Running Gait Posture Optimization Using Embedded IoT Sensor Shoes

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***Abstract*—Running is an essential human exercise that one has access to anytime and anywhere. Compared to its easy accessibility, running carries a risk of developing running related injury (RRI). RRI is caused by many factors, such as anthropometric and personal physical data, injury history, training analysis, footwear, and anatomic malalignment. In order to reduce the occurrence rate of RRI, the document suggests a running gait monitoring wearable IoT device and Mobile application. While several research papers have discussed how to monitor the running gait posture by using motion capture, they overlooked one crucial part; the motion-capturing system is restricted by time and space. This research proposes a running gait monitoring system using an Inertial Measurement Unit (IMU) sensor and Force Sensitive Resistor (FSR). Using these sensors, the IoT cloud platform processes streams of the sensor data using algorithms to extract kinematic parameters. Users are able to monitor the angle of their foot and the initial contact location on the foot for each step while running. Providing innovative application visualizes analyzed feature extraction running gait data and receives the level of training intensity of running for the user. This paper aims to provide support for runners to reduce the occurrence rate of RRI and visualization of the analyzed running gait data received from the wearable IoT device.**

***Index Terms*—running-related injury, strike type and foot angle, IoT wearable device, Inertial Movement Unit**

I. Introduction

The Internet of things (IoT) industry has been developing for decades, and its market size is expected to increase constantly. According to the International Data Corporation (IDC), the growth of the IoT market size is predicted to reach a 20% Compound Annual Growth Rate (CAGR) [1]. Among the sectors of IoT, the healthcare sector is expected to be up to 84% by 2030 [1]. Many people use IoT wearable devices like smartwatches for health and exercise monitoring.

Running requires little prior experience therefore it is accessible to beginners. The advantages of running are not restricted by time or spatial restrictions and utilize the essential physical ability of human beings. Contrary to its easy accessibility, the reoccurrence rate of Running-Related Injury (RRI) among runners is up to 85% [2]. RRIs are multi-factorial diseases from diverse causes associated with individual conditions. Causes of running injuries are anthropometric and personal profile data, injury history, training analysis, the type of footwear, and anatomic malalignment [3]. Several research papers have been conducted on the biomechanical factors for preventing potential injuries. Previous studies monitored running gait using linear and angular velocity, ground reaction force, the center of pressure, muscle activation, and timing patterns [4]. Most researchers used motion capture for gaining features of running [5]. While motion capture has the advantage of tracking throughout the intended motion, several restrictions remained, including the running environment being limited to indoor space, demanding an expert's help, and requiring a high cost. The restricted running space, such as the treadmill, causes different analysis results from general outdoor running situations [6]. The force plates have been used to detect the plantar forces exerted on the ground and also have a critical point that imposes constraints on foot placement. Recent researchers use advanced sensors such as IMU and FSR to overcome previous studies' drawbacks.

This research suggests a sensor-embedded wearable device that recreational runners are able to use in actual circumstances outside the experimental environment. The IMU sensors in users' shoes measure the angle of their feet. The FSRs are attached to each part of the insole and record the foot's first contacting point for each step. This data is gathered and processed during the run, then presented to the user on a mobile application after the run is completed. This application conveniently displays the total time, distance, average pace, foot angle, and landing location. The objective of the research is to create a running monitoring system and complementary mobile application. This system focuses on availability in actual circumstances outside the laboratory setting. The components of the system are sensor-embedded shoes and a data-visualizing application. The IMU sensors embedded in shoes measure the angular information. The FSRs are attached to each part of the insole and record the initial contact of the foot to step on. This data is accumulated during the run, processed, and offered to the user. Each sensor embedded in shoes collects the angle of feet and runner's strike. There are running methods optimized for each person, so the application receives the difficulty level of running from the user. If the user gets pain or feels high intensity, the user checks the statistic of the run on the application. Users are able to use the information from this application as reference material in consultations with experts or as a guide to improving running posture on their own.

