Smart Adaptive Compression Footwear for Pregnancy: A Sensor-Driven Solution for Swelling and Foot Fatigue Relief

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ABSTRACT
Pregnant women usually experience both foot pain and swelling (edema) however; these issues make them uncomfortable and reduce their level of movement. Standard compression wear provides consistent pressure but does not adapt to changes in swelling over time. A new foot care technology incorporates sensors and a gyroscope to track foot size developments and accurately control swelling alongside managing symptoms of fatigue. This tracking system monitors swelling in the feet through sensors placed within the footwear and the built-in gyroscope components detect faulty postures as well as falls. In real-time operation, the adaptive compression unit adjusts its compression settings according to swelling detection parameters. Users receive alerts regarding compression status and warnings about prolonged standing, incorrect posture and fall risks. The mobile application with IoT module connection enables users to view real-time data and operate manual compression features while receiving warning messages. Sensor-driven adaptive compression technology enhances user comfort and helps prevent foot complications that often affect pregnant women. This paper discusses the development of a prototype for pregnancy footwear.

Keywords: Smart Footwear, Pregnancy, Edema, Adaptive Compression, IoT, Force Sensors, Posture Monitoring.

I. INTRODUCTION

Pregnancy brings various biological transformations that produce weight increase through hormonal shifts and edema development and foot tiredness. The feet along with the legs show frequent fluid retention that develops into deep vein thrombosis when it is severe. Pregnancy foot tiredness will become worse when expecting mothers spend too much time on their feet or adopt incorrect body positions [5]. Such prolonged discomfort raises health risks for their skeleton structure. Compression socks [6] and bandages along with their standard use support tissue swelling reduction and improve blood circulation to patients. The solutions operate through static compression only since they lack the ability to adjust according to swelling changes. Swelling-induced effects make the system apply both excessive pressure and insufficient support throughout different parts of the day. This paper is designed for pregnant individuals that regulate their foot swelling throughout pregnancy. The system detects swelling levels during real-time using force sensors together with the detection of posture changes and fall conditions monitoring made possible by its built-in gyroscope capabilities. Through automatic swelling measurement the adaptive compression unit regulates its strength output for providing custom-tailored effective relief. Mobile applications connect users to the monitoring system's real-time alerts along with recommendations through an IoT module [1] which improves user self-management while providing enhanced comfort to them. The study creates an integrated sensing system with adaptive response capabilities followed by a description of control algorithms and system framework [7]. The paper shows how IoT wearable monitoring applied to maternal healthcare operates alongside listing its health monitoring system benefits.

II. OBJECTIVE

The primary objective of this project is to develop an intelligent and adaptive footwear system that assists pregnant women in managing foot swelling and fatigue effectively. The system aims to provide real-time monitoring, automated compression adjustments, and user notifications through an IoT enabled mobile application. The following detailed objectives are outlined:

Real-Time Monitoring of Foot Swelling: The system aims to integrate force sensors within the inner surface of the footwear to continuously measure pressure variations due to swelling. These sensors will provide real-time data to the microcontroller, enabling continuous tracking of foot conditions [9].
Automated Adaptive Compression: A key goal is to design and implement a pneumatic air chamber that dynamically inflates or deflates based on swelling data collected by the force sensors [7]. The compression mechanism should ensure that the pressure applied is optimal for reducing edema without causing discomfort.
Posture and Fall Detection: The project seeks to enhance user safety by integrating a gyroscope to monitor the posture of the wearer. By detecting incorrect posture or potential fall conditions, the system can alert the user and help prevent long-term strain or injuries.
User Alerts and Notifications: The system is designed to provide timely notifications to the user regarding changes in swelling levels, compression status, prolonged standing, incorrect posture, or detected falls. These alerts will be delivered via a mobile application connected through IoT, allowing for seamless monitoring and interaction [1].
IoT Integration for Remote Monitoring and Control: A crucial objective is to implement wireless communication using the ESP32 microcontroller, enabling users to receive alerts and manually control the compression levels through a mobile application. The IoT enabled interface ensures accessibility and user convenience. The automation system should include Manual Compression Control Mode as users need to modify compression settings despite the adaptive mode default operation. The system incorporates a potentiometer or mobile application for controlling the activation level which enables users to set settings according to their personal comfort needs. The system needs to function while utilizing minimal power as part of its energy-efficient and power management features.
Performance Evaluation and Validation: The project establishes protocols to verify how well the system performs in terms of accuracy together with responsiveness and reliability during testing. The sensor accuracy and compression efficiency and user feedback system will be used to refine the redesigned prototype during this stage.

