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Research Article

IoMT-Based Smart Shoe Design for Healthy Foot-Flat Feet Gait Analysis

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Abstract

Flat feet is a condition that negatively affects the quality of life of the person and causes various health problems, such as early fatigue, pain in the feet, inward pressing, bump in the knees, and low back pain. When flat feet is untreated, it causes various health problems as progress an age such as deformity in the feet and calcification in the waist. Therefore, flat feet should be determined through various systems in order to apply the right treatment methods. The Internet of Medical Things (IoMT) is internet-based technology used in health care. IoMT is based on the principle that the data are collected through numerous sensors, pre-processed from smart devices, transferred through the access points, and analyzed through the server to enhance patients' health. In this study, IoMT-based smart shoes were designed to observe the pressure differences in healthy foot compared to flat feet by the gait trials performed with the insole. In the smart shoe design, three force sensors are placed in the medial and lateral forefoot and rear foot to measure intense pressure on the sole. During the walking test, an accelerometer was used to collect speed data, and a Bluetooth module was used for wireless communication. This smart shoe has also been designed as a cost-effective alternative to existing motion capture systems.

Keywords: Internet of Medical Things (IoMT), Pressure Sensor, Smart Shoes, Gait Analysis, Flat Feet, Smart Insole

Düz Taban ve Sağlıklı Taban Yürüyüş Analizi için Medikal Nesnelerin İnterneti Tabanlı Akıllı Ayakkabı Tasarımı

Öz

Düztabanlık, erken yorulma, ayaklarda ağrı, içe doğru basma, dizlerde çarpma, bel ağrısı gibi kişinin yaşam kalitesini olumsuz yönde etkileyen ve çeşitli sağlık sorunlarına neden olan bir durumdur. Düztabanlık tedavi edilmediğinde yaş ilerledikçe ayaklarda şekil bozukluğu, belde kireçlenme gibi çeşitli sağlık sorunlarına neden olmaktadır. Bu nedenle, doğru tedavi yöntemlerinin uygulanabilmesi için çeşitli sistemler vasıtasıyla düz tabanlılığın tespit edilmesi gerekmektedir. Tıbbi Nesnelerin İnterneti (IoMT), sağlık hizmetlerinde kullanılan internet tabanlı bir teknolojidir. IoMT, verilerin çok sayıda sensör aracılığıyla edinilmesi, akıllı cihazlar tarafından önceden işlenmesi, erişim noktaları aracılığıyla aktarılması ve hastaların sağlığını iyileştirmek için sunucu üzerinden analiz edilmesi ilkesine dayanmaktadır. Bu çalışmada, gerçekleştirilen yürüyüş testleri ile sağlıklı taban ve düz taban arasındaki basınç farklarının gözlemlenmesi için IoT tabanlı akıllı ayakkabı tasarlanmıştır. Akıllı ayakkabı tasarımında, ayak tabanına yoğun olarak düşen basıncı ölçmek için orta ve yan ön ve arka ayağa üç kuvvet sensörü yerleştirilmiştir. Yürüme testi sırasında hız verilerini toplamak için ivmeölçer ve kablosuz iletişim için Bluetooth modülü kullanılmıştır. Tasarlanan ayakkabı aynı zamanda mevcut hareket yakalama sistemlerine uygun maliyetli bir alternatif olarak tasarlanmıştır.

Anahtar Kelimeler: Medikal Nesnelerin İnterneti, Basınç Sensörü, Akıllı Ayakkabı, Yürüyüş Analizi, Düz Taban, Akıllı Taban

1. Introduction

People with flat feet have either a very low arch or no arch at all. This means that one or both feet may be flat on the ground. A human foot has 33 joints, over 100 muscles, tendons, and ligaments that hold 26 different bones together. Arches provide a spring to the step and help distribute body weight across the feet and legs. The structure of the arch determines how a person walks. Arches must be tough and flexible to adapt to stress and various surfaces. The feet of people with flat feet can turn inward while standing and walking. This is known as pronation and can cause the feet to point outward.

Pain in the feet, which can occur because of strained muscles and ligamentous injury, is the most common symptom of flat feet. Abnormal stresses on the knees and hips can cause pain in these joints. The pain affects the arch of the foot, cuffs, knees, hips, waist, and mostly lower legs. Flat feet can also cause unequal distribution of body weight. This may cause the shoes to wear out irregularly or faster and may lead to long-term injuries. Figure 1 shows the pressure distributions and arch ratios in high arched/claw feet, normal and flat feet (Imaizumi, Iwakami, & Yamashita, 2011).

