Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 2, No.4, February : 2025

IOT-BASED SMART SHOE INSOLE FOR HEALTHCARE AND REHABILITATION MONITORING

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Abstract
The Internet of Things (IoT) is transforming healthcare by enabling real-time monitoring of vital health parameters. Wearable smart insoles provide an effective solution for continuous health tracking and recovery monitoring. An intelligent insole system is designed with multiple sensors, including pressure, ECG, GPS, temperature, ultrasonic, altitude, and inclination sensors, to collect and analyze real-time physiological data. A local host-based web interface with an IP address is used for visualization, employing HTML, CSS, and JavaScript. Sensor readings are processed, and notifications are triggered in case of abnormalities to ensure timely alerts. This system enhances proactive healthcare and user safety by enabling early diagnosis and preventive care. Additionally, the system aims to improve mobility tracking, rehabilitation, and gait analysis for individuals with mobility impairments.

Keywords:
IoT, Smart Shoe Insole, Healthcare Monitoring, Rehabilitation, Pressure Sensors, ECG Monitoring, GPS, Real-Time Notifications, Wearable Technology, Sensor-Based System, Data Visualization, Gait Analysis, Mobility Tracking.

I. Introduction

The need for real-time health monitoring has led to the adoption of IoT in wearable devices. Traditional healthcare systems rely on periodic check-ups, which often miss critical health changes. Smart insoles with integrated sensors address this gap by continuously tracking vital parameters. Data is transmitted in real-time and visualized through a web-based interface, offering insights into gait patterns, plantar pressure distribution, cardiovascular health, and motion tracking. The system also generates alerts for abnormalities, making it valuable for individuals undergoing recovery, elderly users needing continuous monitoring, and athletes tracking performance.The increasing burden of chronic diseases, including diabetes, cardiovascular diseases, and mobility impairments, has necessitated innovative solutions for health monitoring. IoT-integrated wearables, such as smart insoles, provide non-invasive, real-time data collection, aiding early diagnosis and preventive care. The system can be utilized in various fields such as sports science, elderly care, physiotherapy, and medical rehabilitation.

1. 1 Workflow of the Project

Data Collection**:** The smart insole is embedded with multiple sensors such as pressure, ECG, temperature, gyroscope sensors. These sensors continuously monitor health parameters and movement patterns.

Sensor Integration and Signal Processing**:** The collected sensor signals undergo preprocessing, including noise filtering and signal enhancement, to ensure accurate data representation. The microcontroller processes the raw data before transmission.

Wireless Data Transmission**:** The processed sensor data is transmitted wirelessly to a local hosting server via Wi-Fi. The system ensures secure and encrypted data transfer to prevent breaches.

Data Analysis & Storage**:** The received data is stored and analyzed .Gait pattern analysis, anomaly detection, and health risk predictions are performed to identify potential issues.

User Interface & Real-Time Visualization**:** A web-based dashboard provides an intuitive interface for users and healthcare professionals to view real-time data and graphical representations of sensor readings.

Automated Alert System & Notifications**:** If abnormal readings are detected, such as irregular ECG signals, extreme temperature variations, or abnormal gait patterns, automated alerts are generated and displayed on the local web interface.

