IOT Based Compression Socks with Sensor for Proper Blood Circulation of Leg

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***Abstract*— In modern healthcare, a significant proportion of patients endure blood circulation complications, requiring efficient methods to maintain blood flow. Compression stockings, designed to apply targeted pressure on the lower limbs, play a crucial role in maintaining blood flow, alleviating discomfort, and reducing swelling. This research investigates the use of IoT technology into compression socks to improve their effectiveness for continuous blood circulation monitoring and proactive healthcare management. The proposed IoT-based compression socks incorporate sensors to continuously monitor key physiological parameters related to circulatory health. These sensors measure blood flow, temperature, and pressure, providing real-time data that is transmitted wirelessly to a central monitoring system. The compression socks can detect abnormalities in blood circulation by analyzing sensor data. The early detection of possible circulatory problems is made possible by this real-time monitoring and analysis, which supports proactive healthcare management. Moreover, the Internet of Things-enabled compression socks include an intuitive user interface that makes it possible for patients and medical professionals to obtain thorough circulatory data via online or mobile applications.**

Keywords— IoT, compression, flex sensors, I2C LCD display, GSM communication, real time monitoring.

I. INTRODUCTION

The use of Internet of Things (IoT) technologies in healthcare equipment has drawn a lot of attention lately since it provides innovative solutions to monitor and improve various aspects of the health sector. It has promptly transformed the healthcare industry. This is a system that can work with computing devices, digital and mechanical machines, objects, and living creatures. It can transmit data without requiring communication between computers and humans. The medical field may benefit numerous benefits from reducing human-computer interactions. It has resulted in a new era of personalized and responsive patient care.

In modern medicine, a significant number of patients endure conditions such as diabetes, peripheral artery, venous ulcers, varicose veins, lymphedema and orthostatic hypotension. The increased blood circulation that compression socks promote can be beneficial for people who have a history of circulatory problems because of genetic disorders, surgery, injuries, certain medications, People who are at increased risk of blood clots in the legs known as deep vein thrombosis, or prolonged inactivity like bed rest. Compression socks can help people with venous ulcers, varicose veins, and spider veins manage their symptoms and support their veins, particularly during the healing process after treatment. Ensuring healthy blood circulation in the legs is the basic treatment for these disorders. Varicose veins, diminished circulation, and

Fig.1. IoT based Compression Socks

swelling in the legs and ankles can all be more common in pregnant women who have higher blood volumes. Both this risk and discomfort can be reduced with compression socks. Athletes who want to enhance their performance and alleviate soreness and exhaustion after training are showing a growing interest in compression socks Applying gentle pressure to the foot, compression socks increase muscle pressure, reducing swelling, preventing swelling, and increasing the absorption of excess fluid Furthermore, it prevents dilation of superficial veins, prevents blood accumulation, prevents reflux, and reduces congestion. The study details the design, implementation, and potential clinical applications of these smart compression socks and the transformative impact of IoT on blood circulation.

This study proposes an Internet of Things (IoT)-based on compression socks capable of regulating the blood circulation within specified instructions, time, accuracy, and cost constraints. This smart compression socks use IoT sensors to collect real-time information on parameters affecting blood flow, such as pressure, temperature, and activity level, and transmit this data to a central location for easy processing and research, allowing for precise, personalized adjustments. By combining advanced fabric technology with IoT connectivity, these compression socks aim to provide not only medical benefits but also health conscious strategic use. For circuit simulations, Proteus has been used.

Compression therapy for limb edema traces back to ancient times but gained modern recognition through Conard Jobst's innovation of compression socks in response to his own venous issues. Compression socks, specifically, aid in reducing venous pressure, improving muscle pump function, and enhancing venous return, especially for conditions like Deep Vein Thrombosis (DVT) and swelling caused by gravitational effects on venous pressure. The study measured pressure, lower extremity volume and circumference changes, and subjective comfort impressions using Kansei engineering methods, aiming to elucidate the comfort aspects essential in compression therapy design and application.