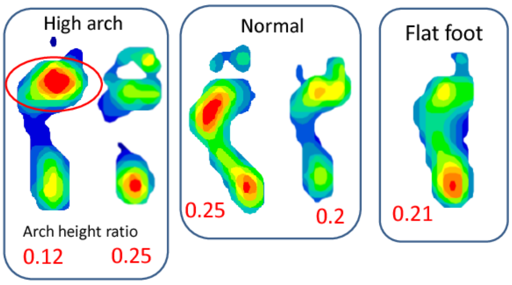

Figure 1. The pressure distributions and arch ratios in high arched/claw foot, normal and flat feet

Internet of Things (IoT) technologies used in health care are called the Internet of Medical Things (IoMT) (Bozbuğa, Tekbaş, & Gülseçen, 2021). IoMT is based on the principle that the data are collected through numerous sensors, pre-processed from smart devices, transferred through the access points, and analyzed through the server to enhance patients' health. The IoMT plays a key role in enhancing its products' quality, efficiency, and effectiveness in the healthcare field (Kumar, Arora, Gupta, & Saini, 2021). Smart shoe designs have been made in order to detect healthy foot and flat feet by using IoMT technologies.

There are many IoT-based smart shoe studies in the literature that collect various variables such as pressure, coordinate (GPS), speed, and so on. Mark Sullivan et al. has designed a smart IoT-shoe that detects abnormal gait patterns by analyzing foot pressure variations to detect gait instability in the elderly (Sullivan, Knox, & Ding, 2017). Wai Kit Cheng et al. have developed a personalized three-dimensional design shoe based on elderly foot care and safety, using GPS RFID technologies and location tracking technologies (Cheng, Lam, Lin, & Ge, 2019). Mohammadreza Abtahi et al. have introduced MagicSox, a new smart textile system that touches with multiple sensors scattered over the surface of the foot. MagicSox has developed to measure gait abnormalities in remote settings such as patients' homes so that clinicians and physiotherapists can evaluate their patients daily. They have also developed an Android smartphone application that uses Bluetooth low energy (BLE) and automates MagicSox's multisensor data collection (Abtahi, Gyllinsky, Paesang, Brlow, Constant, Gomez, Tully, D'Andrea, & Mankodiya, 2018). Haisheng Xia et al. have designed a customized smart shoe to predict the angle of foot progression during walking. They realized the smart shoe design by placing an electronic module with inertia and magnetometer sensing on the sole of a standard walking shoe. The smart shoe can be wirelessly charged, and the collected data (sampled at 100Hz) can be stored locally on the shoe for up to 160 hours (Xia, Xu, Wang, Hunt, & Shull, 2017).

In the study, an IoMT-based smart shoe was designed to observe the pressure differences between healthy foot and flat feet by performing gait trials. In the smart shoe design, a total of three force sensors are placed in the medial-lateral forefoot and rearfoot where the pressure is intense on the sole of the foot. During the walking test, an accelerometer was used to collect speed data, and Bluetooth technology was used for wireless communication. Although systems such as motion capture cameras or force platforms provide very precise and accurate data, these systems are fixed and very expensive. Thanks to the developed smart shoes, walking tests can be performed in the field or in the laboratory as desired. It facilitates the access of many patients and researchers to gait tests with its portability, lightness and comfort advantages, as well as being an inexpensive alternative.

The paper is organized as follows: In Section 2, components and architecture of the developed smart shoe are explained, and the design and implementation of the system are presented in section 3. The paper is concluded in section 4 with final remarks.

2. Material and Method

2.1. Gait Analysis

Gait analysis is a method used to identify biomechanical abnormalities in the gait cycle, as well as a tool for evaluating walking and running patterns. It is a pioneering work area for many technologies with its features such as identifying overactive or underactive muscles in the feet, which may lead to potential injuries and inefficiencies in the future (Whittle, 2007).

Gait analysis is more reliable than many methods, as it allows for measurements with computers and videography and frame-by-frame tracking of movements. In addition to the advantages of videotaping the session, motion capture camera systems assist in the interpretation of data through computer technology and complex measurements of angles, forces, and electromyography. Gait analysis is performed with a force platform and infrared cameras that detect markers placed on the subject. These systems are very expensive, highly sensitive, and limited to specialized laboratory environments.

Gait analyses are performed with two types of tests, static and dynamic. In static testing, the patient remains stationary on the force platform, and the acquisition is taken by the cameras. In the dynamic test, the patient performs the movements determined according to the type of diagnosis (walking straight, running, climbing stairs, etc.). The data collected from these two tests are analyzed with analysis methods adjusted to the system used and the patient is diagnosed. Figure 2 shows a gait analysis made with the motion capture camera system.

