RESEARCH PAPER

Stress Analysis in AFO for Muscular and Gait Abnormalities Rehabilitation

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ABSTRACT-Ankle–Foot Orthoses (AFOs) are helpful devices that support the people who are suffering with neuromuscular conditions or gait abnormalities. They are referred to as individuals with stroke or drop-foot, where impaired muscles limit safe and efficient walking. By balancing the ankle and guiding foot movement, AFOs play an important role in therapy and in rebuilding confidence during motion. Many old AFOs face challenges in discomfort, high stress at particular regions of the device, and limited products for different users.This case explains about mechanical properties and real time monitoring of AFOs. Using finite element analysis, we examine how stresses are distributed across the orthosis during walking, especially in demanding phases like heel-strike and toe-off. At the same time, we incorporate light weight electrical components— including pressure sensors and motion sensors — to monitor gait in real time. This twin strategy not only identifies areas where the orthosis can be redesigned for better strength and comfort, but also introduces the possibility of responsive, feedback-driven rehabilitation.The findings contribute toward the design of next-generation AFOs that are stronger, more comfortable, and smarter, helping patients with neuromuscular and gait impairments regain mobility and independence.

Keywords — Ankle–Foot Orthosis, Gait Rehabilitation, Neuromuscular Disorders, Stress Analysis, Smart Orthotics.

I. INTRODUCTION

real-time feedback. The outcome is that the fast progress of tiny, thin, and energy-capable technologies has greatly controlled research in healthcare sensor applications. This progress is driven by modern medical. Researchers in biomedical learn how these pressure is distributed under the foot during walking or standing. By examining these pressure , we can find where the maximum weight is placed on the foot. This helps in making better shoes, preventing injuries, improving balance, and identifying foot problems early.. In modern times creative applications have also appeared in bio-recognition, position tracking, and therapy support systems. This Studies continuously highlights that correct and steady measurement of plantar pressure over the standard foot length (approximately 30.48 cm) is important for additional progress in this field. Real-time foot pressure systems, whether retail available or used in research laboratories, vary in sensor setup to fulfill requirement application needs. Typically, these systems are based on pressure distribution principles, imaging-based technologies, or in-shoe sensor arrays.When creating a plantar pressure measurement systems, multiple key factors must be viewed as including image clarity, sample rate, exactness, acuteness, and measurement stability. Ankle Foot Orthoses (AFOs) are user-friendly medical devices designed for individuals with neuromuscular disorders or gait abnormalities. Foot drop often requires AFO intervention to compensate for muscle weakness. By improving balance, encouraging safe for waking style, and improving user confidence, AFOs play an important role in modern therapy.