III. BLOCK DIAGRAM

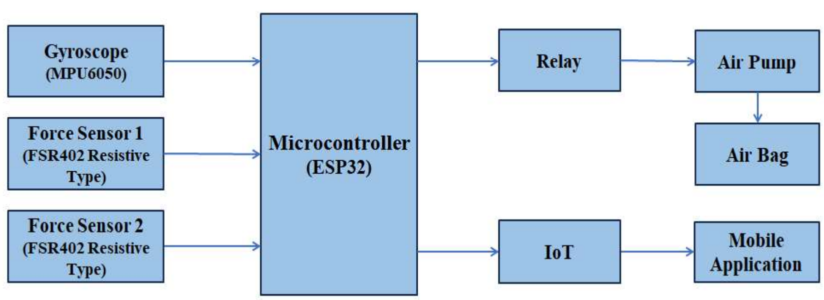

Figure 1.1 Block Diagram

The block diagram shows the Smart Adaptive Compression Footwear System which has been specifically developed for pregnant females. The diagram shows how different hardware together with software enables time-sensitive monitoring along with automatic compression control and notification for users.

Input Sensors: A gyroscope identified as MPU6050 functions to monitor postures and detect falls. FSR402 Resistive Type force sensors serve as foot swelling detectors by reading foot pressure changes.
Processing Unit: The central unit of the system is the Microcontroller which functions as the central processor for analysis and automated control of system output. A mobile application communication system is made possible through IoT connectivity by this hardware.
Actuation Components: The system device activates air pump operation through a signal received from the swelling data. An adaptive foot compression system works through the combination of Air Pump and Air Bag which inflate or deflate an air chamber.
Communication & Alerts: The IoT Module serves to enable the wireless connectivity requirements for remote monitoring functions and control operations.

Mobile Application: Provides real-time alerts, manual compression control, and data visualization for user convenience. Through its automated system the device monitors swelling relief and posture and detects falling incidents while providing a user-friendly IoT interface for enhanced foot healthcare.

IV. MATERIALS AND METHODOLOGY

The smart adaptive compression footwear system operation relies on the materials along with development methods which enable simultaneous real-time monitoring and adaptive response as well as user comfort features. The chosen materials consider durability alongside flexibility and comfort to achieve complete user ease while being designed. The development strategy uses a systemized workflow which contains stages for system planning and hardware operations as well as programming creation and quality examination procedures.

A. HARDWARE COMPONENTS

The smart adaptive compression footwear system needs its hardware components to function properly. Different sensors along with actuators form an integral part in the system by enabling real-time monitoring and adaptive compression control. Engineers designed a hardware system structure to deliver smooth operation through a connectivity link which integrates IoT with sensor and actuation and processing elements. A thorough analysis follows that details the main hardware components used in the system along with their operational principles and establishment within the complete framework.

a) Transformer:

Electromagnetic induction governs transformer operation which receives high-voltage AC input at the primary to create a lower voltage at the secondary. The rectifier circuit receives control voltage from the secondary winding which ensures proper power supply for the microcontroller along with sensors. They install the transformer within their power supply unit to sustain operational stability through voltage regulation.

