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Design and Validation of a Pressure-Based Insole for the Quantitative Assessment of Gait Abnormalities

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***Abstract*—This study presents the design and validation of a wearable in-shoe system for real-time monitoring and quantitative analysis of plantar pressure distribution during walking. The system incorporates ten force-sensitive resistor (FSR) sensors strategically placed at key anatomical regions of each foot, enabling high-resolution pressure mapping. Data acquisition and wireless transmission are managed via an ESP32 microcontroller using TCP/IP protocol, with onboard microSD storage for redundancy. A custom graphical user interface (GUI), developed in Delphi, enables live visualization and recording. It also supports signal processing techniques, including dynamic time warping (DTW) for temporal alignment and signal averaging for noise reduction. Experimental trials were conducted on four adult participants (aged 22–45), including one individual with a normal gait and three with abnormal patterns, such as internal rotation, external rotation, and supination. Each participant completed multiple walking trials on a treadmill at a constant speed for a duration of 1 minute under standardized footwear conditions. The results confirmed that the system achieved high accuracy in distinguishing gait abnormalities, validated through quantitative metrics and visual pressure profiles. The proposed system provides a low-cost, portable, and clinically relevant solution for early detection of gait disorders and long-term rehabilitation monitoring. Its modular architecture and real-time performance demonstrate its potential as an effective tool for both clinical and remote rehabilitation monitoring.**

***Index Terms*--biomechanics, DTW, FSR sensor, Gait Analysis, Plantar Pressure Distribution, Postural Disorders, Rehabilitation Monitoring, Wearable Systems, Wireless Sensor Networks, Motion Impairment Detection**

NOMENCLATURE

FSR	Force Sensitive Resistor
PCA	Principal Component Analysis
SVM	Support Vector Machine
DTW	Dynamic Time Warping

I. INTRODUCTION

GAIT abnormalities are often early indicators of underlying neuromuscular, orthopedic, or metabolic disorders. If left undetected, they can lead to chronic pain, reduced mobility, and increased healthcare costs. Early diagnosis and continuous monitoring of gait patterns are therefore essential for effective rehabilitation and prevention of secondary injuries [1]. Among various biomechanical parameters, plantar pressure distribution provides valuable insights into foot function and postural control during walking.

Since the introduction of plantar pressure measurement systems in the 1960s [2], technological advancements have enabled more precise and dynamic assessment of gait. In-shoe pressure sensors, particularly force-sensitive resistors

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(FSRs), have proven effective in capturing gait-related data in both clinical and non-clinical environments [3].

Factors such as age, neuromuscular conditions, joint pathologies, and walking speed influence gait dynamics. Moreover, plantar pressure distribution depends on foot structure and postural control, playing a vital role in gait evaluation. The gait cycle encompasses multiple stages, beginning with heel strike and continuing until the same foot returns to ground contact (Fig. 1) [1], [4], [5].

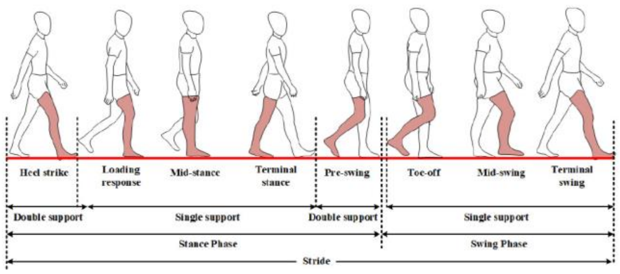

Fig. 1. A stride consists of multiple actions of the legs and feet [1]

Continuous gait monitoring, especially during rehabilitation, can accelerate recovery and reduce the risk of further injury. Pressure-sensing systems have been widely applied to assess motor impairments such as flatfoot, foot deformities, and neuropathies. However, many existing systems suffer from limitations, including bulky design, low accuracy, high energy consumption, and dependence on laboratory-grade setups [5].

In addition to hardware design, plantar pressure sensors can capture the distribution of forces across the foot in both static and dynamic conditions. The collected data can be analyzed using machine learning techniques to extract patient-specific patterns and strategies [6].

To address these challenges, we propose a lightweight, low-cost, and portable in-shoe system for real-time gait analysis. Unlike commercial platforms that often require specialized environments and complex configurations, our system is designed for ease of use in everyday settings. It operates reliably on flat surfaces or treadmills, with the latter offering speed consistency for enhanced measurement accuracy. The system uses a standardized shoe and elastic upper to minimize variability caused by footwear differences, ensuring consistent gait data across participants. Compared to existing commercial systems, which often require laboratory-grade setups and trained personnel, our platform emphasizes accessibility and ease of deployment in real-world scenarios.