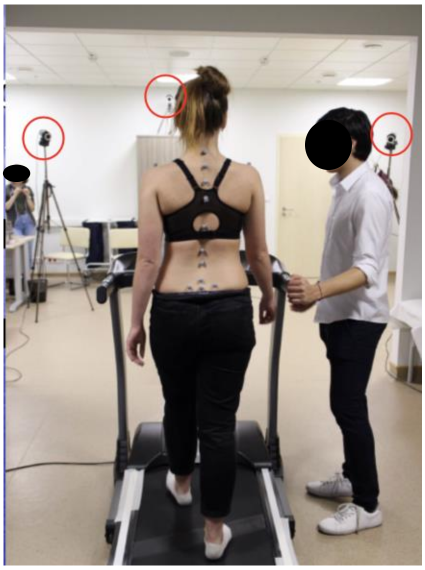

Figure 2. Gait analysis made with the motion capture camera system

2.2. System Architecture

This section describes the hardware components used in smart shoe design. Afterward, the circuit design that creates the smart shoe design is mentioned.

Arduino Nano development board was preferred as a microcontroller in the design since it is very useful for wearable technologies and provides users with a flexible movement opportunity thanks to its small size. There is an Atmega328P microcontroller, 14 digital input/output pins (6 PWM outputs), 8 analog inputs, 16Mhz crystal, a USB socket, an ICSP connector, and a reset button on the development board (Arduino, 2022). Bluetooth module (HC-06) has been used for wireless communication. Bluetooth is a communication protocol developed for short-distance communications, using the 2.4 - 2.48 GHz ISM band. The communication distance between the Bluetooth modules varies between 20-200 meters, and the communication speeds are up to 50 Mbps (HC-06, 2022).

In the system design, a force-sensing resistor has been used to measure the foot pressure. Force-sensing resistor are sensors that detect physical stress, compression, and weight. RP-C183-LT model thin film pressure sensor is used in the designed system. These sensors have been preferred because of their small size, low cost, and especially for smart shoe technology. ADXL345 model accelerometer was used to collect speed information in smart shoe design. Figure 3 shows the smart shoe circuit diagram, Figure 4 shows the designed circuit, and Figure 5 shows the developed smart shoe system.

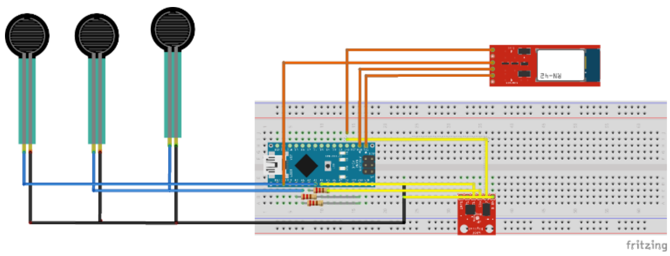

Figure 3. Circuit diagram

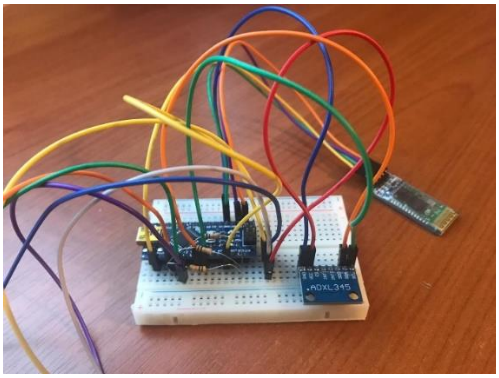

Figure 4. Designed Circuit

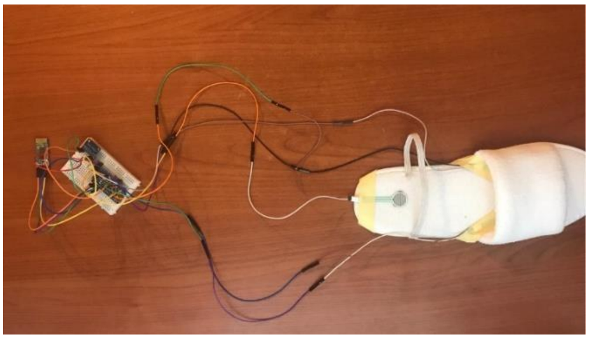

Figure 5. Developed smart shoe system

2.2. Gait Test

In the study carried out, two tests, static and dynamic, were applied to the subjects in order to make a comparison of healthy foot-flat feet. The first subject has a healthy foot and is 27 years old, 1.70 m tall, and 53 kilos. The second subject, on the other hand, has flat feet and is 22 years old, 1.71 meters tall, and 57 kilograms. In static and dynamic tests, speed and pressure values were collected from the right feet of the subjects.