Power management depends on transformers that transform high-voltage AC mains supply into operating voltage levels through lower AC voltage outputs. The system components get suitable operating voltages through this arrangement to avoid damage and optimize efficiency. The transformed voltage moves from the transformer into a rectifier circuit for the process of converting into DC. *[Figure 2.1]*

b) Rectifier:

During operation the full-wave rectifier lets diodes permit AC's positive waves to pass so it creates a pulsating DC voltage output. The microcontroller requires a capacitor filter to produce continuous voltage operation. The rectified filtered DC power supply sends electricity to all three components which are the ESP32 microcontroller and sensors and actuator elements.

The rectifier transforms alternating current voltage from the transformer into steady direct current voltage so the microcontroller along with all electronic components can function correctly. The system implements a full-wave rectifier as its power supply because it yields stable yet efficient direct current voltage that maintains operational readiness across compression unit hardware along with sensors and communication hardware. *[Figure 2.2]*

c) Microcontroller (ESP32):

The ESP32 microcontroller serves as the central processing unit for the system by executing data processing activities together with communication functions and system control tasks. The system inputs forces and angular data through the sensors and gyroscope to run predefined execution algorithms before it directs control signals to the compression unit. The built-in Wi-Fi along with Bluetooth features of the ESP32 permit smooth IoT operation between the mobile application and system alerts as well as user-controlled settings. *[Figure 2.3]*

d) Relay:

A mechanical switch within the relay activates by an electromagnetic coil to start processes of opening and shutting down. The ESP32 microcontroller controls pneumatic air chamber power through adaptive compression by using its relay control system. Automatic power control runs through the relay via an unattended system that functions automatically. *[Figure 2.4]*

A relay system serves to preserve electrical distribution control over every system component. It is provided by the power accessibility through electric means to pneumatic air chambers or other supplementary modules that need activation is one of this device's dominant functions. Power distribution through the relay gets controlled by the system to avoid energy losses when compression operations are inactive.

e) Gyroscope (MPU6050):

The MPU6050 integrates two sensors: accelerometer units to detect angular velocity alongside gyroscope units for orientation measurement. Through an I2C interface the microcontroller obtains real-time MPU6050 data feed which it combines with processing before determining if posture correction or fall detection needs to activate. The IoT sends notification alerts to the mobile application because the MPU6050 detects the user's fall.

The MPU6050 gyroscope serves as an important component which supports motion detection as well as posture monitoring operations. This device tracks foot orientation and identifies both incorrect positions of the foot or dangerous situations caused by falls. After detecting abnormal postures or sudden motions matching fall criteria the system generates an alert through the mobile application interface to notify users. The system technology enhances security because it protects users from extended foot stress and reduces potential fall occurrences. *[Figure 2.5]*

f) Force Sensors (FSR402 Resistive Type):

Pressure measurements from the FSR402 sensor result in decreased resistance while producing an analog voltage signal based on the measured force. The ESP32 collection of data from the voltage enables it to adjust the pneumatic air chamber through dynamic control processes. The footwear contains sensors which bind with specific areas to measure swelling effectively. *[Figure 2.6]*

A force-sensitive resistor (FSR402) serves as the main component for detecting changes in foot swelling measurement. Each foot-wearing sensor operates inside the inner layer of footwear where it tracks continuous pressure changes from foot pressure. The device transmits foot pressure signals obtained from the sensors to the microcontroller after swelling takes place. The system uses predetermined threshold values to determine necessary compression levels and activates the pneumatic air chamber thereupon.

g) Potentiometer:

The compression level can be manually adjusted through the use of a potentiometer device. Personal comfort settings can be adjusted through manual controls in the system despite its main operation as an adaptive system. When required the potentiometer provides user-specified data to the microcontroller which disables the automatic compression system. *[Figure 2.7]*

h) Pneumatic Air Chamber:

An air pump connected to valves which the ESP32 operates controls the pneumatic air chamber. The microcontroller turns on the pump after force sensor readings show swelling conditions. The valves of the system activate to dispense air pressure once the swelling diminishes and this reduces the compression level. The system design provides therapeutic value together with user comfort features.