II. LITERATURE SURVEY

The research mainly focuses on analysing the pressure on the foot. The pressure that forms among the foot and the ground during walking or doing daily activities is called foot plantar strain. The device uses Force Sensitive Resistor (FSR) sensors, which are fixed inside the shoe. These sensors help to know the pressure of the foot. The Arduino UNO board is connected to the sensors. It collects the data and shows how the pressure is spread on the foot in real time. The results are displayed and studied using a special program made in [Rasheedha A (2023)]. To estimate foot pressure distribution during walking using a cost-effective insole system, pressure data can serve as a quantitative indicator for assessing structural foot irregularities and for detecting and monitoring abnormal gait patterns. The primary goal of this work was to develop a deep learning model capable of interpreting full-foot pressure distribution from the collected data. [Frederick Mun (2022)]. "Wireless foot pressure monitoring system for gait rehabilitation". Monitoring foot pressure distribution plays an important role in rehabilitation and enhancing performance . In this study, a wireless foot pressure monitoring system is performed for gait rehabilitation. The system employs an insole-based sensor module consisting of four Force Sensing Resistors (FSRs) majorly placed at key regions of the foot, along with a gyrometer to measure foot across the x, y, and z axes. This setup is used for continuous monitoring foot pressure and movement, offering meaningful data for clinician and rehabilitation [Serhat Kucukbermenci (2024)]. It presents a novel and inventive prototype for measuring plantar pressure in the foot. The goal is to enable those with peripheral neuropathy, such as those with diabetes, to monitor any abrupt rise in pressure and avert further, more catastrophic injuries. The prototype that is being shown is wireless and connects to an Android app over a Bluetooth Classic connection [Ecampos (2021)]. The sensory role of the foot. A crucial sensory structure in the balance system are the feet. Our feet serve the primary and direct link between our body and the ground, facilitating us to detect and interact with our surroundings. Our capacity to stand upright is aided by sensory data from the foot skin related and muscular, afferent nerves and body oscillation is required to recognize the location and motion of the body in space. [Frederic J.F. Viseux (2020)]. Peripheral neuropathy is a neurological disorder known for pain, numbness, and tingling sensations that cause nerve damage. This problem has become an increasing public health concern in Kuwait, affecting a major part of the population, the study reveals the importance of exploring patients' lived experiences. Knowing these experiences is important to know gaps in at present healthcare practices and to develop strategies for improving the quality of care and patient outcomes. [Maryam Alkandari (2023)]. One conservative treatment strategy for knee osteoarthritis is to modify walking biomechanics with novel designs of lateral wedge insoles with arch support. Individual responses to insole treatments may be influenced by differences in foot posture, albeit these effects are currently unknown. [Calvin T. F. Tsc (2020)]. Understanding how people walk is important in both research and clinical practice, and technologies like instrumented gait analysis and inverse dynamics help experts study how the lower-limb joints work—such as how much force they produce and how much power they generate during movement (Spencer Ray, 2020). Foot pressure distribution is another valuable indicator used to identify foot structure problems and unusual walking patterns, especially in patients with medical conditions. This is mainly important for diabetic patients, as they experience sudden neuropathy when their blood sugar levels are controlled too quickly, which is seen in clinical care (N. Siddique, 2020). To control these problems, new wearable devices that continuously monitor the foot's condition have been introduced, and they have shown promise in preventing serious diabetic foot complications (Jose de Jesus Sandoval-Palomares, 2021).

Ankle–Foot Orthoses (AFOs) are devices used for rehabilitation for walking in people with muscle or bone problems. Traditional AFOs are made by hand using plaster molds, which is a slow and skill-dependent process that can be uncomfortable and difficult to adjust, especially for children who quickly outgrow them. To solve these issues, new digital methods like 3D scanning, CAD, and 3D printing are being used to make AFOs faster, more accurate, and more customizable. These modern techniques still need enhancement to assure a perfect fit and user friendly for orthotists. Different types of AFOs exist, such as plastic, carbon-fiber, and walking boots Recent updates, like switched on AFOs, can help with motion by offering extra force, while AFOs can track walking patterns and pressure for more comfort and therapy. Overall, there is a shift from traditional handmade AFOs to modern, technology-based designs that are more efficient, comfortable, and personalized.This case represents an ankle-foot orthosis (AFO) system mainly focused for patients with neuromuscular disabilities by enhancing gait balance. Using gait phase diagnosis, force sensors, and Bluetooth monitoring, the device offer controlled ankle motion and real-time feedback to increase motion and reduce fall risk [Ravindrakumar (2025)].

III. EXISTING METHODS

3.1 F-Scan GO System: This is an advanced tool created for clinicians and researchers to determine foot pressure, force, and step interval during motion. It provides accurate, real-time value into foot function, helping in orthotic design, diabetic foot , and performance in athletes. The system uses ultralight, wireless electronics with built-in data storage, allowing users to walk naturally without movement restrictions. The Foot View software connects with the sensors to calibrate, record, and process data efficiently.By eliminating cords and distance limits, it captures natural gait patterns with high-resolution accuracy. The F-Scan GO sensors have an excellent level of detail for full in-shoe pressure representation. These sensors are light weight, elastic, and strong, capable of multiple uses without loss of precision. The small design improves user comfort while making sure safe motion mechanics data collection. In general, the F-Scan system allows real-world gait analysis with precision, freedom of movement, and superior data quality for both clinical and research applications.Figure 1 shows F scan GO.