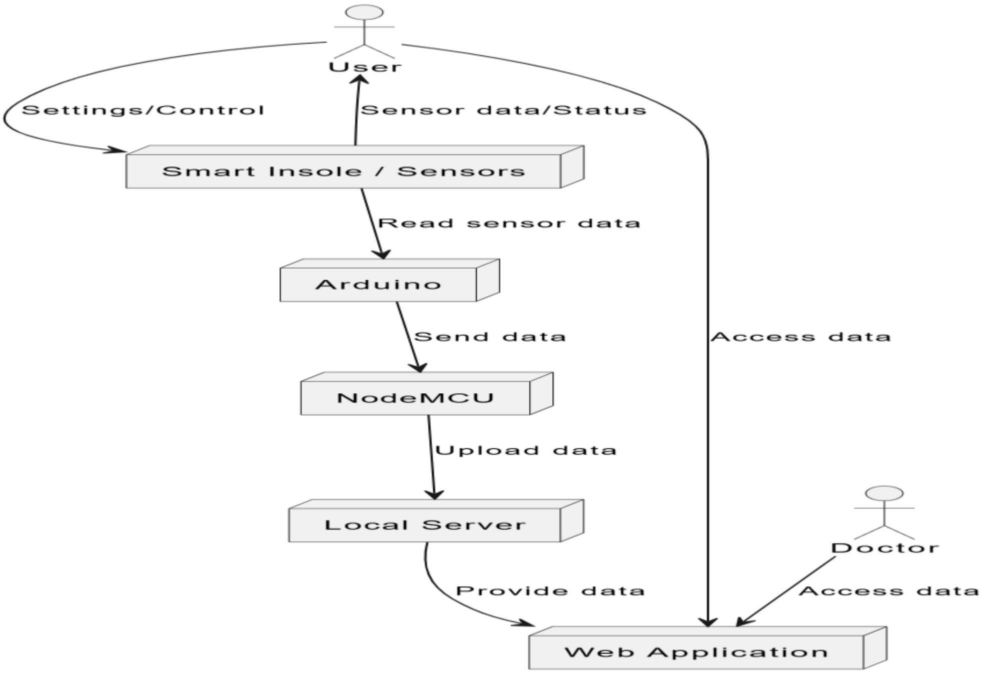

Figure 1:Workflow

This workflow ensures comprehensive real-time health tracking and monitoring, enhancing user safety, rehabilitation efficiency, and proactive healthcare management. By integrating IoT and real-time data visualization, the system offers a reliable solution for personalized healthcare.

II. Literature

Several studies have explored the integration of IoT in wearable health monitoring systems. Research by Choi & Lee (2020) reviewed various IoT-based wearable technologies, emphasizing their role in real-time health tracking, rehabilitation, and telemedicine. They highlighted how wearable devices, including smart insoles, can provide continuous health monitoring without requiring clinical visits, thus improving patient outcomes. Their study also stressed the need for enhanced data security in wearable IoT systems to protect patient privacy. Additionally, they discussed the challenges of IoT integration in healthcare, such as the need for energy-efficient sensors, robust wireless communication, and improved interoperability between devices.

Kim & Lee (2021) conducted an in-depth study on smart footwear systems for health monitoring, specifically analyzing their impact on foot movement tracking and cardiovascular health assessment. Their research demonstrated that smart insoles equipped with pressure and ECG sensors could assist in the early detection of foot deformities, abnormal gait patterns, and heart-related issues. They concluded that integrating IoT with wearable footwear could significantly enhance mobility assistance, injury prevention, and healthcare diagnostics. Their research also emphasized the importance of real-time data visualization, allowing healthcare professionals to monitor patients remotely and provide timely interventions.

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A study by Patel et al. (2012) examined the effectiveness of wearable sensors in rehabilitation and mobility tracking. Their findings showed that pressure and gyroscope sensors play a crucial role in detecting postural imbalances, assessing weight distribution, and aiding physiotherapists in developing personalized recovery programs for patients with musculoskeletal injuries. Additionally, their research explored how IoT-enabled insoles could assist individuals recovering from surgeries by providing real-time feedback on gait correction, foot pressure distribution, and mobility patterns. They emphasized the role of AI-based predictive models in analyzing sensor data to anticipate falls, detect early signs of mobility disorders, and recommend corrective exercises.

Bandaru & Maria (2022) investigated the broader impact of technology in the healthcare sector, particularly focusing on psycho-informatics and its role in enhancing patient care and mental health management. Their study outlined how advancements in IoT, artificial intelligence, and sensor-based monitoring have contributed to personalized healthcare, allowing individuals to track their health conditions in real time. They also discussed how integrating smart insoles with cloud-based analytics and machine learning can provide predictive insights into mobility impairments, chronic illnesses, and stress-related health conditions. Furthermore, they analyzed the ethical considerations and privacy concerns associated with wearable healthcare devices and emphasized the importance of secure data encryption and patient consent protocols in IoT-based health monitoring systems.

Another significant study by Bandaru & Abhinaya (2023) explored IoT-based stress management systems, integrating machine learning techniques for personalized healthcare solutions. Their research examined how continuous physiological monitoring using IoT sensors, including ECG and motion sensors, could detect stress levels, fatigue, and early signs of mental exhaustion. They highlighted the potential of combining smart insoles with psycho-informatics to enhance mental health monitoring, offering a comprehensive approach to overall well-being. Additionally, they suggested that wearable IoT technology could be integrated with cognitive-behavioral therapy (CBT) applications to provide real-time feedback on stress management techniques, relaxation exercises, and mindfulness training.