II. Related Works

Running is a uniquely different skill. Moreover, age, race, gender, and weight cause slightly vary for each runner. 9Most smart shoes systems aim to monitor and identify abnormal gait patterns for the elderly groups or particular medical patients, such as the blind or those undergoing stroke rehabilition. [21]–[24] On the other hand, one of the objectives of this study is to propose and estimate users' usual running posture. Gait analysis is often performed by technologies based on wearable sensors. [10]. Running parameters such as pressure distribution, vertical force, spatiotemporal gait parameters, relative joint angle, and acceleration [4] are obtained from sensors. Accelerometers, gyroscopes, and magnetometers are primarily used to acquire gait data such as running speed, stride time, and stride length. The thin FSRs attached to the insole make various experimental settings.

Satetha Siyang *et al.* [13] introduced a smartphone-based system for analyzing characteristics of gait using FSR. The device was designed with a 3-axis accelerometer and an on-chip gyroscope sensor. The constructed experiments focused on counting steps and showed precise monitoring data. However, to check the results, users needed to download an additional commercial mobile application such as a pedometer. This study aims to provide a user-friendly mobile application. The effective user-interface encourages the users to monitor their running posture.

On the contrary, a different approach [10] did not interact with users directly. Instead of attaching sensors to the body, it required a complex process and limited experimental environment, like floor sensors or image processing. Image processing relies on optic sensors to capture gait data. The Optimal Motion Capture (OMC) tracks the markers affixed to the subject and analyses the movement of interest [4]. OMC equipment must be installed indoors. Cameras are optimized and aligned at regular intervals and detect markers attached to the subject's body. Despite the comparable accuracy with IMU [7], OMC devices are very expensive for the average user. Also, a significant number of markers or an insufficient number of cameras makes the optical system prone to marker confusion [4]. Treadmills are often used to analyze walking and running gait to overcome issues surrounding small capture volumes [4]. However, experiments conducted on treadmills bring drawbacks for running analysis that is not applied to the daily exercise environment. Motion capture needs skilled operators to analyze complex motion data [9].

In walking analysis, which is analogous to running monitoring, researchers applied an IMU sensor instead of motion capture [14]. The study demonstrated that the result measured by the IMU sensor is reliable as motion capture [7]. Previous studies on running gait lack variety and were conducted in limited experimental environments. This paper proposed system relies on wireless communication and inexpensive sensors to allow for a more low-cost, light-weight and flexible experimental environment.

III. Methodology

Running gait posture optimization using embedded IoT sensor shoes gather comprehensive data on a runner's gait posture. The conclusions drawn from the collected data vary depending on the sensor's placement and type. This section presents a structured approach, beginning with the sensor design, followed by the system of processing running gait data, and concluding with the development of a mobile application.

A. Architecture of System

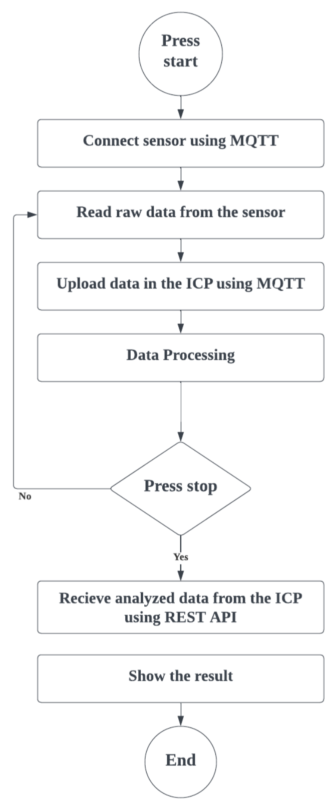


Fig. 1. Running Gait Monitoring System Diagram

Fig. 1 shows the flow chart of the running gait monitoring system. When the user presses the start button on the application, the measurement process begins with sending a signal to the IoT Cloud Platform (ICP). If the sensor gets a signal from the ICP using MQTT, the sensor starts to collect raw data from the runner's movement. The gathered data is sent to the ICP in JSON strings through the MQTT. As the gathered data is uploaded to the ICP, it executes the processing of extracted data. While the data is being processed, if runner presses the stop button, the ICP stops to analyze the data and the Application request it to ICP. Getting the analyzed data using REST API from ThingsBoard, the application visualizes the outcome of runner's gait posture data utilizing the heat map, graph and diagram in Flutter. This is the overall process in which the runner presses the application button to start the measurement and confirm the analyzed running gait posture.