The static test has performed with the subjects standing still and upright. The static test was carried out to obtain pressure data on the medial-lateral forefoot and heel of the subjects while standing still. The subject stood still for a few seconds at a single point in the area to be tested, and the collected data was transferred to the microcontroller via the Bluetooth communication module. At the end of the test, the data were recorded locally, and dynamic test was started. The tests were repeated several times to obtain correct data. Figure 6 shows how the static test is performed.

Figure 6. Static test

The dynamic test was carried out to collect pressure data on the soles of the feet during the gait of the subjects. Subjects walked at a normal pace at a predetermined distance in the test area. The tests were repeated several times to obtain correct data. Figure 7 shows how the dynamic test is performed.

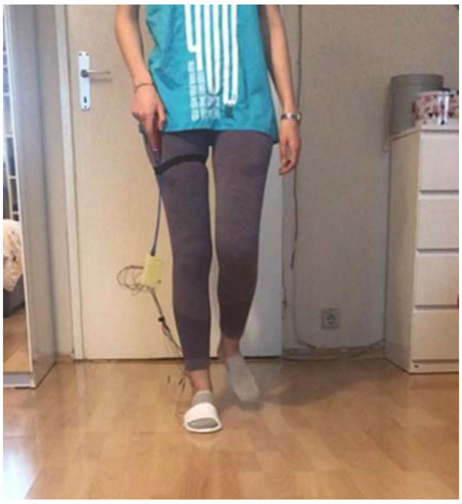

Figure 7. Dynamic test

3. Results and Discussion

As a result of the tests, the locally recorded data has been uploaded to the Thingspeak platform and graphed. ThingSpeak is an IoT analytics platform service that allows the aggregate, visualization, and analyze live data streams in the cloud (Thingspeak, 2022). The sensors are named force1, force 2, and force3 in the graphs. Force1 is the heel sensor, force2 is the lateral forefoot sensor, and force 3 is the medial forefoot sensor. In Figure 8, the placement of the sensors on the designed shoe is shown.

Figure 8. The placement of the sensors on the designed shoe

Considering the values obtained from the static tests, a pressure of approximately 10 Newtons is observed in the medial-lateral forefoot region of the subject with a healthy foot, while a pressure of approximately 40 Newtons is observed in the heel part. Velocity values are fixed due to static tests in x-y coordinates. Figure 9 shows the static test graph of a person with a healthy foot.

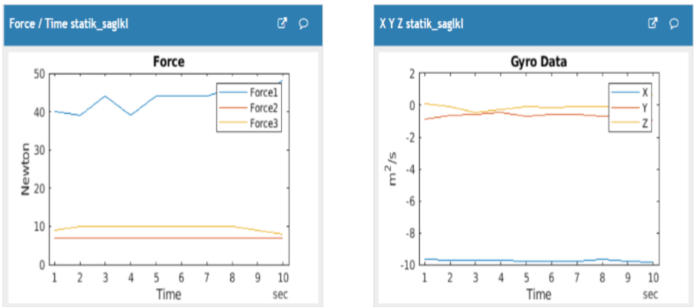

Figure 9. Static test graph of a person with healthy foot (Pressure values on the left, speed values on the right)

In the dynamic tests of the subject with a healthy foot, it can be understood that the force3 value decreases to zero between the second and third seconds. In the third-fourth second interval, the heel touches the ground again and the pressure values increase as the load is increasing. In the fifth second, when it reaches its highest point, it is observed that the left foot moves away from the ground and the load is placed on the right foot. In a healthy foot, pressure is applied to the heel area most intensely. According to the values of force2 and force3 sensors, it is seen that pressure is applied more to the medial forefoot in the static test, while more pressure is applied to the medial in the dynamic test. Figure 10 shows the dynamic test graph of a person with a healthy foot.