Our platform integrates ten FSR sensors per insole, strategically positioned at key anatomical locations to capture high-resolution pressure data. Data acquisition and wireless transmission are managed via an ESP32 microcontroller using TCP/IP protocol, with onboard microSD storage for redundancy. A custom graphical user interface (GUI), developed in Delphi, enables live visualization, recording, and signal processing—including dynamic time warping (DTW) for temporal alignment and signal averaging for noise reduction.

This study presents the design, implementation, and experimental validation of the proposed system, highlighting its potential for clinical gait assessment, remote rehabilitation monitoring, and early diagnosis of movement disorders. The system offers several key features:

- Real-time data acquisition and analysis;
- Simultaneous measurement of both feet for bilateral gait analysis;
- Dynamic data collection during natural walking or treadmill use;
- Thin and lightweight insoles that do not interfere with walking;
- A custom-designed printed circuit board (PCB) with embedded sensors, eliminating wiring to enhance durability, data precision, and user safety;
- A compact electronics module mounted on the front of the shoe to avoid discomfort;
- High-speed wireless data transmission via Wi-Fi for user convenience;
- Intuitive usability without the need for user training;
- Usability in non-laboratory and non-clinical settings;
- An adjustable, elastic upper design accommodating men’s shoe sizes 39 to 43.

Compared to existing commercial insoles and laboratory-grade pressure mats, which often suffer from high cost, limited portability, dependence on controlled environments, and proprietary licensed software, our system represents a significant advancement in usability and accessibility. It eliminates the need for specialized equipment or trained personnel, supports real-time bilateral gait analysis, and enables remote monitoring in everyday settings. By combining lightweight hardware, standardized footwear, and a fully customizable and intuitive software platform that can be tailored to meet the specific needs of each patient, individual user, or intended usage environment, the proposed platform addresses key limitations of previous systems—namely cost, bulkiness, data inconsistency, restricted deployment, and software accessibility—making it a practical and scalable solution for clinical and home-based rehabilitation.

II. Research Overview

Numerous studies have investigated plantar pressure measurement systems for applications such as gait analysis, detection of foot abnormalities, and rehabilitation monitoring. Over the years, these systems have progressed from simple wired configurations to advanced wireless platforms incorporating integrated sensors and intelligent algorithms. This section provides a structured overview of major developments in the field, emphasizing technological innovations, diagnostic applications, and the growing role of machine learning techniques. By reviewing existing approaches and their limitations, we highlight the motivation for the proposed system and its anticipated contributions to both clinical practice and remote gait assessment.

The following subsections present a categorized review of prior research, organized thematically to highlight historical milestones, technological innovations, and diagnostic methodologies relevant to plantar pressure analysis and gait assessment.

A. Historical Evolution of In-shoe Systems

Applications of plantar pressure measurement date back to 1963, when Bowman and Brend used basic devices to assess footwear in patients with leprosy [2]. Early systems were wired and limited in mobility. In 1997, Lawrence and Schmidt introduced the first wireless in-shoe system for analyzing gait in both healthy and paraplegic individuals. A persistent challenge in these systems has been sensor slippage, emphasizing the need for precise sensor placement [7].

B. Commercial Systems and Limitations

Advanced commercial platforms, such as Pedar and Tekscan, offer high-resolution data and robust performance. However, their high cost, reliance on numerous sensors, and need for controlled environments limit their accessibility and scalability. These systems are often confined to laboratory settings and require trained personnel, making them impractical for widespread clinical or home-based use.

C. Emergence of FSR-Based Solutions

Force-sensitive resistors (FSRs) have gained attention as a cost-effective alternative for plantar pressure measurement. Studies have demonstrated their stability under static conditions and feasibility in low-cost setups using FSR406, Arduino, and LCD modules [8]. For example, Wei-Chun Hsu et al. used five FSR sensors to correlate plantar pressure with the Arch index, showing strong performance in both static and dynamic conditions [9].

D. Foot Arch Classification and Pressure Mapping

Several studies have explored detecting foot arch types (flat, normal, high). One investigation combined plantar pressure data with webcam images for flatfoot analysis. Another study examined how arch types influence pressure distribution during running, revealing increased heel pressure at a higher speed [10]. A stair-climbing study showed unexpected lateral pressure shifts in flat-footed individuals, suggesting compensatory mechanisms for balance [11].

E. Machine Learning Integration in Smart Insoles

Recent systems have integrated machine learning algorithms to enhance diagnostic capabilities. For instance, a smart insole with seven FSRs and a BLE transmission achieved 63% accuracy in pressure pattern classification [12]. Sonaria et al. developed footwear with 12 sensors (FSRs, accelerometers, gyroscopes) and applied PCA, Random Forest, and SVM to detect gait abnormalities. Another expert system combined FSRs with image processing to generate personalized treatment reports [13].