B. IoT Cloud Platform (ICP)

ICP is able to collect data from several heterogeneous devices, which often communicate through different network protocols. They also provide proper security layers and support for data visualization and analysis [18]. The IoT architecture described in this paper is made up of the ThingsBoard platform, which has a rule chain that allows developers to build event-based workflows. It can also store data received from devices as telemetries and enable rapid development, management, and storing of IoT systems. This platform is an IoT gateway which supports MQTT, CoAp, and HTTP as IoT protocols. It also gives the possibility to create rich dashboards updated in real-time for data visualization, which can be customized with more than 30 widgets. A typical dashboard can include, for instance, a cartesian diagram showing the trend of a monitored parameter over a certain temporal window [18].

C. Device design

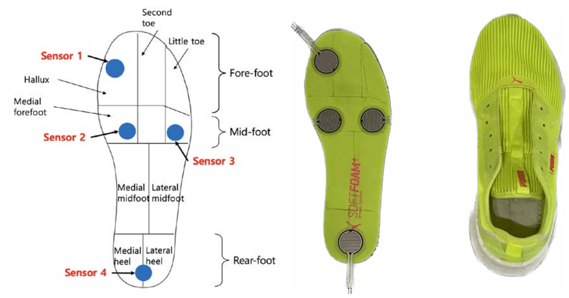
FSR is composed of multi-layer thin films. The top layer of the sensor is a semiconductor and the bottom has many active points. When the force is delivered to the sensor, the gap between the semi-conductor and active points decreases and the resistance value changes. The voltage and the resistance are calculated as follows:

$$V_{out} = V_{in} \times \frac{R_a}{R_a + R_c} \quad (1)$$

When a current with a voltage value of V_{in} comes into the circuit, each branch has the voltage in proportion to its resistance value by the voltage divider rule. V_{out} is the voltage detected at ESP32 by Analog to Digital Converter (ADC) and varies when the R_c that FSR's resistance is changed. The pull-down resistor to prevent floating is fixed at R_a. When the resistance value of FSR R_c decreases, the value of V_{out} increases. This formula shows positive correlations between the pressure impact on FSR and V_{out}.

Fig. 2. Running strike type

During a run, there are three principal strikes; rear-foot, mid-foot, and fore-foot strikes. As fore-foot and mid-foot strikes absorb shock better than rear-foot strikes, they assist in reducing RRI. [15] The shoes collect the pressure value while the subject is running, and the four FSRs are used to identify the first foot position. Fig. 3 shows each sensor placement: Sensor 1 measures the fore-foot, Sensor 2 and Sensor 3 watch the mid-foot, and Sensor 4 watches the rear-foot.



(a) location (b) insole location

Fig. 3. Four sensors location

The IMU sensor is equipped to effectively monitor a body tracking system. Depending on where the sensor is located, different running gait features can be monitored. [20] Therefore, finding the optimal sensor placement and the parameters that influence the extraction of running gait features is essential. To increase the accuracy of the experiment, the research performed by Arif Reza Anwary *et al.* [16] was adopted. The highest accuracy for detecting stride number was in the medial aspect of the foot (location 1 in Fig. 4). Considering the movement of foot interference with accelerometer output, the IMU is placed in location 2 in Fig. 4. [17]

Fig. 4. IMU location

Fig. 5 describes a full circuit with a micro control unit and sensors. The four FSRs are used to detect pressure Where the foot initially contacts the ground. One IMU collects angular velocity and calculates the rotation angle of the foot. Power to the ESP 32 is supplied via the on-board USB Micro connector or directly via the input pin. The ESP 32 can operate on an external supply of 6 to 20 volts. If using more than 12V, the voltage regulator may overheat and damage the device. The recommended range for this circuit device is 9 to 12 volts.

Four FSRs distributed under the insole of the shoes cover three main plantar areas. The main goal of this design is to perform a wireless shoe acquisition system able to measure the angle of the foot and plantar pressure of different zones on the foot.