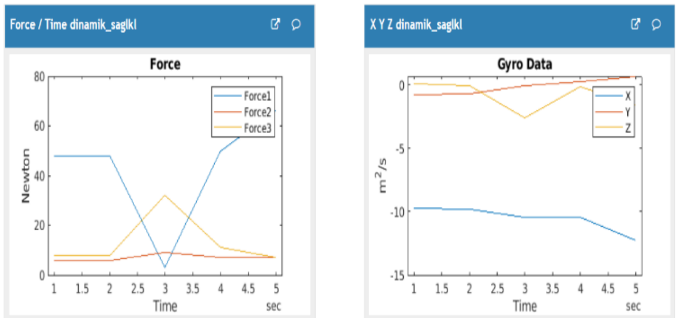

Figure 10. Dynamic test graph of a person with healthy foot (Pressure values on the left, speed values on the right)

Considering the values obtained from the static tests, a pressure of approximately 10 Newtons is observed in the medial-lateral forefoot region of the subject with flat feet, the lateral forefoot is around 15 Newtons while a pressure of approximately 50 Newtons is observed in the heel part. Velocity values are fixed due to static tests in x-y coordinates. Figure 11 shows the static test graph of a person with flat feet.

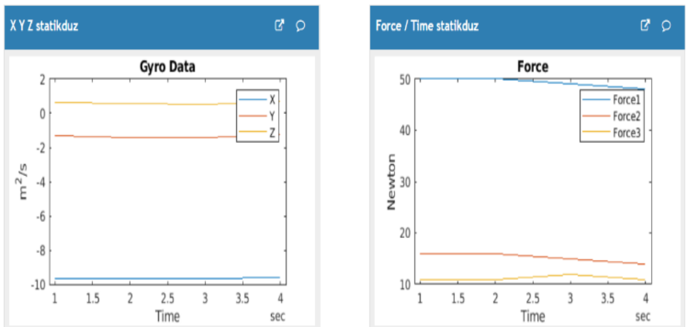

Figure 11. Static test graph of a person with flat feet (Pressure values on the right, speed values on the left)

In the dynamic tests of the subject with flat feet, it can be understood that the force3 value decreases to zero between the fourth and sixth seconds. From the first peak value, it is seen that the load gets on the right foot between the first and second seconds. Between the second and fourth seconds, the load is slowly transferred to the left foot. It is observed that the load gets on the right foot again between the sixth and seventh seconds It is seen that the pressure is applied mostly to the medial part in the lateral-medial forefoot part (force2-force3). At the same time, pressure is applied more in the lateral part in the static test, while in the dynamic test it is applied more in the medial part. Figure 12 shows the dynamic test graph of a person with flat feet.

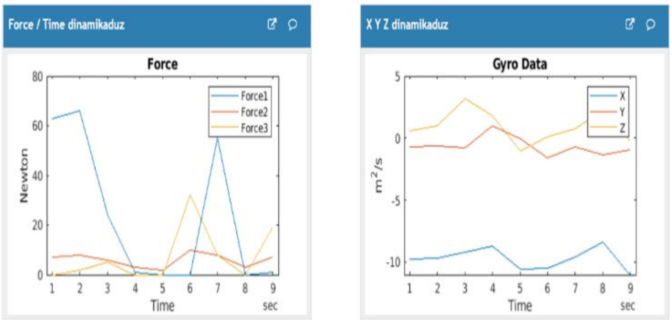

Figure 12. Dynamic test graph of a person with flat feet (Pressure values on the left, speed values on the right)

In the static test, it was observed that the pressure was applied to the heel most intensely and to the lateral part of the lateral-medial region on both soles (flat feet-healthy foot). However, it was determined that the pressure was applied more on flat feet than on healthy feet in all regions. In the dynamic test, when flat feet and healthy foot were examined together, it was observed that the values were higher for flat soles and that the pressure increased and decreased more rapidly during foot change during walking on flat soles in the lateral-medial region.

4. Conclusions

Motion capture cameras and force platform systems are preferred for more sensitive and accurate data acquisition. However, these systems, which are only measured in specialized laboratories, are expensive and sensitive, making it difficult for patients and researchers to access them. Gait tests were carried out successfully with IoMT-based smart shoes, designed to be an alternative to these systems, and the flat feet and healthy foot pressure values were observed and compared. However, even though the gait pattern trends were followed correctly, the limited amount of force sensors and low quality of the sensors caused inaccurate force values. Therefore, future studies must include high-quality and an adequate number of sensors. With the designed shoes, tests can be carried out practically and quickly with wireless communication (Bluetooth technology) in any region without an internet connection. Due to its low cost and practical use, it is a design that is accessible to both patients and researchers.

In future studies, it is considered to develop a design more compatible with wearable technology by adding more sensors to the design. In addition, it is planned to make real-time foot classification online by sending the data to be collected to the Thingspeak environment instantly.

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