical properties out of measurements.

3. EXPERIMENTS

3.1 Motion Test

After the system was completed, we checked accuracy of motion corresponding to given commands. A trajectory of the foot among several is given in Table. 2 and the path of the foot is given in Fig. 2. The error of the path was 10^{-1}mm order that is small enough for us to use the system as a measuring device.

Table 2 The coordinates of assigned 4 points

(x, y)	6 joint angles
(40,-15)	0, 29.776, -173.477, -180, -71.434, 32.2
(60,-15)	0, 1.568, -124.094, -180, -50.259, 32.2
(60, 15	0, 36.223, -124.094, -180, -15.603, 32.2
(40, 15)	0, 64.431, -173.477, -180, -36.779, 32.2

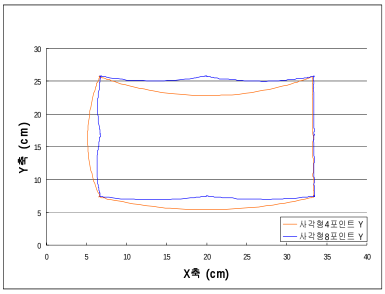

Fig. 2 Trajectories of assigned 4 and 8 points.

3.2 Foot Model Test

To test the linearity of stiffness of the foot model upon dynamic deformation occurred during heel impact of walking motion, we performed 4 experiments with different walking depths such as a reference depth and 3, 6, 9mm under the reference. The reference depth was selected when F_z of the GRF reached 40N while walking motion was generated from the manipulator. Fig. 3 shows F_z responses (impact forces) that are linearly increased according to the depth of walking. Hence we could assume the foot model gives linear response upon dynamic walking motion.

3.3 Impact test of assembled shoes

Since the impact of the rear foot is severely high about 1.5 to 3 times of human weight during heel strike of walking period, serious and repetitive impact may cause damage in the knee joint as well as the brain. Hence we want to reduce peak of the rear foot impact by selecting proper hardness of outsole, midsole and insole and their design. Here we try to bring this device to measure hardness of a shoe after it is assembled from parts in a factory.

In order to test the validation of the device, we have prepared three kinds of shoe of which the outsole is made of Shore hardness rubber 55, 65 and 75, respectively. At first, we ask one adult to wear those shoe specimens on and to walk along a straight path several times with 4km/hr speed. On the floor of the path we placed the Force Platform to measure the GRF while walking. In Figs. 4~6, we can see the inconsistent results lack in repeatability, where the trend of F_z also varies

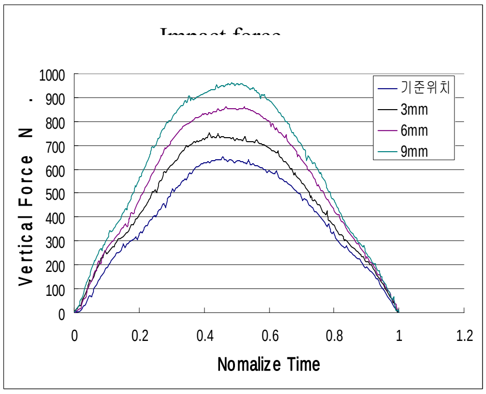

Fig. 3 The responses of F_z corresponding to the the amount of deformation.

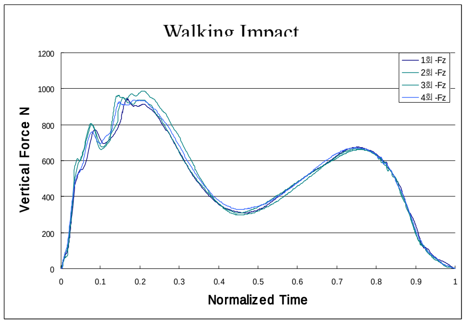

Fig. 4. F_z responses of outsole hardness 55 while walking

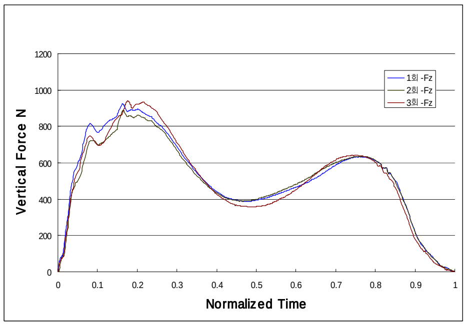

Fig. 5 F_z responses of outsole hardness 65 while walking

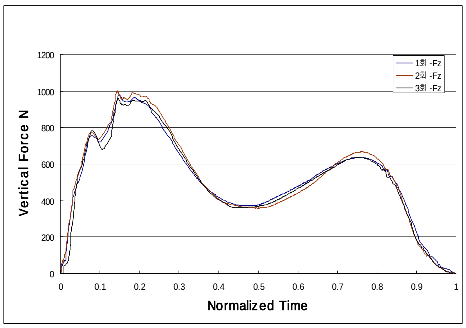

Fig. 6 F_z responses of outsole hardness 75 while walking in every trial with same hardness shoe. We can hardly find the

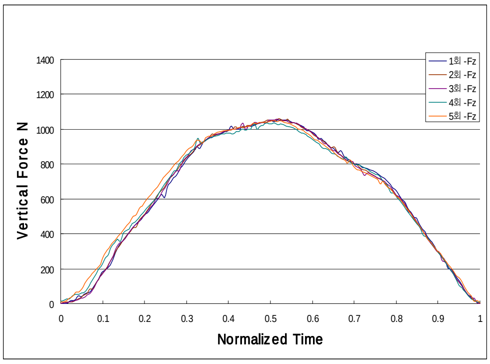

Fig. 7 F_z responses for the badminton shoe with Shore hardness 55.

