Portable Foot Pressure Measurement For Early Dection Of Abnormal Gait Pattern

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***Abstract*—Abnormal gait patterns are often early indicators of neurological, orthopedic, and diabetic foot–related disorders. Continuous and accurate monitoring of foot pressure distribution during walking can help in the early detection of such abnormalities. This project presents the design and development of a portable foot pressure measurement system for the early detection of abnormal gait patterns.**

The proposed system uses multiple force-sensitive pressure sensors embedded inside a wearable insole to capture plantar pressure data in real time. The sensor data are acquired through a low-power microcontroller and transmitted wirelessly for processing and analysis. Key gait parameters such as pressure distribution, stance time, and load variation across different regions of the foot are extracted. By comparing these parameters with normal gait patterns, the system can identify deviations that indicate abnormal gait.

The portability, low cost, and ease of use of the proposed system make it suitable for continuous monitoring in daily life as well as clinical environments. This system can assist doctors and physiotherapists in early diagnosis, treatment planning, and rehabilitation monitoring. The results demonstrate that the proposed foot pressure measurement system is effective for basic gait analysis and early detection of abnormal gait patterns.

***Index Terms*—Half –Bridge Load Cells,MAX4194ESA+T Load Cell Amplifier,ADC,Microcontroller.**

I. Introduction

Human gait reflects the functional condition of the musculoskeletal and nervous systems. Any deviation from normal gait patterns may indicate underlying health problems such as neurological disorders, orthopedic injuries, diabetic foot complications, or age-related mobility impairments. Early detection of abnormal gait is essential to prevent disease progression, reduce the risk of falls, and improve rehabilitation outcomes.

Traditional gait analysis techniques are commonly performed in laboratories using motion capture systems, force plates, and camera-based setups. Although these methods provide high accuracy, they are expensive, complex, and restricted to controlled environments. As a result, they are not suitable for continuous or real-time monitoring in daily life. This limitation creates a strong need for a portable, low-cost, and user-friendly gait monitoring solution.

Foot plantar pressure measurement is a reliable method for analyzing gait characteristics, as it directly reflects the interaction between the foot and the ground during walking. Changes in pressure distribution, stance duration, and load transfer across different regions of the foot can effectively indicate abnormal gait patterns. Recent advancements in wearable sensor technology and embedded systems have enabled the development of compact and portable gait analysis devices.

In this project, a portable foot pressure measurement system is proposed for the early detection of abnormal gait patterns. The system integrates multiple pressure sensors embedded in a wearable insole, a microcontroller for data acquisition, and a wireless communication module for real-time monitoring and analysis. By extracting key gait parameters and comparing them with normal gait characteristics, the proposed system can identify gait abnormalities at an early stage.

The main objective of this work is to develop a low-cost, portable, and efficient gait monitoring system that can be used in both clinical and daily-life environments. This system aims to assist healthcare professionals in early diagnosis, rehabilitation assessment, and long-term gait monitoring.

II. LITERATURE REVIEW

"Development of a Low-Cost Foot Pressure Monitoring System for Basic Gait Analysis "Mayank Mundra" 2025" Gait analysis plays a vital role in the assessment of walking patterns and the early detection of mobility-related disorders. However, conventional gait analysis systems such as motion capture and force plates are expensive and limited to laboratory environments. To overcome these limitations, several studies have focused on the development of low-cost foot pressure monitoring systems for basic gait analysis. This literature survey reviews existing research that utilizes affordable pressure sensors such as force-sensitive resistors and load cells integrated into insoles or foot platforms.

"Gait Pattern Identification Using Gait Features Min-Jung Kim, Ji-Hun Han, Woo-Chul Shin and Youn-Sik Hong 2024" Gait pattern identification is an important area of research for assessing human movement and detecting abnormalities related to neurological, musculoskeletal, and age-related disorders. Existing literature highlights the use of gait features extracted from walking data to classify and identify different gait patterns. These features commonly include spatiotemporal parameters such as step length, stride length, cadence, walking speed, stance time, and swing time, as well as plantar pressure distribution and kinematic characteristics.