F. Sensor Density and Diagnostic Accuracy

Studies have experimented with varying sensor counts. A system with 30 FSRs revealed peak pressure in the heel region, while another with 15 sensors predicted flatfoot risk with over 80% accuracy [14]. Protective layering and anatomical sensor placement were used to enhance durability and precise position [15]. The most recent research utilized ResNet50 with CBAM attention modules to analyze plantar pressure images, achieving 96.6% classification accuracy [16].

G. Recent Innovations and Mobile Integration

The I-shoe project introduced a smart insole equipped with eight FSRs and a low-power microcontroller, paired with a mobile application that visualizes real-time pressure data and heatmaps. Machine learning algorithms were used to detect flatfoot and gait imbalance, with successful testing across multiple individuals. The system demonstrated potential for diabetic foot detection, rehabilitation, and athlete monitoring [17].

In summary, while prior research has demonstrated the feasibility of FSR-based systems for gait analysis and foot abnormality detection, challenges remain in achieving high-resolution data, ergonomic design, and clinical applicability. The proposed system in this study builds upon these foundations by integrating optimized sensor placement, standardized footwear, and real-time wireless transmission—aiming to bridge the gap between laboratory-grade accuracy and everyday usability.

In the following section, we present the design and implementation details of the proposed system, outlining its hardware architecture, sensor configuration, and data acquisition methodology.

III. Materials and Methods

This section presents the overall architecture of the proposed system along with its hardware components, including the insole sensor module. In addition, the design and implementation of the graphical user interface (GUI) for data visualization, as well as the experimental protocol used for data collection, are described in detail.

A. System Architecture

The proposed system consists of a central workstation that wirelessly communicates with a set of wearable sensors. This workstation is responsible for executing processing algorithms and displaying real-time data. The overall system architecture is designed to enable seamless integration of hardware and software components for acquiring, transmitting, and analyzing plantar pressure data in real time. The analysis results are visually presented to the user via an intuitive graphical user interface. The system architecture is illustrated in Fig.2. The system architecture consists of three primary components: (1) a set of force-sensitive resistor (FSR) sensors embedded in the insole to capture plantar pressure data, (2) an ESP32-based microcontroller responsible for data acquisition and wireless transmission, and (3) a graphical user interface (GUI) developed in Delphi for real-time visualization and analysis. This modular design ensures seamless integration between hardware and software, enabling efficient monitoring and interpretation of gait patterns.

Fig.2. System Architecture Diagram

The data acquisition hardware includes a customized insole equipped with 10 force-sensitive resistor (FSR) sensors strategically placed at key points under the foot. These sensors measure pressure distribution across various regions of the foot during different phases of the gait cycle, enabling more precise analysis of walking patterns.

The ESP32 module has been selected as the central control unit due to its versatile features and high compatibility with wearable systems. In addition to supporting wireless communication via Wi-Fi and Bluetooth, the ESP32 offers adequate processing power, low energy consumption, and a compact size, making it ideal for portable applications. Its dual-core architecture, support for the TCP/IP protocol, and ability to maintain real-time communication with a host computer make it a suitable choice for collecting and transmitting multisensory data. Moreover, its ease of programming and availability of extensive development resources significantly accelerate system development and implementation.

Each shoe is equipped with a dedicated microcontroller, with the ESP32 module embedded in the right shoe functioning as the master unit and the module in the left shoe serving as the slave. Each insole is powered by a 700 mAh lithium-ion battery, providing approximately four hours of continuous operation per charge. The total weight of the embedded electronics is 85 grams per shoe. Preliminary tests demonstrated that an additional weight of up to 300 grams on the shoe system did not cause any observable interference with the natural gait pattern [18]. These findings confirm that the hardware configuration does not disrupt locomotion and is well-suited for wearable gait monitoring applications.

This design results in a lightweight, ergonomic, and wearable platform capable of effectively monitoring foot abnormalities in real time and analyzing the performance of the musculoskeletal system. Fig.3(a) shows an overview of the designed shoe, while Fig.3(b) illustrates the positioning of the electronic board and control module.

Fig. 3(a). Overview of the designed shoe: The custom-designed footwear integrates a sensorized insole equipped with 10 force-sensitive resistors (FSRs) strategically placed to capture plantar pressure data. The image illustrates the ergonomic layout of the sensors within the shoe, ensuring minimal interference with natural gait mechanics. The design prioritizes comfort, wearability, and accurate data acquisition during walking trials.

Fig. 3(b). Positioning of the electronic board and control module: The image shows the internal layout of the electronic components embedded within the shoe, including the ESP32 microcontroller, Li-ion battery (700 mAh), and supporting circuitry. The compact and lightweight arrangement ensures minimal interference with foot movement and maintains user comfort during walking trials. The modular placement facilitates easy maintenance and future upgrades.