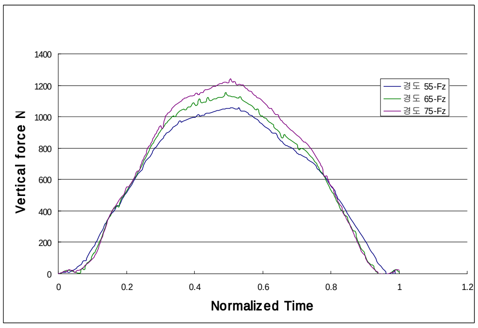

Fig. 8 F_z responses for the badminton shoes with Shore hardness 55, 65, and 75, respectively.

difference in the maximum of F_z from different hardness in Figs. 4~6. It might be because a human cannot perform a same walking pattern every time and is willing to quickly adapt on change of walking condition.

Then we put those same shoes on the foot model of the device instead of a human to check whether the device can produce reliable results on the walking motion with different kinds of shoes. If so, we could use the device to measure the dynamic response of a shoe while walking. We performed walking motion of the device after three different kinds of shoes put on the foot model and measured the response of the F_z. After collecting data from the experiments, we showed one results in the case of Shore hardness 55 of outsole in Fig. 7, where the trend seems very consistent in every trial. After taking the three different result sets, Shore hardness 55, 65 and 75 of outsole, we combined them in the Fig. 8, where the trends seem proportional. Hence we could utilize the data taken from the developed device as a reference to measure the hardness of assembled shoes. We could expand various walking conditions, such as walking speed, walking style and ground condition, etc.

3.4 Bending Stiffness test of assembled shoes

For the next study, we concerned the stiffness of assembled shoes. Generally the stiffness of bending is an important factor on sports performance. Its small difference may cause significant difference in runner's fatigue in marathon. Since a shoe is assembled from several parts, insole, midsole, outsole, texon with their own stiffness, we may want to know the bending stiffness of the shoe after those parts assembled. Here we want to use the developed device to measure the bending stiffness of any shoe after instructing the device to generate a

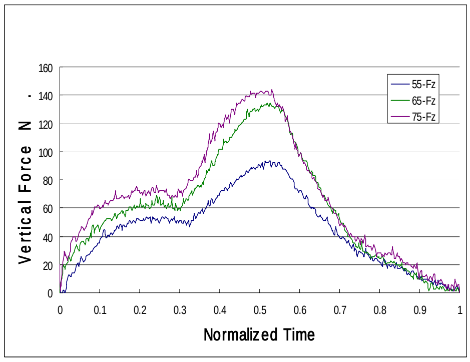

Fig. 9 Trend of bending stiffness of three different shoes

proper motion of forefoot bending.

We chose three badminton shoes with different outsole hardness, 55, 65, and 75, like the previous section. Then we put those onto the foot model, and performed the prescribed motion and measured the F_z of GRF from the force platform. The trends are shown in Fig. 9. At one third of the total period of motion, a notch type of discontinuity could be seen. This could be caused from the foot model and the bending motion. We can also observe the responses increased linearly according to the hardness of outsole of shoes. Hence, the overall trends, we can see reasonable difference between each test so that after some correction of the foot model and the bending motion, the device could be a proper measurement device to test the bending stiffness of assembled shoes.

3.4 Pronation test of assembled shoes

Pronation is defined as roll motion of shoe while walking on a floor and it depends on the shoe material and design. Generally proper pronation of foot could reduce the peak impact of the walking motion. However, excessive pronation occurred in the shoe may cause fatigue in the ankle of foot and the knee joint. Hence, we want to measure this factor of shoes after a shoe assembled. Pronation could be measured through long and tedious procedure such as recording the walking motion, digitizing the data and analyzing the angle change of a given line. In this process, it is hard to keep human walking motion consistently through out several trials for different shoes. Instead of conventional way, we want to use the developed device to measure the pronation trend of a shoe during heel strike of walking motion. When we try to measure this pronation trend during heel strike of an adult with Shore hardness 55, 65 and 75. It was not easy to find certain trends or difference corresponding to the hardness, but even with one hardness there are huge variation in the angle response shown as Figs. 10, 11, and 12 due to lack of repeatability of human walking motion. Figs 10, 11 and 12 could not produce a similar trend through 6 trials of heel strike motion with Shore hardness 75 badminton shoe.