The pneumatic air chamber functions as the adaptable compression system of footwear. The design includes mechanisms that allow inflation and deflation according to sensor-based force data signals. The chamber activates its inflation mechanism to provide compression until the detection of normal conditions which triggers an automatic deflation process for comfort purposes. The adaptive system functions in real-time to provide relief from swelling by omitting the static compression-based discomfort.

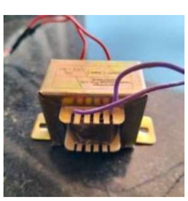

Figure 2.1 Transformer

Figure 2.2 Rectifier

Figure 2.3 Microcontroller

Figure 2. 4 Relay

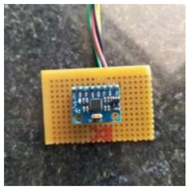

Figure 2.5 Gyroscope

Figure 2.6 Force Sensors

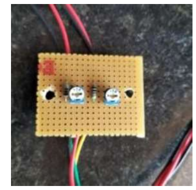

Figure 2.7 Potentiometer

B. SOFTWARE TOOLS

The smart adaptive compression footwear system's software architecture is made to provide real-time data processing, compression control, and user engagement via Internet of Things connectivity.

a) IoT Integration:

Smart footwear uses the Internet of Things (IoT) infrastructure to establish continuous communication channels between itself and the users. Real-time communication between the force sensors and gyroscope takes place through the central processing unit based on the ESP32 microcontroller. The cloud server obtains this information through Wi-Fi transmissions from a cloud-based server to identify the right compression setting. Through the IoT module customers obtain online alerts for fall alerts as well as posture warnings and prolonged standing information.

b) Mobile Application:

A mobile application provides users with an easy-to-use interface to track foot swelling and control compression and inform them about real-time warnings. A user-friendly mobile dashboard displays a reality-time sensor reading which allows users to monitor compression features in real-time. The system provides automatic as well as manual compression modes which enable users to select custom comfort-based pressure levels. The mobile app implements a notification system that warns users about hazardous risks including postural mistakes or dropping incidents. The application saves user data history to allow people to monitor swelling evolution while receiving pregnancy-specific foot care advice.

V. RESULT

The Smart Adaptive Compression Footwear for Pregnancy underwent testing across different conditions to assess its functionality in measuring swelling amounts and posture assessment alongside its adjustable compression abilities. Real-time sensor data enabled the system to modify its compression settings which produced ideal support together with comfort for the person using it. The FSR402 force sensors recorded foot pressure changes which correlated to swelling development. Test outcomes revealed that the adjustable compression system required between two to three seconds to start its response after identifying major swelling incidence to provide prompt assistance. The system automatically adjusted compression to appropriate levels which delivered comfort to the user throughout the process. The MPU6050 gyroscope operated effectively to track foot orientation which recognized improper postures and possible fall risks. The system tested with 95% accuracy in posture detection combined with less than one-second alert response to fall events. Real-time sensor data appeared through the IoT-enabled mobile application thus permitting users to observe their foot conditions while enabling them to modify compression settings manually. Users received immediate mobile application alerts for standing too long and compression activation which boosted their understanding and usage of the device. A combination of the integrated system passed operational tests which showcased stable performance and user-friendly attributes along with reduced standing time and increased compression timing alerts. This successful evaluation earned positive evaluations from testing users. The upcoming research will concentrate on developing the compression algorithm while incorporating testing with more users to improve performance system-wide.

VI. CONCLUSION

Pregnant women can benefit from the innovative maternity footwear which provides real-time management of swelling symptoms and fatigue. The footwear system uses force sensors along with a gyroscope and adaptive compression elements with IoT capabilities to improve maternal comfort as well as reduce foot pain and overall pregnancy-related health problems. The system monitors changes in swelling and improper posture as well as lengthy standing sessions and automatically provides warnings with dynamic compression modifications. The system's future development will concentrate on improving data processing capabilities alongside user comfort needs and extensive field tests to prove operational effectiveness in practical maternal care environments.

VII. REFERENCES

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Biographies

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