Fig 1 : F-Scan GO[1]

3.2 Pedar Mobile System by Novel: The Pedar system is made up of special insoles that can sense pressure and a small portable device that records data. It helps measure foot pressure in real time while a person is walking, standing, or doing other activities. This system is very useful for studying how pressure is distributed on the foot and is often used in hospitals, clinics, and research. The Pedar system is accurate and dependable in measuring pressure under the foot and the shoe. It has many useful features and settings, making it easy to use for different types of tests. The system uses electronics, which send the pressure data through Wi-Fi to a computer, where the information is shown instantly. It can also save data internally with its 32 GB memory.Figure 2 is shown below.

Fig 2: Dynamic pressure distribution inside the footwear.[2]

3.3 Pressure Mapping System by Sensor Medics : Pressure measurement is an advanced testing method majorly used in research and product design to know how pressure is distributed across a surface. It enables engineers and scientists to understand surface exchange and enhance product performance. Many companies apply this technology to know design problems and improve their innovations. The system offers how the information on pressure is applied between two surfaces, including key parameters such as total force, maximum pressure points, and the center of pressure. It also shows a visual map showing how pressure is distributed. Data can be seen in wave form and monitored in real time. The major components of the system include sensors, data acquisition devices, and customised software. The durable sensors can be placed among contacting surfaces without affecting their function, allowing for precise and complete pressure measurement across the entire test area.Figure 3 shows the Minimally invasive high resolution sensor and 4foot pressure sensor.

Fig 3: Minimally invasive high resolution sensor AND 4Foot pressure[3]

3.4 Foot pressure sensors: Foot pressure sensors are designed to work both distribution and intensity of pressure applied by foot onto a surface. These sensors play a major role in fields like medical diagnostics, sports performance evaluation, and the development of footwear. There are three types of Foot Pressure Sensors. Firstly, we have capacitive sensors which analyse variations in capacitance due to pressure. Next, we have piezoelectric sensors which produce an electrical charge when pressure is applied. Lastly, we have resistive sensors which change their resistance in accordance with pressure, also found in force-sensitive resistors (FSRs).The medical diagnostics using foot pressure sensors are gait analysis, diabetes care, athlete training, equipment design, rehabilitation, physical therapy and ergonomics. In gait analysis the foot pressure sensor assists in identifying gait irregularities and developing treatment plans. Next in diabetes care, it monitors foot pressure to help prevent ulcer formation in diabetic patients. Further we have sports performance and athlete training where the foot pressure sensor evaluates foot pressure patterns to optimize performance and minimizes risk of injury. Coming to equipment design the foot pressure sensor supports the creation of customized footwear and sports gear based on pressure distribution needs of an individual. Rehabilitation When we look at physical therapy, these sensors monitor rehabilitation progress and the effectiveness of exercises. Research and Development: Lastly when we look at ergonomics it analyses pressure distribution to improve the design of ergonomic products**.**

IV. PROPOSED METHOD

The finite element model is used for the analysis of stress analysis in AFO.The muscular and gait abnormality can be analyzed using the contact pressure, biomechanical behavior and load distribution. Here from the sensors the stress and pressure distribution data throughput the foot is measured using the embedded system. The embedded system consists of sensors, data acquisition unit and STM32 microcontroller. The ARM based STM32 is preferred for its high computational infrastructure and data handling capacity. A finite element model is applied to analyze the anatomical structure of the rehabilitation unit. The AFO should be designed to meet the standard and manage the stress applied on the foot. The 3D model of the AFO is to be developed in the near future. The Integration of AFO structure with data obtained from the sensors will be done.