"Artificial Neural Network-Based Abnormal Gait Patter Classification Using Smart Shoes with a Gyro Sensor
" Kimin Jeong and Kyung-Chang Lee"
2022" Abnormal gait patterns can indicate neurological or musculoskeletal disorders, and early detection is crucial for effective intervention. Recent research has focused on integrating smart shoes with wearable sensors, such as gyroscopes and accelerometers, to monitor gait in real time. This literature survey reviews studies that utilize artificial neural networks (ANN) for classifying abnormal gait patterns based on sensor data collected from smart footwear.

The reviewed literature highlights that ANN models are highly effective in analyzing complex gait features, including angular velocity, stride variability, and joint motion, to distinguish between normal and abnormal gait patterns. Smart shoes equipped with gyroscopic sensors enable continuous, non-invasive monitoring in both clinical and real-world environments. Studies report that combining sensor-based gait data with ANN algorithms improves classification accuracy and allows early detection of gait abnormalities, potentially aiding rehabilitation and fall prevention.

"Experiences of living with leprosy: A systematic review and qualitative evidence synthesis "Norana Abdul RahmanID, Vaikunthan Rajaratnam, George L. Burchell , Ruth M. H. Peters, Marjolein B. M. Zweekhorst" 2022"

Leprosy is a chronic infectious disease that can lead to physical disabilities, social stigma, and psychological challenges. Understanding the lived experiences of people affected by leprosy is essential for improving healthcare delivery, rehabilitation, and social support systems. This literature survey reviews studies that systematically explore the personal, social, and emotional experiences of individuals living with leprosy using qualitative research methods.

The reviewed literature highlights common challenges faced by leprosy-affected individuals, including social exclusion, discrimination, mobility limitations due to physical deformities, and difficulties in accessing healthcare services. Studies emphasize the impact of stigma on mental health, self-esteem, and quality of life. The synthesis also reports coping strategies employed by patients, such as reliance on family support, peer networks, and community rehabilitation programs.

III. EXISTING SYSTEM

3.1 Laboratory-Based Gait Analysis Systems:

In the existing scenario, gait analysis is predominantly carried out in clinical and research laboratories using force plates, pressure-sensitive walkways, and motion capture systems. Force plates measure ground reaction forces, while high-speed cameras and reflective markers are used to capture joint kinematics. These systems provide highly accurate and reliable data; however, they require sophisticated infrastructure, trained personnel, and controlled environments. Due to their high installation and maintenance cost, their application is largely restricted to hospitals and research institutions.

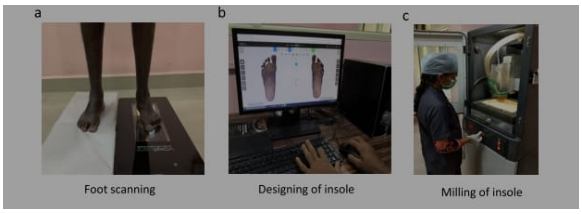

Fig no. 3.1 EXISTING SYSTEM

3.2 In-Shoe and Pressure Mat Systems:

Several commercial in-shoe pressure measurement systems and plantar pressure mats have been developed to analyze foot pressure distribution. These systems typically use force-sensitive resistors (FSRs), capacitive sensors, or piezoelectric sensors embedded in insoles or floor platforms. Although they offer better portability compared to laboratory-based systems, many of them involve wired connections, external data acquisition units, and proprietary software. The cost of these systems remains relatively high, limiting their accessibility for routine monitoring and large-scale screening applications.

3.3 Limitations of the Existing System:

The major limitations of existing systems include high cost, limited portability, lack of real-time remote monitoring, and dependency on clinical supervision. Most systems are designed for short-term assessment rather than continuous daily monitoring. Consequently, early detection of abnormal gait patterns associated with neurological disorders, diabetic neuropathy, or musculoskeletal impairments becomes challenging. These drawbacks emphasize the necessity for a compact, cost-effective, and portable foot pressure measurement system suitable for real-time and home-based applications, in accordance with IEEE and Anna University project standards.