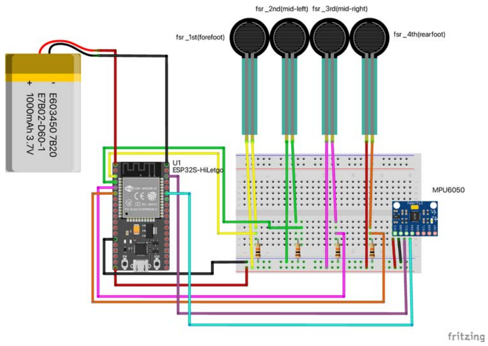


Fig. 5. Circuit of the micro control unit and sensors

D. Application

When the application sends and receives data to and from ThingsBoard, it uses the REST API for HTTP communication. From the Client's point of view, the REST API enables communication with the server using the same API regardless of the platform [28]. ThingsBoard provides API client packages for the Flutter platform which is an open-source framework for cross-platform development [14], (Android, IOS, and the Web). As ThingsBoard's documentation provides instruction on how to connect ThingsBoard to Flutter, the Flutter developing platform was chosen for this project. Information processed by ThingsBoard can be directly visualized in the Flutter application.

IV. Implementation

A. Running Gait Data Processing

While subjects are running, both the IMU sensors and FSR sensors are monitoring the overall foot movement of the patient. The ESP32 unit sends 10 data points to ThingsBoard where 6 data points are from the IMU sensor and 4 data points are from the FSR on each foot. Taking this into account, a total of 20 points of data come in to the ThingsBoard every 10 ms, and three algorithms are required to process the data.

Algorithm 1 IMU-Based initial contact time estimation

while User starts $Running$ **do**
  Read 3-axis accelerometer data x, y, z from IMU
  $magnitude \leftarrow \sqrt{x^2 + y^2 + z^2}$
  Compare with previous values to find an initial contact starting point
  if $Initial\_Conatct$ status starts **then**
    return True
  else
    return False
  end if
end while

1) Initial Contact Time Process: Algorithm 1 shows the pseudo-code for detecting the initial contact in the gait cycle through the IMU sensor. By computing the magnitude of the acceleration vector, this algorithm determines the total acceleration. The IMU sensor is deployed for initial foot contact identified by observing significant gradient changes. This process identifies initial contact which is the start of the foot step point in vertical acceleration. Finding the peak pressure value which is higher than the threshold one and a high peak in the acceleration magnitude was identified, then the algorithm determines that moment as a starting of the stance phase. After that, the ICP check the IMU and the FSR to find out the foot angle and the pressure value at that moment. If the procedure returns True, the initial contact foot time is validated, continuing the next algorithm.

Algorithm 2 IMU-Based finding foot angle

Read gyro data from IMU
if User stopped $Running$ **then**
  Get average of $foot\_angle$
  return average of $foot\_angle$
else
  if $Swingphase$ is **True then**
    Measure $change$ of foot angle
    $foot\_angle \leftarrow previousAngle + change$
    return $foot\_angle$
  end if
end if

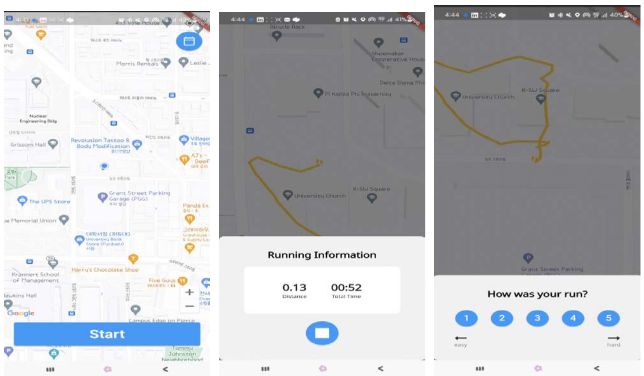
2) Finding Foot Angle Process: Algorithm 2 shows the pseudo-code for measuring the runner's foot angle using the incoming three-axis gyro data from IMU. The amount of *change* in foot angle was measured by integrating each gyro value collected during the *Swing phase*. This process measures the foot angle while running by calculating the change between the previous foot angle and the current foot angle. When the runner stops running, the ICP returns *the average foot angle*.