4.1 Design and implementation of a Smart Insole System: The Technical function and design of a TRIPS sensor was discussed in earlier papers. Capacitive-based sensing was employed to evaluate vertical & lateral force using thin film sensors. Every sensor has an active area with thickness of only 1mm, making it flexible and lightweight . The main goal is to develop a smart insole which has these sensors in a wearable form. The complete design was developed to integrate many sensors, power supply, store data and wireless transmission, making device comfort for daily use and continuous monitoring.

4.2 Sensor Location and Design: The insole is designed with four TRIPS sensors, each measuring 20 mm x 20 mm 1 mm. These sensors are placed under important parts of the plantar region: the rear foot, first metatarsal region (5 mm), third metatarsal region (3 mm), and the big toe, as shown in Figure 4(a). These places were chosen because they carry most of the foot's weight and experience strong path and pull forces, especially during walking or running.The front-back direction, the heel, 5MM, IMM, and big toe sensors were placed at 10%, 53%, 72%, and 92% of the total foot length, respectively, from the back point of the heel. These placements were based on earlier analytical and underfoot force distribution studies. Similarly, in the side-side direction, the 5MM, 1MM, and big toe sensors were placed at 0%, 15%, and 15% of the foot's total transverse dimensions from the long axis. These placements were determined based on established plantar pressure data the figure 4(b) shows, the insole consists of three material layers. Ethylene-vinyl acetate (EVA; Lunatec®), flexible but long-lasting polymer, was used for the upper and bottom layer, while a layer of synthetic leather was integrated for wearability and toughness. The sensors were placed between the EVA layers and connected to an elastic cable for signal transmission. This design provide very good functional flexibility, padding effect, and shock resistance while keeping strength under repeated loading.

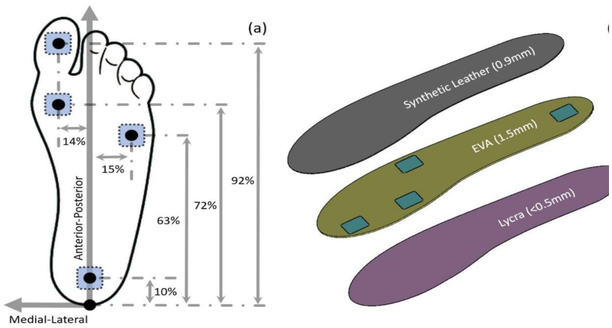

Fig 4: (a) Foot-Length and Foot-Width Based Sensor Positioning
(b) Multi-Layer Smart Insole Layout Showing Sensor Centers.

4.3 Insole Construction: It is made up of three layers of material. They are ethylene, vinyl, acetate, and synthetic leather. These are the common materials used for layer construction, support, and stability of the foot as they establish appropriateness, biocompatibility, resilience, and impact resistance opposed to industry standards. Wrapped inside the middle EVA layer, four square cavities were designed in the central layer to accommodate the sensors at the corresponding anatomical points, ensuring a flush surface alignment. The up and down surfaces of the middle layer were coated with synthetic leather and Lycra material respectively. This arrangement verifies that the sensors do not directly touch the skin, reducing the restricted stress prompted by their presence. With an overall thickness of less than 3 mm, the insoles can be functioned separately or be synchronized with the prescribed insoles for wider clinical applications. The sensor was related to the signal processing and data collection hub through a thin flexible cable, ensuring clarity with user movement. A posterior lateral cable exit was chosen to avoid exchange with the navicular area, minimizing the risk of tissue damage. The device was included to the lateral collar of the footwear without changing the user's shoes, enabling wearability in everyday environments. The performance is essential for the DFU risk assessment.