Furthermore, existing literature supports the application of IoT in fall detection and injury prevention among elderly individuals and patients with mobility impairments. Studies have shown that smart insoles embedded with motion sensors, GPS tracking, and pressure detection systems can prevent falls by providing early warnings based on irregular movement patterns, sudden shifts in weight distribution, and muscle weakness detection. Research also suggests that AI-powered predictive analysis can improve the accuracy of abnormal gait detection, helping caregivers take preventive measures before injuries occur. A study on IoT-assisted rehabilitation found that smart insoles can be programmed to adapt to a user's movement patterns, providing real-time corrective feedback to individuals recovering from strokes, spinal cord injuries, or lower limb surgeries.

Additionally, researchers have investigated the role of IoT-based smart footwear in sports science. Studies indicate that athletes can benefit from real-time foot pressure analysis, stride optimization, and performance tracking. By integrating IoT-enabled insoles with biomechanics research, sports professionals can analyze balance efficiency, injury risks, and impact force distribution to enhance training methodologies. Some research also suggests that wearable insoles equipped with AI-powered analytics can predict potential stress fractures, overuse injuries, and joint strain before they become severe.

Another crucial aspect of wearable IoT healthcare research involves chronic disease management. Studies suggest that smart insoles can be highly effective for patients with diabetes, arthritis, and cardiovascular diseases. Continuous pressure and temperature monitoring in diabetic patients can help prevent foot ulcers and detect poor circulation, reducing the risk of complications such as diabetic neuropathy and foot amputations. Similarly, patients with arthritis can benefit from joint stress analysis and real-time gait correction, minimizing pain and preventing further joint damage.

In summary, the growing body of literature highlights the increasing relevance of IoT in wearable health monitoring, particularly through smart insoles. These studies collectively demonstrate that integrating IoT with advanced sensor technology, AI-based predictive analytics, and real-time data visualization has the potential to transform healthcare by enabling early diagnosis, enhancing rehabilitation, and improving patient outcomes through continuous health tracking. Furthermore, researchers emphasize that future advancements in battery efficiency, lightweight sensor materials, and 5G-based connectivity will further enhance the functionality, accuracy, and user-friendliness of IoT-integrated smart insoles.

2.1 Sensors Used in the System

The pressure sensors embedded in the smart insole are crucial for gait analysis and posture assessment. These sensors detect variations in foot pressure distribution, allowing for a comprehensive understanding of an individual's walking pattern. They help monitor balance disorders. By providing insights into pressure points and areas at risk of injury, especially for diabetic patients, these sensors assist physiotherapists in designing custom rehabilitation plans. The sensors function by converting the force exerted on different regions of the foot into electrical signals, which are processed to analyze weight distribution and walking stability. Early detection of biomechanical issues enables timely medical interventions, preventing long-term damage. Additionally, these sensors aid athletes in optimizing their gait, reducing the risk of injuries, and improving overall performance.

The ECG sensor plays a vital role in continuously monitoring heart activity by measuring the electrical signals produced by the heart. It helps detect cardiac anomalies such as irregular heartbeats. The sensor consists of electrodes that capture heart rhythms and send the data to the microcontroller for analysis. By integrating ECG sensors into the smart insole, users can receive continuous heart monitoring without requiring bulky medical equipment. This is particularly useful for elderly individuals and those at risk of heart disease. The real-time ECG data can be visualized on the web-based dashboard, allowing healthcare professionals and caregivers to monitor heart activity remotely. If an abnormal heart pattern is detected, alerts are generated to ensure timely medical intervention, reducing the risk of severe cardiac events.

The GPS module in the smart insole enables real-time location tracking. This feature is particularly beneficial for elderly individuals, rehabilitation patients, and athletes. In the case of an emergency, GPS tracking allows caregivers to locate users quickly. The GPS system utilizes satellite signals to determine the precise location of the individual and transmits this information to the local host. For elderly individuals with dementia or cognitive impairments, the GPS module ensures safety by providing real-time location updates to caregivers. Athletes can use GPS tracking to monitor their movement patterns, assess speed, and evaluate performance over time. Additionally, the GPS module integrates with motion tracking sensors to provide accurate gait analysis.

The temperature sensor monitors foot temperature variations, helping detect circulatory issues and inflammation. This is particularly useful for diabetic patients who are at risk of developing neuropathy, where reduced blood flow to the feet can lead to ulcers and infections. The sensor continuously measures foot temperature and sends real-time data to the microcontroller for processing. If an abnormal temperature deviation is detected, alerts are triggered to enable early diagnosis and treatment. This feature is essential for preventing severe complications associated with poor circulation, such as foot ulcers and infections. Additionally, the temperature sensor helps in assessing the effectiveness of rehabilitation exercises by tracking changes in blood flow to the feet. It also provides valuable insights for individuals recovering from surgeries or injuries, ensuring proper circulation and preventing temperature-related health risks.