Fig. 3 (a). Overview of the designed shoe

Fig. 3 (b). Positioning of the electronic board and control module

B. Insole Shoe

In this study, customized insoles were employed to enable precise analysis of gait patterns and plantar pressure distribution for detecting motor abnormalities and asymmetries in bilateral foot function. Each insole is equipped with 10 force-sensitive resistors (FSRs), strategically positioned in anatomically significant and distinguishable regions of the foot, as commonly adopted in clinical gait analysis protocols [19].

The choice of 10 FSR sensors per insole was based on a trade-off between spatial resolution, system cost, and ergonomic feasibility. Pilot tests with fewer sensors (e.g., 6 or 8) showed reduced sensitivity in detecting localized pressure variations, while configurations with more than 10 sensors increased system complexity and user discomfort. This configuration is consistent with sensor mapping strategies used in prior gait analysis research [19], ensuring coverage of key anatomical regions while maintaining wearability. Additionally, these locations were carefully selected to effectively capture pressure variations caused by body weight during the gait cycle and to be responsive to common foot abnormalities.

The selected sensors are thin, flexible, and lightweight, ensuring minimal interference with the user's walking mechanics and making them well-suited for wearable systems. The sensor layout was designed to capture pressure signals from the most functionally relevant areas of the foot that contribute to gait dynamics. This configuration enables detailed analysis of pressure distribution and facilitates the identification of abnormalities such as flat feet, pronation, supination, and foot instability. The sensor placement is illustrated in Fig. 4.

Gait analysis serves as an effective tool for the early detection of locomotor disorders, as these conditions, if not diagnosed and addressed in time, can lead to chronic pain, fatigue, and musculoskeletal injuries. Traditional assessment methods primarily rely on clinical observations and expert opinion, which may lack precision and objectivity. Therefore, developing systems capable of accurately measuring plantar pressure and algorithmically analyzing the data to provide objective classification of foot disorders is essential. This design supports continuous gait monitoring and enables early detection of foot-related motor disorders through detailed plantar pressure analysis.

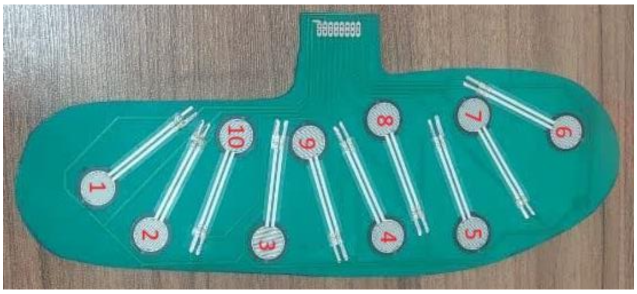

Fig.4. Sensor placement in insole shoe

C. Graphical User Interface

The software infrastructure of this system includes a graphical user interface (GUI) that provides functionalities such as real-time data visualization, pressure chart plotting, and data export. The GUI was developed using Delphi, a robust object-oriented programming language known for its rapid application development capabilities and native Windows support. This choice enabled efficient implementation of interactive features and ensured compatibility with the system's hardware architecture. Unlike commercial software packages often imposing rigid structures and licensing constraints, this GUI was fully developed in-house, allowing seamless customization based on user-specific requirements. Its modular codebase enables tailored adaptations for diverse clinical or research applications, offering a flexible alternative to proprietary platforms. Once collected, the incoming data undergoes processing for various analyses, including assessing pressure distribution. The results of these analyses are presented as graphs that illustrate pressure variations across different plantar regions throughout the gait cycle. The modular design of both hardware and software components enables future system scalability and integration with machine learning algorithms. This architecture not only supports clinical evaluations and rehabilitation monitoring but also offers a cost-effective platform for continuous at-home monitoring of plantar dysfunctions.

Fig. 5. View of the developed graphical user interface (GUI).

The GUI displays real-time pressure data from all 10 sensors embedded in each insole, with separate plots for the left and right foot. Each chart illustrates pressure variations across the gait cycle, enabling visual comparison between healthy and pathological gait patterns. In addition to graphical plots, the GUI supports numerical summaries of key gait parameters, Fourier analysis, and additional features such as data storage and printing, thereby enhancing clinical interpretability. The central schematic of foot anatomy aids in sensor localization, while the modular layout supports intuitive navigation and data export. This interface facilitates clinical interpretation and remote monitoring of plantar pressure dynamics in real-world settings.