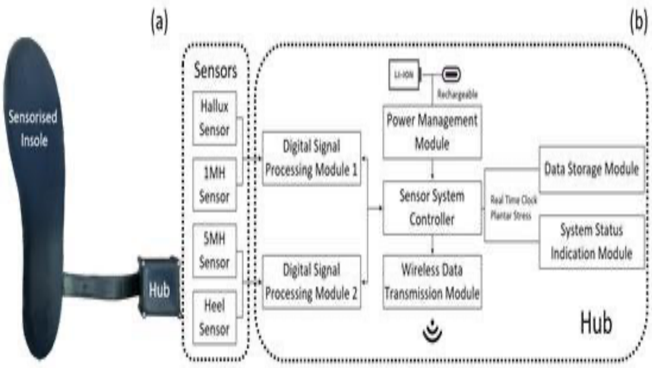

Fig 5: (a) Photograph of the sensorised insole system
(b) Functional block diagram of the hub modules

4.4 Smart Sensorised Insole System: A sensorised insole is soft and flexible inserted inside the AFO which contains pressure and motion sensors to capture the real-time data during walking.The microcontroller in it processes the data and sends it to the external device. This data is analyzed further to identify abnormal gait patterns,muscle weakness,pressure imbalances and walking asymmetry. Gait analysis refers to the study of how a person walks. This sensorised insole helps record important walking parameters such as step length and cadence,stance and swing time,Centre of pressure and symmetry between left and right feet.

V. SPECIFICATION

- **ESP32** – a small microcontroller that connects wirelessly using Wi-Fi or Bluetooth.
- **Motherboard** – connects and controls all the components.
- Vibration motor – gives vibration alerts when high pressure is detected.
- **Battery** – powers the whole system.
- **Piezoelectric sensors** – placed in the insole to measure foot pressure.

VI. WORKING

Step 1 – The insole system starts either through a manual or automatically through a connected wearable device.
Step 2 – Once powered on, the battery powers all components. The power unit is designed for long periods, reducing the need for continuous charging and monitoring.
Step 3 – The gyroscope sensor is then interacted to identify the user's present activity, such as standing, walking, or shifting posture. These readings form the basis for assisting motion patterns and gait performance.
Step 4 – Data acquired by the gyroscope is sent to the control unit, where movement is known. This step allows the system to interpret activity levels and provide meaningful feedback related to gait stability and foot health
Step 5 – The Force-Sensitive Resistor (FSR) sensor is switched on to record pressure over different parts of the foot. These readings play a major role in detecting stress, which may represent injury risk.
Step 6 – The temperature sensor continuously monitors the surface temperature of the foot. Temperature variations help in knowing hotspots or uneven patterns that could process the signal or circuit issues.
Step 7 – A small vibration module is activated regularly to encourage blood circulation in the foot. This gentle motivation helps in keeping healthy blood flow and recovers for long periods of inactivity.
Step 8 – The system can be switched off by hand by the user or will automatically power down after a current period, assuring energy performance and safe operation. This system uses modern data tools to give information and customized design for foot care. This data is studied using machine learning to find unusual patterns like uneven pressure, temperature changes, or strange foot movements. The system can also collaborate with health devices and apps, to give a complete profile of a person's health. User-friendly dashboards help doctors and users to understand the data

clearly. It can be used as predictive tools to warn foot problems, like ulcers or infections, before they become serious. Real-time alerts help users and doctors act quickly if there are changes in foot health.

VII. RESULTS AND CONCLUSION

The developed smart sensing-enabled insole system was successfully tested under normal walking conditions to estimate its performance in monitoring plantar pressure and gait characteristics. The experimental setup, as shown in Figure X, demonstrated stable operation and reliable data acquisition throughout the testing period.The pressure sensors embedded in the insole reliably detected variations in plantar pressure at different regions of the foot during walking. Higher pressure values were recorded at the heel during the foot contact phase, while increased pressure was recorded at the metatarsus and toe area during the push-off phase. These observations confirm that the system precisely records the natural gait cycle.