Venous leg ulcers (VLUs) are open sores that usually occur between the ankle and knee. Non-healing wounds, including VLUs, have a significant impact on economic resources. The findings revealed that all tested garments ,including compression socks, shorts, and tights, were effective in enhancing resting venous return and muscle blood flow. The study emphasizes the potential benefits of sports compression garments and highlights the need for precise sizing and pressure control.

This research paper explores a novel approach to treating varicose veins through a home-based system utilizing automated compression stockings. The system incorporates pressure sensors and an microcontroller to provide periodic vibration massage, addressing varicose veins symptoms more effectively than traditional compression stockings alone

This study investigated the effects of prolonged sitting on leg muscles using graduated compression stockings. Measurements showed that the compressed leg had less change in calf size, extracellular water, and muscle oxygenation compared to the uncompressed leg.

This paper explored the effects of compression stockings on cardiovascular health in ME/CFS patients during tilt tests. When participants wore 20–25 mmHg stockings, losses in cardiac output and cerebral blood flow were lessened than when they did not wear stockings. This shows that during orthostatic stress, cardiovascular function is supported.

Compression socks, widely employed for venous disorder prophylaxis and treatment, apply pressure to the lower leg to address conditions ranging from venous incompetence to chronic venous leg ulcers. This study explores the physiological effects of compression socks, elucidating the mechanism of action, standards, and classification based on compression pressure.

The study explores the effects of graduated compression stockings, nearby vibration, and their combination on popliteal venous blood velocity. Within the introduction, the method of reasoning for the research is established, emphasizing the importance of understanding the impact of these interventions on venous blood flow.

In the introduction, the research aims to address the effectiveness of compression stockings in enhancing blood circulation and reducing symptoms such as swelling and discomfort. This study explores the integration of biomechanical concepts into the design of these socks to optimize their effectiveness.

The study investigates the impact of sports compression garments on resting markers of venous return and muscle blood flow in male basketball players. In the introduction, the research aims to explore potential benefits of compression garments in enhancing physiological parameters crucial for athletic performance and recovery.

This study investigates the impact of compression stockings on suppressed muscle blood volume and oxygenation levels induced by persistent sitting. Prolonged sitting is associated with reduced vascular function and oxygen delivery to muscles, posing potential health risks. Compression stockings are hypothesized to mitigate these effects by enhancing blood circulation.

II. Proposed System Methodology

This system primarily analyzes patient pulse rate and temperature data to ensure whether the patient can take the compression treatment. The average resting heart rate for an adult is between 60 and 100 beats per minute. Adults typically have body temperatures between 97 and 99 degrees Fahrenheit. For infants and children, the temperature range is 97.9 to 100.4 F. So, our aim is to analyze the heart rate, oxygen label and the body temperature of patients using the sensors to understand whether the person's leg blood circulation is normal or not. When blood isn't flowing properly, temperature will fluctuate Poor blood circulation indicates lower body temperature and high rate of pulse rate. The compression of socks ranging from extra firm to mild:

Light compression (15-20mmHg): Helps prevent and relieve small to smooth muscles, relieve tired and sore feet, and reduce minor swelling of feet and legs.

Moderate pressure (20-30mmHg):This pressure range is used to treat mild to severe varicose veins, control mild to severe lymphedema, and encourage wound healing or the treatment of thrombotic syndrome.

Firm compression (30–40 mmHg): Intended for the treatment of thrombotic syndrome and wounds.