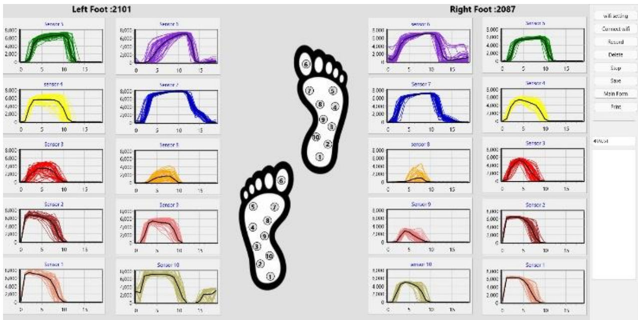

Fig.5. View of GUI

D. Experimental Protocol

To evaluate the performance of the developed system, data were collected from four male participants: one with a normal gait pattern and three with foot abnormalities, including external rotation, internal rotation, and supination. Participants ranged in age from 22 to 45 years, with BMIs between 22 and 25. Aside from the observed gait abnormalities, none of the participants reported any history of neurological or musculoskeletal disorders.

The participants had shoe sizes ranging from 39 to 43 and body weights between 70 and 80 kilograms.

All participants wore the custom-designed shoes, and the sensors were positioned according to the key pressure regions of the plantar surface. All walking trials were conducted in a controlled indoor environment with uniform lighting and temperature. Participants walked on a treadmill while wearing identical shoes. The walking speed was the same for all individuals, and no external distractions were present during data collection. No external distractions were present during data collection.

Before data recording began, participants were asked to walk on the treadmill to establish a natural and steady gait pattern. Once a natural and unconstrained walking rhythm was achieved, plantar pressure data were recorded for one minute under these controlled conditions. The primary objective of this experiment was to analyze the gait pattern across different conditions with high precision. For this purpose, the recorded signals were first segmented, and individual gait cycles were identified. In this study, a gait cycle was defined as the time interval between heel-off and subsequent heel contact. This method allows for analyzing various gait cycle components, such as the heel-strike phase, without the need for precise event detection, while preserving temporal coherence within each cycle. In addition to pressure signals, derived gait parameters such as contact duration and step length were extracted to support comprehensive gait analysis.

Next, the DTW algorithm was employed to perform temporal alignment of the gait cycles. DTW was selected over traditional Euclidean distance methods due to its robustness in handling temporal variations and proven effectiveness in gait analysis applications. DTW, a widely used technique for time-series analysis, enables the comparison of sequences with varying lengths or speeds by establishing a nonlinear alignment between them.

After alignment, point-wise averaging was applied to the time-normalized gait cycles to generate a representative signal for each individual or condition. This process reduced intra-subject variability and noise, enhancing the clarity of the final signal. Only gait cycles with successful alignment and comparable normalized durations were included in this step. The outcome was a smooth and stable signal that accurately reflected the average gait pattern while minimizing the influence of outlier steps or transient noise [1], [11].

This methodological framework ensures accurate acquisition and analysis of plantar pressure data, laying the foundation for reliable gait assessment and early detection of foot abnormalities. While the sample size was limited to four participants, the protocol was designed to ensure consistency and reliability. Future studies with larger and more diverse populations are planned to validate and generalize the findings.

IV. Experimental Results

The data collected from the designed shoe demonstrates the system's high performance in accurately reconstructing plantar pressure patterns under various conditions. The graphs obtained from the sensor data clearly confirm the system's ability to distinguish pressure variations across different regions of the foot, which is consistent with the findings of previous studies [20]. Figures 6 to 9 illustrate the average pressure patterns recorded by each sensor for four participants: a healthy individual, a subject with an external rotation deformity, a subject with an internal rotation deformity, and a subject with supination. As observed, the average gait pattern for all participants corresponds to the fundamental gait cycle during the stance phase, ensuring reliable segmentation and extraction of gait cycles for subsequent analysis. For a more precise comparison, the right and left foot patterns are shown in blue and red, respectively.

Figure 6 illustrates the gait pattern of the healthy subject. Across all 10 sensors, it is evident that the pressure distribution and step length in both feet are nearly identical, and the red and blue waveform signals exhibit good coordination. The slight difference in signal amplitude may result from greater pressure applied to one foot during stepping, which is a natural characteristic of human gait.