However, Fig. 13 shows similar trends and consistent data after 6 trials of heel strike motion with Shore hardness 75 badminton shoe. Here we measure the M_y response instead of angle response of rear foot. Furthermore, as shown in Fig. 14, there is linearity in the response of hardness corresponding to hardness of shoe outsole. The maximum moment M_y is 25Ncm for Shore hardness 55 outsole shoe, 22.5Ncm for Shore hardness 65 outsole shoe, and 20Ncm for 75, respectively. Since we made the same shoes except the different hardness of outsole of the shoe, the difference in moment M_y is considered only due to the outsole hardness of the shoe. When the outsole is softer, we can easily recognize that the pronation of the shoe occurs bigger. Hence we can consider to use the developed device to measure the pronation property of an assembled shoe. This device could provide only the data of pronation properties of shoes so that the users need a further research to find a set of criteria of pronation corresponding to sports activities.

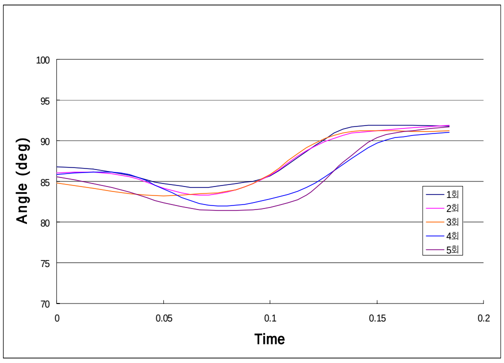

Fig. 10 Angle response of vertical line of foot while walking motion with Shoe hardness 55 badminton shoe

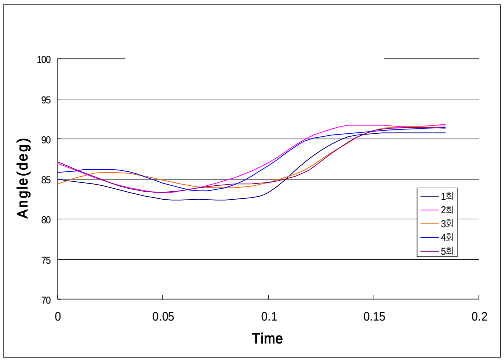

Fig. 11 Angle response of vertical line of foot while walking motion with Shoe hardness 65 badminton shoe

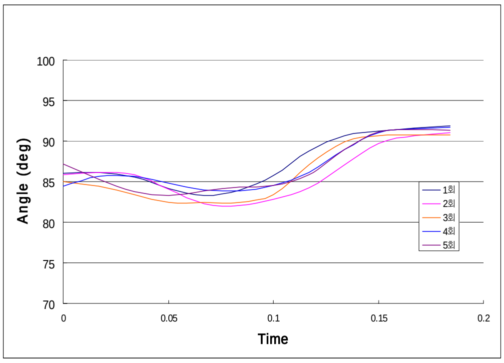

Fig. 12 Angle response of vertical line of foot while walking motion with Shoe hardness 75 badminton shoe

4. CONCLUSIONS

A commercial robot manipulator was adopted to perform a human walking and to substitute a human for building a test device to measure mechanical properties of an assembled shoe. After several experiments were performed, this device can eliminate uncertainty and lack of repeatability inherent in the human walking behavior. As the results of the developed test items that this device could pursue, impact test, bending test, and pronation test are introduced here. After three set specimens of shoes with different outsole hardness 55, 65, and 75 are prepared and tested according to the prescribed motions. From the results, the device was successfully utilized to differentiate mechanical properties of assembled shoes corresponding to construction materials and their design. This is experimental trial of a robot system into a human walking simulator and a measuring device. Throughout this work, some possibility of using robot system into shoe industry was accomplished.

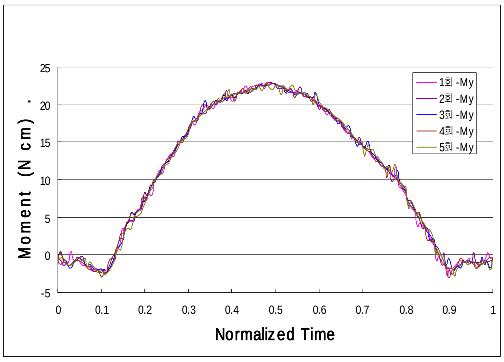

Fig. 13 M_z responses from walking motion with Shore hardness 75 Badminton shoe

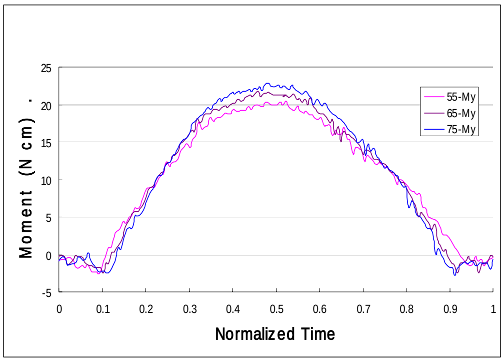

Fig. 14 Comparison of M_y responses from walking motion with Shore hardness 55, 65, and 75 Badminton shoe

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