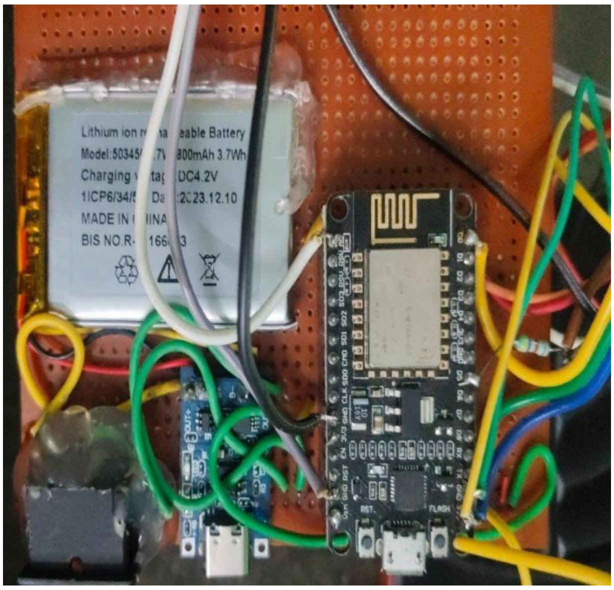

Fig 7.1: Smart Insole for Foot pressure monitor

INSOLE OF PRODUCT

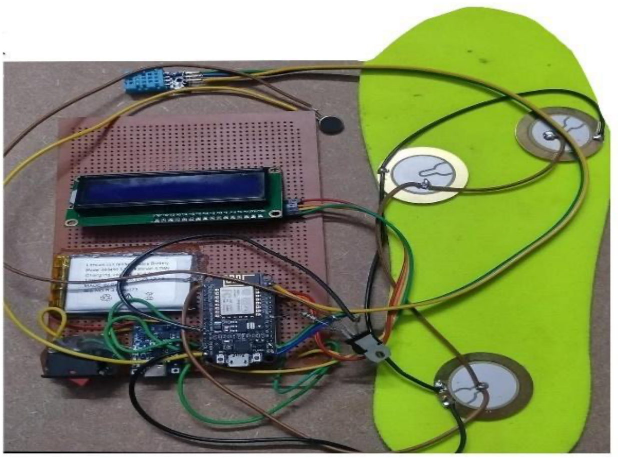

Fig 7.2: Motherboard of the product

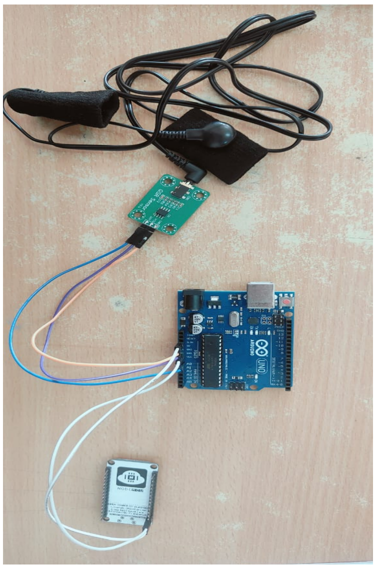

Fig 7.3 : Prototype device

The Atmel microcontroller board continuously processed the sensor outputs without noticeable delay, indicating real-time performance capability. The collected data clearly distinguished between stance and swing phases of gait, enabling the identification of abnormal pressure distribution patterns. This is particularly useful for patients using Ankle–Foot Orthoses (AFOs), where stable performance may otherwise lead to distress or reduced walking efficiency. The system also demonstrated reliable behavior, producing similar pressure patterns across multiple gait trials. This confirms the stability and uniformity of the designed hardware configuration. The compact and lightweight design of the setup did not interrupt with natural walking, ensuring user comfort during data collection. Overall, the results illustrate that the suggested sensor-equipped insole and Atmel microcontroller based system is effective for real-time plantar pressure monitoring and gait analysis. The obtained pressure data can be further applied for stress analysis of AFOs and for optimizing orthosis design and therapy approaches.

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