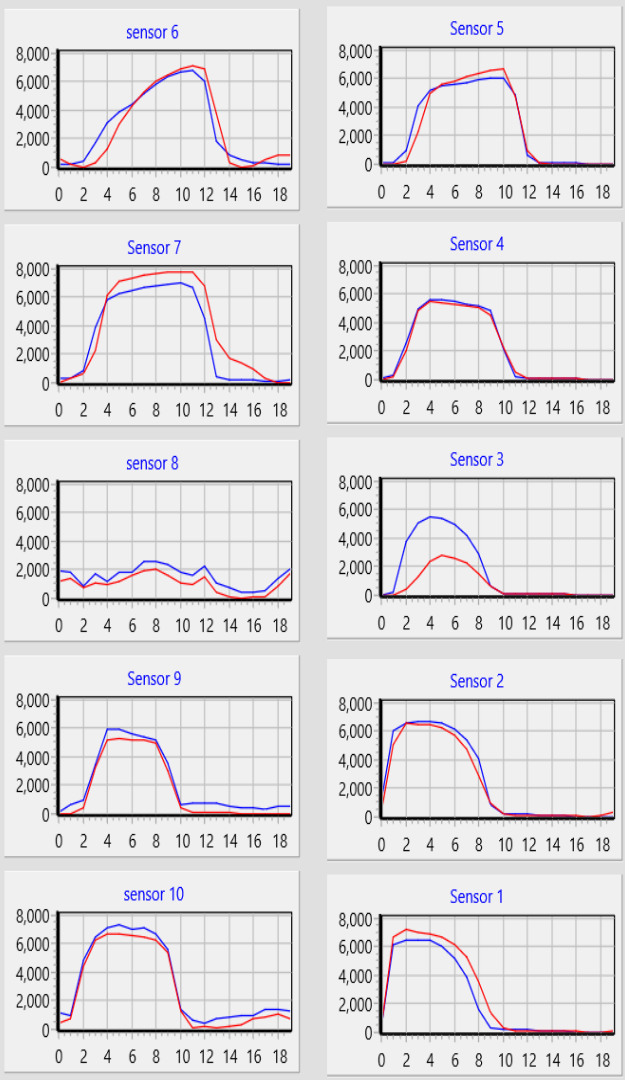

Fig. 6. Gait pattern of a healthy subject

Fig. 7 illustrates the gait pattern of a subject with an external rotation deformity. This condition, characterized by the outward deviation of the foot's motion axis (commonly referred to as out-toeing), has resulted in a shorter step length for the right foot compared to the left. This observation indicates that the subject spent a longer duration in the weight-bearing phase on the left foot. Nevertheless, a relative symmetry between the two feet is still maintained, suggesting that the gait mechanics are not severely disrupted despite the deformity.

Fig. 8 corresponds to the subject with an internal rotation deformity, a condition in which the toes point inward during walking (in-toeing). In this case, there is no significant difference in step length between the two feet; however, sensor number 7, located in the forefoot region, has recorded higher pressure in one foot. This observation suggests increased force application in that area due to the internal rotation of the foot, resulting in concentrated pressure on the anteromedial (front-inner) region of the plantar surface.