IV. METHODOLOGY

Methodology – Sensor Integration and Signal Conditioning:

The proposed system is designed using six half-bridge load cells embedded at critical plantar regions (toe, metatarsal heads, arch, and heel) within the footwear platform to capture distributed pressure variations during gait. Each load cell produces a low-level differential voltage proportional to the applied force. To obtain accurate and stable measurements, the output of each sensor is interfaced with the MAX4194ESA+T precision load cell amplifier. The amplifier enhances the millivolt-level signals to a measurable range while maintaining high common-mode rejection and low noise performance. Passive components such as resistors and capacitors are incorporated for signal filtering, gain setting, and noise suppression to ensure reliable analog conditioning.

Methodology – Data Acquisition and Embedded Processing:

The conditioned analog signals are fed into an Analog-to-Digital Converter (ADC), which converts the continuous voltage signals into high-resolution digital values. The microcontroller acts as the central processing unit of the system, acquiring synchronized data from all six channels. It performs calibration, scaling, and digital filtering to convert raw ADC counts into meaningful pressure values. The processed data is formatted for further analysis, enabling real-time monitoring and gait pattern evaluation. This structured acquisition process ensures accuracy, repeatability, and efficient embedded computation suitable for biomedical applications.

Methodology – Power Management and System Integration:

For portability, the system is powered by a rechargeable Lithium-Ion battery. A dedicated battery charger module ensures safe charging, over-current protection, and battery health management. A 3.3 V Low Dropout Regulator (LDO) provides a stable and noise-free voltage supply to sensitive components such as the amplifier, ADC, and microcontroller. All modules are compactly integrated within the shoe/footwear platform using secure wiring connections to maintain structural stability and user comfort. This methodology ensures a lightweight, energy-efficient, and portable hardware architecture suitable

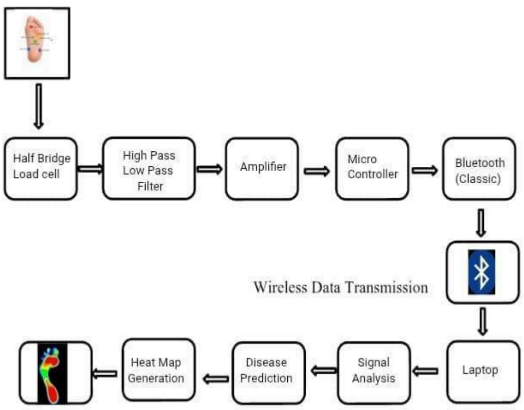

Fig 4.1 Portable Foot Pressure Measurement For Early Dection of Abnormal Gait Pattern.

Pressure Sensing Points

1. Big Toe Area – Near the base of the big toe
2. Ball of Foot – Left – Under the 1st–2nd metatarsal heads
3. Ball of Foot – Right – Under the 3rd–4th metatarsal heads
4. Midfoot (Arch) – Center of the foot arch
5. Heel – Left – Inner heel (medial calcaneus)
6. Heel – Right – Outer heel (lateral calcaneus)

Fig 3.2 Half-Bridge Load Cell Sensor

V. HARDWARE IMPLEMENTATION

The system begins with 6 × Half-Bridge Load Cells placed inside the shoe platform to measure foot pressure at different regions. When a person walks or stands, force applied on the footwear creates small resistance changes in the load cells. These tiny analog signals are very weak, so the MAX4194ESA+T Load Cell Amplifier amplifies the signals to a measurable voltage level. Proper resistors and capacitors are used for signal filtering and noise reduction to ensure stable and accurate pressure measurement.

The amplified analog signals are then sent to the Analog-to-Digital Converter (ADC), which converts the continuous analog voltage into digital data. This digital data is processed by the microcontroller, which reads pressure values from all six load cells. The microcontroller performs calculations, calibration, and data formatting. It ensures synchronized data acquisition from multiple sensors to analyze pressure distribution and gait pattern accurately.