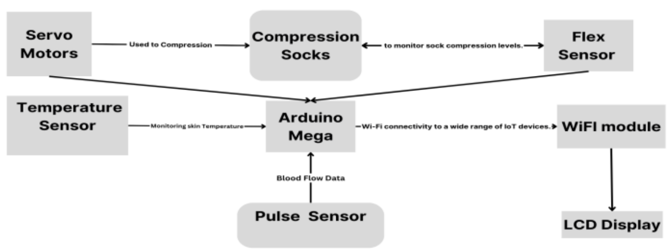

Fig.2. Block diagram of the IoT based compressed socks

Now to develop a prototype for remote sensing and monitoring, the system requires some sensors interfacing with the controller. LM35 Temperature sensor is used to collect patient body temperature. Pulse Oximeter sensor used to collect pulse rate, Flex sensor to monitor socks compression labels ,Servo motors used to compress the socks, Pressure sensor to control the pressure applied to the socks .The data is gathered by the sensors and transmitted to the Microcontroller Arduino for processing. All collected data can be displayed to users through LCD display. GSM or Wi-Fi module connects to the internet and transmits data to the server of the IoT device. Based on the data received from sensors, a set of instructions will be implemented to adjust compression levels in the socks. Compression will be done by servo motors. For each socks compression 1 servo motor will be used. If reduced oxygen levels or abnormal temperatures are detected, the compression levels can be adjusted accordingly to improve blood flow. The GSM or Wifi module can send a message to the patient's caregiver. The output of the patient's need is also displayed on the LCD display

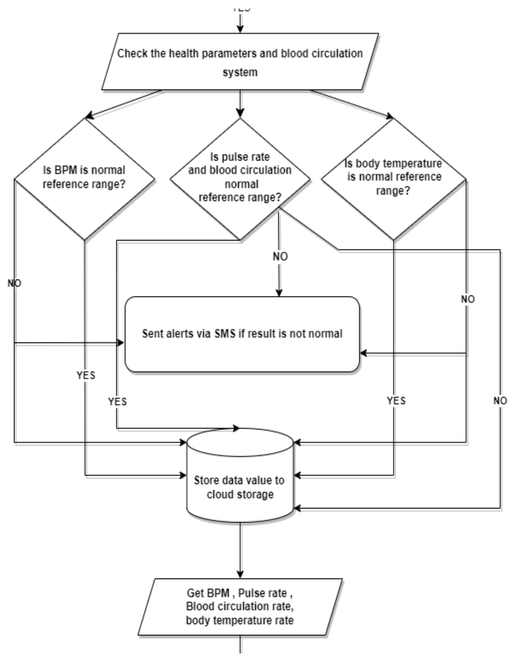

Fig.3. Flowchart of the IoT based compressed socks

In this system we will be using two different modes:

A. Observation Mode: Using sensors, the device will gather information from the patient's body and continually check their vital signs. If the result is normal , data will be stored in the storage and results will be shown to the system display.
B. Alert Mode: The alarm mode will be triggered by the system upon detecting significant alterations in the patient's health data. Then, the results will be sent via SMS.

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The study investigates the use of elastic compression stockings to mitigate intradialytic hypotension in patients undergoing hemodialysis. The researchers, Hyun-Jung Kim and Hee-Jung Kim, conducted an intervention study to assess the effects of this intervention. The methodology involved applying elastic compression stockings to a group of patients during hemodialysis sessions and monitoring various physiological parameters.

The study primarily focused on monitoring blood pressure, pulse rate, and hypotensive symptoms in the patients. The key intervention was the application of elastic compression stockings. While the summary does not provide specific equations, it can be assumed that standard measurements and statistical analyses were conducted to assess the impact of the intervention.

Inclusion of randomized controlled trials (RCTs) involving GCS alone or in combination with other DVT prophylactic methods. Data collection, analysis, and risk of bias assessment performed by review authors. Subgroup analysis based on the specialty of hospitalization (surgical or medical patients).

The methodology involves a home-based system utilizing a wearable device integrated into compression stockings for varicose veins treatment. Continuous monitoring of blood pressure variations between upper and lower body regions, represented by values P1 and P2, informs an equation that triggers localized vibration treatment when P2 exceeds P1, ensuring targeted massage until pressure equalization.

The study aimed to objectively evaluate the physical and mechanical properties of various compression sock designs through standardized laboratory testing. Mechanical testing equipment was then used to conduct tensile strength, elongation, stiffness, compression force, and interface pressure assessments according to established textile industry protocols.

The research methodology required 12 male runners, who were made to participate in a standard running warm up and a 5 km time trial race (TT1). They were then given a 1 hour resting period and after that, the same warm up followed by another 5 km time trial race (TT2). The TT1 and TT2 were done in 2 sessions by all the 12 participants, once with compression socks and once without them, which was the control case.

The test methodology included 4 different kinds of compression socks .The participants were 10 healthy women who were asked to avoid caffeine or alcohol.The measuring factors in the test were vertical jump height, blood oxygen saturation, local hemoglobin, blood flow, and Visual Analogue Score (VAS).