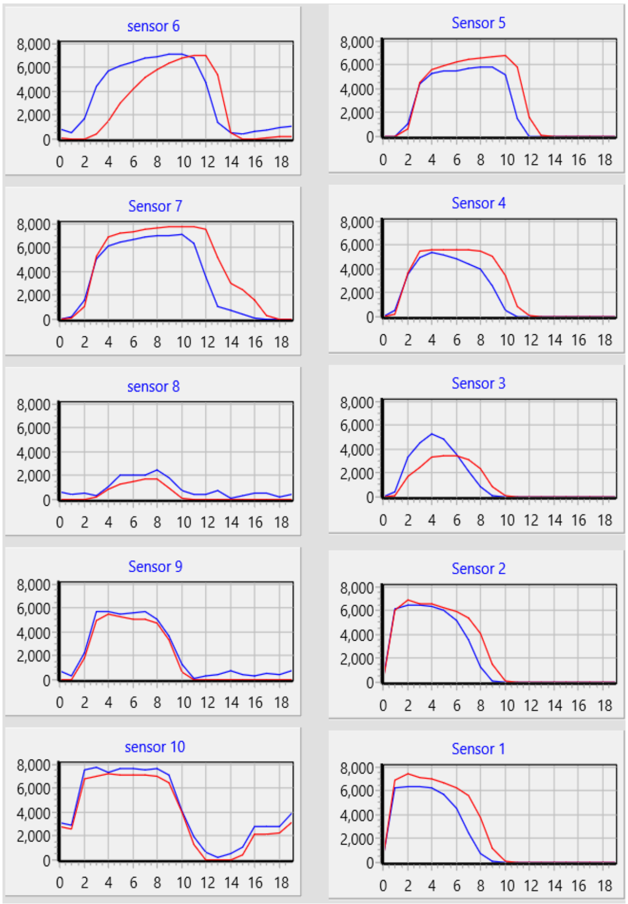

Fig. 7. Gait pattern of the external rotation subject

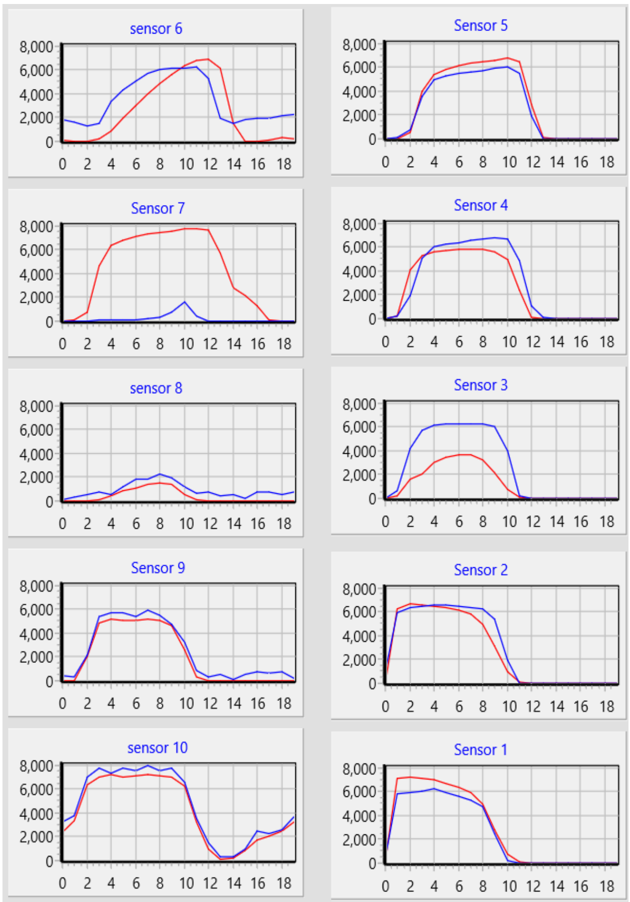

Fig. 8. Gait pattern of the internal rotation subject

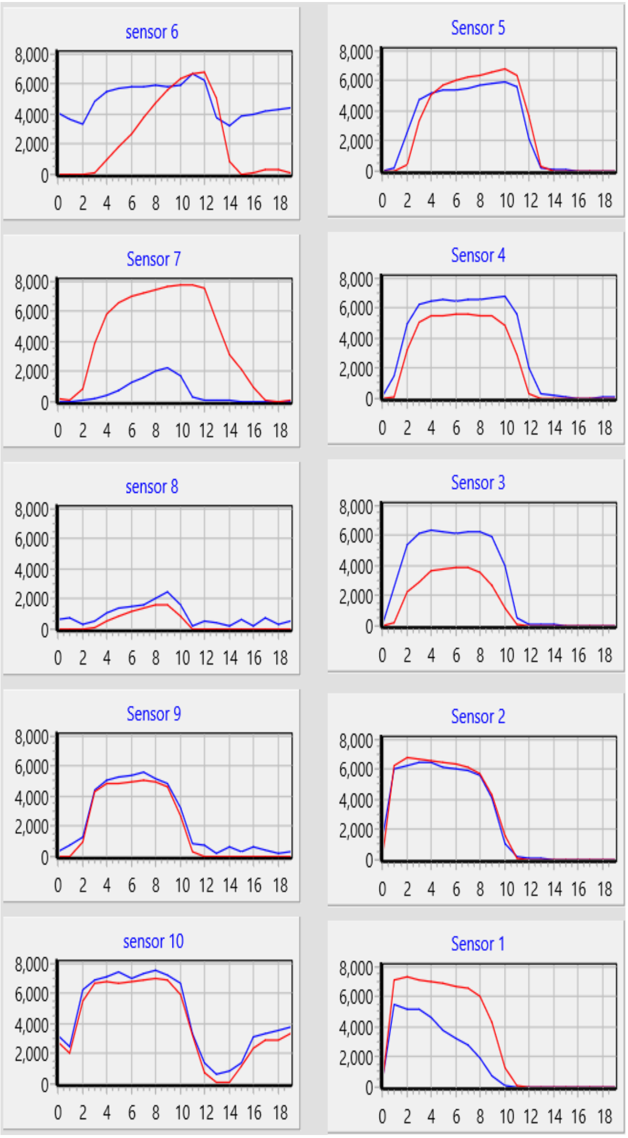

Fig. 9. Gait pattern of a supination subject

Fig. 9 presents the gait pattern of a subject with a supination deformity. This condition, marked by the outward rotation of the ankle and increased pressure on the outer edge of the foot, has led to noticeable alterations in the patterns recorded by specific sensors. Notably, sensors 6 and 7, positioned in the anterior and lateral regions of the foot, exhibit significant deviations. These findings are consistent with the biomechanical characteristics of supination, wherein body weight is asymmetrically distributed toward the lateral side of the foot. Such load distribution may contribute to long-term functional issues if not addressed.

The peak pressure values were calculated for different plantar regions, and the results for the four participants (healthy, external rotation deformity, internal rotation deformity, and supination) are presented in Table 1. This table allows for a detailed comparison of pressure across each foot region and facilitates the analysis of gait-related abnormalities. The headings S1 to S10 correspond to sensors numbered 1 through 10, respectively. The sensor locations can be seen in Fig. 4.