Algorithm 3 Finding the strike type using FSR

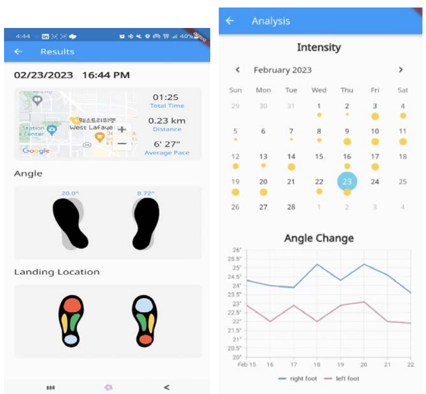
Read force data from each four FSR
if User stopped $Running$ **then**
  return each FSR's acumulative value
else
  if $Initial\_Contact$ status is **True then**
    Measure $pressure\_value$ from each sensor
    Accumulate data values for each sensor
    return $pressure\_value$
  end if
end if

3) Finding Foot Strike Type Process: Algorithm 3 shows the pseudo-code for finding the incoming force values of each plantar section through FSR. Each input value from the sensors was accumulated to determine the strike type. When the user stops running, the ICP returns the accumulated value for each sensor. The part of the attached sensor with the highest calculative FSR value becomes the user's strike type. In conclusion, we discovered an initial foot contact time during the step cycle. Additionally, our findings suggest that the runner's foot angle and strike type can be used to monitor their gait posture while running.

B. Application for Monitoring



(a) Start(showing current map) (b) Running-1 (c) Running-2



(d) Result (e) Analysis

Fig. 6. Application User Interface

The mobile application, which represents the analyzed data of runner's gait posture in this IoT system. It serves as an role for the visualizing running gait posture to users. The application's User Interface (UI) consists of concise design, so as to represent the core principles of the monitoring application. As shown in Fig. 6, there are two buttons, and each of them has a different function. One button records the user's run, and the other views statistics and analysis results related to the run. When the user presses the start button, the recording of the run begins. In Fig. 6(b)., the user can visually have an access the path he or she is running through the yellow line. Running information including distance, total time, and average pace is shown in a pop-up window. Distance is measured by the GPS of the mobile phone. Time measurement commences when the start button is pressed and lasts until the stop button is clicked. The average pace is implemented to continuously change as total time changes by dividing time by distance. When the user stops recording, a pop-up window appears with a question that asks how his or her run was, as shown in Fig. 6(c). The user selects one of the five numbers to record his or her feeling on how hard the run was. The number means the intensity of the exercise, and the bigger the number, the harder the exercise was. After answering the question, the user gets to see the result screen Fig. 6(d). It shows not only running information such as date, time, running path, total time, distance, and average time, but also analysis results of the foot angle measured through the IMU sensor and landing location measured through FSR.

Fig. 6(e). displays a screen that collects statistics and analysis results related to the run. Each time, the intensity of the run is gathered, statistics are taken from each day and displayed on the calendar. If the user runs several times a day, the average value is calculated to indicate the intensity of the run. The larger the size of the yellow circle, the higher the intensity. In the Angle Change Section, a graph shows how the rotation angle of each foot is changing. The blue line indicates the left foot, and the red line indicates the right foot. The x-axis points to the date and the y-axis points to the angle.

The Google Map API is used to display maps, show the user's running process, and track routes. First, after obtaining the user's consent, the user's location is determined through the built-in GPS of the mobile phone, and the user's location change is continuously detected. Each time the position changes, a yellow dot is displayed on the map, followed by another yellow dot, so that the path of movement is seen as a line as shown in Fig. 6(b). When the user finishes running, the user's movement path is viewed on the Result screen. After storing the user's location point as a list during the run, the list stored on the running screen is sent to the Result screen, and all points were connected to show the movement path.

V. Result

The study enrolled 1 healthy volunteer (women; age: 28 years; height: 158 cm; body mass: 48 kg). The runner performed exhausting total 45-min runs on a outdoor track. The outdoor running track was chosen to be as flat as possible, to exclude variations of running kinematics particular to the track. The GPS tracker ensured steadiness of the speed during the outdoor run. The participant was required to run on a street road. The participant wore the same shoes during the test and was given sufficient time to familiarize herself with the testing procedure.

During the run,the left shoe's sensor connector parts were broken. Otherwise, the test results displayed the right foot. The subject ran 0.23 kilometre in 1 minute 25 seconds. The mobile application allowed the user to monitor her running posture.