The altitude and inclination sensors measure elevation changes, foot angles, and walking patterns. They are particularly beneficial for rehabilitation therapy, as they help assess movement stability and balance in patients recovering from musculoskeletal injuries. The inclination sensor detects foot angles and variations in walking posture, providing real-time feedback for gait correction. Athletes can use these sensors to improve their performance by optimizing their movement efficiency. The altitude sensor is useful for tracking elevation changes, especially in outdoor settings where individuals may be walking on uneven surfaces. These sensors provide valuable data for physiotherapists and sports trainers, enabling personalized training and rehabilitation programs based on precise movement analysis. By continuously monitoring inclination and altitude changes, these sensors contribute to improved mobility, posture correction, and injury prevention strategies.

The gyroscope and accelerometer work together to measure motion, orientation, and acceleration of the foot. These sensors help detect sudden changes in gait, falls, and improper walking postures. The accelerometer measures linear acceleration, allowing the system to identify movement speed and intensity, while the gyroscope detects angular motion, enabling accurate analysis of foot orientation. These sensors are crucial in rehabilitation and sports training, as they provide insights into movement stability, coordination, and balance. By continuously tracking motion dynamics, the gyroscope and accelerometer help prevent falls, assess walking efficiency, and optimize performance in athletic activities. If sudden deviations from normal walking patterns are detected, alerts can be generated to notify caregivers or users of potential risks. This feature is particularly beneficial for elderly individuals who are at risk of falling.

The force-sensitive resistors (FSR) measure the amount of force applied to different regions of the foot, allowing for advanced analysis of foot biomechanics and weight distribution. These sensors are particularly useful in rehabilitation settings, as they provide real-time feedback on how weight is distributed during movement. This data helps in post-injury assessment and recovery monitoring, allowing physiotherapists to design personalized rehabilitation programs. FSR sensors also aid in fall prevention by detecting imbalances in weight distribution and providing alerts for corrective action. Athletes can benefit from these sensors by analyzing their foot strike patterns and optimizing their movement efficiency. By continuously monitoring force distribution, FSR sensors play a vital role in injury prevention, rehabilitation, and gait optimization.

2.2 Arduino Microcontroller

The Arduino microcontroller serves as the central processing unit for the smart insole system. It is responsible for collecting sensor data, processing the information, and transmitting it to the local host server for visualization. The Arduino efficiently manages real-time monitoring by integrating multiple sensor inputs, ensuring seamless data collection. It processes pressure, ECG, temperature, motion, and GPS data before sending the analyzed results for visualization. The microcontroller is chosen for its ease of use, flexibility, and open-source compatibility, making it an ideal choice for IoT-based healthcare applications. By handling multiple data streams simultaneously, Arduino enhances the efficiency and reliability of the smart insole system, making it a crucial component of the project.

2.3 Wi-Fi Module (NodeMCU ESP8266)

The NodeMCU ESP8266 Wi-Fi module is responsible for enabling wireless communication in the smart insole system. It facilitates real-time data transmission from the insole to the local hosting server, ensuring continuous monitoring and visualization. This module supports a stable internet connection, allowing for seamless data exchange between the smart insole and the monitoring system. By reducing power consumption while maintaining efficient connectivity, the NodeMCU enhances the system's ability to operate effectively over extended periods. The integration of this Wi-Fi module ensures that users and caregivers can access real-time health and mobility data, making it an essential component of the smart insole.

III.Conclusion

The IoT-enabled smart shoe insole integrates multiple sensors to provide real-time health monitoring and rehabilitation support. It tracks plantar pressure, heart activity, temperature, and motion, aiding in early detection of abnormalities. The system enables users to receive timely health alerts, preventing complications related to mobility disorders, cardiovascular diseases, and temperature-related ailments. Wi-Fi-based data transmission ensures secure, local monitoring without cloud dependence, mitigating privacy concerns. Additionally, real-time alerts and data visualization enhance its effectiveness for healthcare professionals, caregivers, and patients. This solution bridges the gap between clinical and personal monitoring, offering a cost-effective and accessible approach to continuous health tracking. Future developments could focus on AI-driven predictive analytics and improved energy efficiency for long-term usability.

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