The entire hardware system is powered by a Lithium-Ion Battery. A Battery Charger Module safely charges the battery, while the 3.3V Low Dropout Regulator (LDO) provides a stable voltage supply to sensitive components like the microcontroller, ADC, and amplifier. Proper wiring and compact placement inside the shoe platform ensure portability and reliability. Together, these components create a complete embedded system that measures foot pressure and supports early detection of abnormal gait patterns.

VI. SOFTWARE IMPLEMENTATION

This HTML application uses the Web Serial API to communicate with the microcontroller through a selected COM port. When the user clicks the "Connect" button, the system opens the serial port with the chosen baud rate (e.g., 115200). The program continuously reads incoming data from the device in real time. It looks for complete data packets that start with the symbol $ and end with ~. Once a full packet is received, it extracts six comma-separated values (D1 to D6), which represent pressure readings from the six load cells placed inside the footwear.

After extracting the six pressure values, the system updates the heatmap on the right panel. Each pressure point (D1–D6) corresponds to a specific area of the foot such as toe, ball, arch, and heel. The values are limited between 0–50 kg and converted into a color gradient (green → yellow → red) to represent low to high pressure. At the same time, the numeric values are displayed both on the foot diagram and in the pressure information section below.

The left panel provides serial control options such as port selection, baud rate configuration, connect/disconnect buttons, and real-time data logs. Every received packet is timestamped and displayed in the log section for monitoring and debugging. The system ensures smooth real-time visualization while keeping only the latest 50 packets to maintain performance. Overall, this interface enables live foot pressure monitoring and heatmap-based gait analysis visualization in a clear and user-friendly manner.

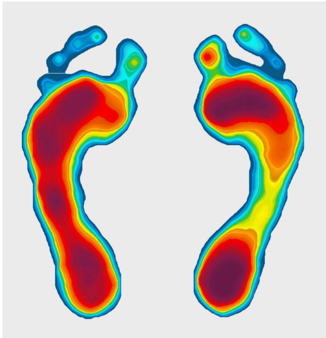

Fig no .6.1 Heat Map Generation

VII. RESULT

The developed Portable Foot Pressure Measurement for Early Detection of Abnormal Gait Pattern system successfully provides real-time visualization of plantar pressure distribution in a home environment without the need for hospital-based gait laboratories. The hardware prototype accurately captures pressure variations from multiple sensing points, and the processed data is transmitted wirelessly to a user interface that displays a clear heat-map representation of foot pressure. The system effectively identifies peak pressure regions, imbalance between left and right foot, and irregular walking phases such as heel strike and toe-off. The portability and simple interface allow users to perform gait assessment independently at home with minimal technical assistance.

The experimental results indicate that the system can detect early signs of abnormal gait patterns, including uneven weight distribution and prolonged stance phases, which are common in diabetic neuropathy, musculoskeletal disorders, and post-injury conditions. The visual heat-map output enhances easy understanding for both patients and clinicians, enabling quick interpretation of abnormal pressure zones. By reducing the dependency on expensive hospital equipment and frequent clinical visits, the proposed system demonstrates practical applicability for continuous monitoring and early diagnosis

VIII. CONCLUSION

The proposed system titled Portable Foot Pressure Measurement for Early Detection of Abnormal Gait Pattern successfully demonstrates a compact, low-cost, and efficient solution for real-time plantar pressure monitoring. By integrating load cell sensors, signal conditioning circuits, a microcontroller, and wireless communication, the system effectively captures and processes foot pressure data during walking. The generated heat-map visualization enables clear identification of pressure distribution and asymmetry patterns, which are critical indicators of gait abnormalities. The portability and battery-powered design make the system suitable for both clinical and home-based monitoring applications.

Overall, the developed prototype provides a reliable platform for early detection of gait-related disorders associated with neurological conditions, diabetic neuropathy, and musculoskeletal injuries. Compared to conventional laboratory-based gait analysis systems, the proposed model offers affordability, ease of use, and real-time data transmission. With further optimization in firmware accuracy and clinical validation, the system can be extended for rehabilitation monitoring, sports performance analysis, and preventive healthcare applications, aligning with the objectives and standards expected in IEEE format as per Anna University guidelines.

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