VI. Conclusion

This paper presents a method for a running gait posture analysis application based on an IoT wearable device. The analysis showed the runner's foot angle and strike type while running. By using the analysis results, runners are able to monitor their running gait posture by themselves and use the data as a reference when they discuss with an expert. Compared with other IoT gait analysis approaches, our experiment was also possible on outdoor tracks and was not limited by time. Through this research, it is expected that the rate of RRI is reduced. Furthermore, the results of the data analysis is visualized for the users using a graph and heat map to make a user-friendly application. The practicality of the current system may benefit the industry in the cost-effective runner's health support market part.

VII. ACKNOWLEDGMENT

This research was supported by the MSIT(Ministry of Science and ICT), Korea, under the National Program for Excellence in SW supervised by the IITP(Institute of Information & communications Technology Planning & Evaluation) in 2023 (2021-0990-03)

REFERENCES

[1] S. Al-Sarawi, M. Anbar, R. Abdullah, and A. B. Al Hawari,"Internet of Things Market Analysis Forecasts, 2020–2030," *2020 4th World Conference on Smart Trends in System, Security and Sustainability (WorldS4)*, London, UK, 2020, pp. 449-453, doi: 10.1109/WorldS450073.2020.9210375.

[2] R. O. Nielsen, I. Buist, H. Sørensen, M. Lind, and S. Rasmussen, "Training errors and running related injuries: a systematic review," *International Journal of sports physical therapy*, vol. 7, no. 1, pp. 58-75, Feb. 2012.

[3] E. Benca *et al.*, "Analysis of Running-Related Injuries: The Vienna Study," *J. of Clin. Medicine*, vol. 9, no. 2, p. 438, Feb. 2020, doi: 10.3390/jcm9020438.

[4] B. K. Higginson, "Methods of running gait analysis," *Current sports medicine reports*, vol. 8, no. 3, pp. 136-141, May/Jun. 2009, doi: 10.1249/JSR.0b013e3181a6187a.

[5] J. A. Albert, V. Owolabi, A. Gebel, C. M. Brahms, U. Granacher, and B. Arnrich, "Evaluation of the Pose Tracking Performance of the Azure Kinect and Kinect v2 for Gait Analysis in Comparison with a Gold Standard: A Pilot Study," *Sensors*, vol. 20, no. 18, pp. 5104, Sep. 2020, doi: 10.3390/s20185104.

[6] M. A. D. Brodie *et al.*, "Wearable pendant device monitoring using new wavelet-based methods shows daily life and laboratory gaits are different," *MBEC*, vol. 54, no. 4, pp. 663-674, Apr. 2016, doi: 10.1007/s11517-015-1357-9.

[7] S. Ciklacandir, S. Ozkan and Y. Isler, "A Comparison of the Performances of Video-Based and IMU Sensor-Based Motion Capture Systems on Joint Angles," *2022 Innovations in Intelligent Systems and Applications Conference (ASYU)*, Antalya, Turkey, 2022, pp. 1-5, doi: 10.1109/ASYU56188.2022.9925507.

[8] B. M. Nigg, R. W. D. Boer, and V. Fisher, "A kinematic comparison of overground and treadmill running," *MSSE*, vol. 27, no. 1, pp. 98-105, Jan. 1995, PMID: 7898346.

[9] A. M. Sabatini, C. Martelloni, S. Scapellato and F. Cavallo,"Assessment of walking features from foot inertial sensing," in *IEEE Transactions on Biomedical Engineering*, vol. 52, no. 3, pp. 486-494, March. 2005, doi: 10.1109/TBME.2004.840727.

[10] A. d. Q. Burle, T. B. d. G. Lafayette, J. R. Fonseca, V. Teichrieb, and A. E. F. D. Gama, "Real-time approach for gait analysis using the Kinect v2 sensor for clinical assessment purpose," *2020 22nd Symposium on Virtual and Augmented Reality (SVR)*, Porto de Galinhas, Brazil, 2020, pp. 144-153, doi: 10.1109/SVR51698.2020.00034.

[11] I. P. I. Pappas, M. R. Popovic, T. Keller, V. Dietz, and M. Morari, "A reliable gait phase detection system," in *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 9, no. 2, pp. 113-125, June 2001, doi: 10.1109/7333.928571.