As shown in Table I, the peak pressure values recorded by sensors S1 through S10 reveal distinct gait characteristics across participants, enabling detailed analysis of plantar load distribution and associated abnormalities.

TABLE I
Peak Pressure Values (N/cm^2) Across Plantar Regions for Four Participants

Foot Region	Healthy	External Rotation	Internal Rotation	Supination
S1	7.5	7.8	7.2	8.0
S2	7.2	7.9	7.1	8.3
S3	6.0	6.5	5.8	8.5
S4	5.8	6.7	6.0	8.2
S5	5.5	5.0	5.2	6.0
S6	5.4	5.1	5.3	6.1
S7	11.2	10.0	11.0	10.5
S8	10.8	10.2	11.3	10.7
S9	2.0	2.2	1.8	2.0
S10	1.8	2.3	2.0	2.2

- **Healthy Participant**: Pressure values are relatively balanced across all regions. Sensors S7 and S8, located in the forefoot area, show the highest readings, which align with the natural weight transfer during the propulsion phase of gait.
- **External Rotation Deformity**: Slightly elevated pressure is observed in the lateral regions (S1–S4), indicating a shift in weight toward the outer edge of the foot due to the outward deviation of the motion axis. Reduced pressure in the midfoot (S5 and S6) may reflect compromised central stability.
- **Internal Rotation Deformity**: Sensor S7 records notably higher pressure in one foot, suggesting increased force concentration in the anteromedial region of the plantar surface. This pattern is consistent with inward toe positioning and altered load distribution.
- **Supination**: This participant exhibits elevated pressure values in the lateral and anterior regions (S3–S4 and S6–S8), consistent with the sensor-based observations illustrated in Figure 9. This asymmetric load distribution, typical of supination, may contribute to long-term structural or functional complications if left unaddressed.

The numerical differences across participants reveal that each deformity induces distinct and quantifiable shifts in plantar pressure distribution. These variations are not only evident in peak values but also in spatial pressure patterns. The data serve as quantitative indicators for early detection of gait abnormalities and can be instrumental in monitoring rehabilitation progress or tailoring clinical interventions.

Overall, the experimental data collected using the proposed system validate its strong capability in accurately detecting and differentiating gait features, reinforcing its clinical applicability in gait assessment and rehabilitation monitoring.

V. Discussion and Future Works

In this study, a wearable foot pressure monitoring system based on a wireless architecture was successfully designed and implemented. The system integrates modular hardware components and an advanced graphical user interface for real-time data visualization. Experimental results demonstrated that the proposed system possesses high accuracy in capturing pressure variations across different regions of the foot and can provide meaningful insights into gait patterns under both normal and pathological conditions. This performance is particularly notable in distinguishing subtle gait deviations, as evidenced by the system's ability to detect asymmetries in supination and internal rotation cases.

The analysis of pressure sensor data enabled the identification of gait components and the visualization of plantar pressure distribution throughout different phases of walking. This capability not only facilitates the detection of abnormalities such as flatfoot, internal and external rotation, or supination but also serves as an effective tool for tracking patients' rehabilitation progress during treatment. The developed platform also holds promise for clinical and home-based applications, particularly for continuous monitoring of motor performance in patients and the elderly. Although the system shows promise for home-based use, its performance under uncontrolled environmental conditions remains to be validated.

Despite the promising results, the system still faces certain limitations. One major challenge is the latency in data processing, mainly due to the high volume of sensor input and limited computational resources on the client side. This latency occasionally affects real-time responsiveness, particularly during prolonged walking sessions or high-frequency sampling. Optimizing data structures and improving the processing algorithms could significantly mitigate these delays.

Future research will focus on leveraging this platform for the early detection of foot-related functional disorders and assessing movement impairments associated with ankle joint conditions. Future work will explore convolutional neural networks (CNNs) for automated gait classification and test the system in post-stroke patients to assess rehabilitation outcomes. Integrating machine learning algorithms for more precise classification of gait patterns, expanding the participant population to enhance generalizability, and developing lighter and more portable system versions will further broaden this platform's clinical and practical applications.

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CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHORS' CONTRIBUTIONS

Data collection and experimentation: (Maryam Farivar, Hadi Soltanizadeh, Mohammad Zahrayee)

Data analysis and interpretation: (Maryam Farivar, Hadi Soltanizadeh, Mohammad Zahrayee)

Manuscript writing and editing: (Maryam Farivar, Hadi Soltanizadeh

Supervision and project administration: (Maryam Farivar, Hadi Soltanizadeh

STATEMENT ON THE USE OF GENERAL AI

We used AI as a tool for language editing.

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