[12] "Flutter – Build apps for any screen." Flutter.dev. https://flutter.dev/ (accessed Feb. 10, 2023).

[13] S. Siyang, T. Nilpanapan and T. Kerdcharoen, "Development of IoT-Based Data Shoes for Daily Life Step Count," *2018 IEEE 7th Global Conference on Consumer Electronics (GCCE)*, Nara, Japan, 2018, pp. 524-525, doi: 10.1109/GCCE.2018.8574793.

[14] E. T. Purcell, "Fault diagnosis assistant (VLSI chips)," in *IEEE Circuits and Devices Magazine*, vol. 4, no. 1, pp. 47-59, Jan. 1988, doi: 10.1109/101.930.

[15] S. Saidani, R. Haddad and R. Bouallegue, "A prototype design of a smart shoe insole system for real-time monitoring of patients," *2020 6th IEEE Congress on Information Science and Technology (CiSt)*, Agadir - Essaouira, Morocco, 2020, pp. 116-121, doi: 10.1109/CiSt49399.2021.9357177.

[16] A. R. Anwary, H. Yu and M. Vassallo, "Optimal Foot Location for Placing Wearable IMU Sensors and Automatic Feature Extraction for Gait Analysis," in IEEE Sensors Journal, vol. 18, no. 6, pp. 2555-2567, 15 March15, 2018, doi: 10.1109/JSEN.2017.2786587.

[17] Bouten, C.V.C., Sauren, A.A.H.J., Verduin, M. et al. Effects of placement and orientation of body-fixed accelerometers on the assessment of energy expenditure during walking. Med. Biol. Eng. Comput. 35, 50–56 (1997).

[18] L. T. De Paolis, V. De Luca and R. Paiano, "Sensor data collection and analytics with thingsboard and spark streaming," *2018 IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems (EESMS)*, Salerno, Italy, 2018, pp. 1-6, doi: 10.1109/EESMS.2018.8405822.

[19] B. P. de Fontenay, J. S. Roy, B. Dubois, L. Bouyer and J. F. Esculier, "Validating Commercial Wearable Sensors for Running Gait Parameters Estimation," in *IEEE Sensors Journal*, vol. 20, no. 14, pp. 7783-7791, 15 July15, 2020, doi: 10.1109/JSEN.2020.2982568.

[20] B. M. Eskofier, E. Musho and H. Schlarb, "Pattern classification of foot strike type using body worn accelerometers," *2013 IEEE International Conference on Body Sensor Networks*, Cambridge, MA, USA, 2013, pp. 1-4, doi: 10.1109/BSN.2013.6575457.

[21] A. K. M. Jahangir A. Majumder, Y. ElSaadany, M. ElSaadany, D. R. Ucci and F. Rahman, "A wireless IoT system towards gait detection in stroke patients," *2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)*, Kona, HI, USA, 2017, pp. 449-454, doi: 10.1109/PERCOMW.2017.7917605.

[22] J. Sudharshan, G. Goodman and N. Bourbakis, "Smart Shoes for Temporal Identification and Corrections to Assist People with Abnormal Walking Patterns," *2020 IEEE 20th International Conference on Bioinformatics and Bioengineering (BIBE)*, Cincinnati, OH, USA, 2020, pp. 929-933, doi: 10.1109/BIBE50027.2020.00157.

[23] T. Nilpanapan and T. Kerdcharoen, "Social data shoes for gait monitoring of elderly people in smart home," *2016 9th Biomedical Engineering International Conference (BMEiCON)*, Laung Prabang, Laos, 2016, pp. 1-5, doi: 10.1109/BMEiCON.2016.7859611.

[24] M. Anisha et al., "Low-Cost Smart Shoe for Visually Impaired," *2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV)*, Tirunelveli, India, 2021, pp. 1108-1111, doi: 10.1109/ICICV50876.2021.9388432.

[25] K. Boonchuay, Y. Intasorn and K. Rattanaopas, "Design and implementation a REST API for association rule mining," *2017 14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, Phuket, Thailand, 2017, pp. 668-671, doi: 10.1109/ECTICon.2017.8096326.

[26] "REST API." REST API - ThingsBoard Community. https://thingsboard.io/docs/reference/rest-api/ (accessed Feb. 26, 2023)