The study employed a randomized controlled trial design with participants engaging in extended sitting periods. Near-infrared spectroscopy and vascular occlusion techniques were used to assess muscle blood volume and oxygenation levels.

Methodology involves a systematic approach, including participant selection, data collection, and analysis. The study utilizes a sample population to assess the wearing performance of compression stockings, employing both subjective feedback from participants and objective measurements.

The methodology employs a randomized crossover design with participants undergoing separate sessions of compression, vibration, combined intervention, and control.

III. SYSTEM DESIGN AND SIMULATION

The research paper focuses on the development of IoT-enabled compression socks integrated with sensors centers on the development of an advanced system designed to assist individuals with compromised blood circulation. These smart socks have sensors that can track the wearer's blood flow continuously and notify the wearer of any issues that arise. Temperature, pressure, and heart rate fluctuations can all be detected by the sensors, which can then send the data to a smartphone app of their choice or other devices that are connected.

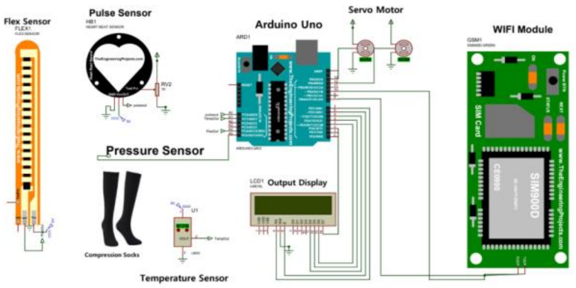

Fig.4. FPROTEUS schematic of the proposed Compression Socks

The Arduino Mega features a total of 70 pins, with 54 digital input and output pins (0-53).There are 16 analogue input pins (A0 to A15) and 14 analogue output pins (Pin 0 to 13) on this board. With the use of these pins, it may interface with a variety of actuators, sensors, and other digital devices to create a broad range of projects and applications. In the simulation, the servo motors are connected to any of the digital input pins on the Arduino Mega, and any of the analogue input pins are used to connect the temperature, pulse, and flex sensors. The LED display is attached to any digital pin on the Arduino Mega, and the power supply is connected to one of the USB ports on the device. The compiled data on an LCD display system, ensuring user accessibility. In addition, the system incorporates servo motors to facilitate sock compression, with each compression cycle utilizing a single servo motor. Compression levels dynamically adjust based on real-time data received from the sensors. If anomalies such as reduced oxygen levels or abnormal temperatures are detected, the compression levels are modified to optimize blood flow.

To enhance connectivity, the system features a GSM or Wi-Fi module that establishes an internet connection, allowing seamless data transmission to the IoT device's server. This comprehensive setup seamlessly combines advanced sensor technology, microcontroller processing, and IoT connectivity to create an intelligent compression sock system aimed at improving vascular health.

The IoT based compression socks with sensor for proper blood circulation. System is successfully simulated by using Arduino software. During the simulation, the flex sensor accurately measured, and the temperature sensor provided reliable temperature readings which were correct. The pressure sensor effectively detected pressure labels. The pulse sensor accurately captured and displayed heart activity on the LCD display, and critical events triggered immediate alerts through the Wi-Fi Module. The communication between the Arduino Mega and the Wi-Fi module facilitated real-time data transmission to caregivers or medical professionals.

TABLE.I PARAMETERS SPECIFICATIONS OF THE SYSTEM

Components	Type
Arduino Mega	Microcontroller
Flex Sensor	Passive
Power Supply	AC/DC
Temperature Sensor	Passive/ Active
16x2 LCD Display	Alphanumeric
Pulse Sensor	Optical
Servo Motors	Rotary
Wi-Fi Module	Wireless

[1]Data analysis involved specialized software for near-infrared spectroscopy data interpretation, enabling the quantification of muscle blood volume and oxygenation levels. Statistical analysis was performed using standard statistical software to assess the efficacy of compression stockings in counteracting the adverse effects of prolonged sitting.

The software aspect involves data analysis tools to interpret subjective feedback and quantify objective measurements, facilitating a comprehensive understanding of the stockings' impact on blood flow.

Here using software is data analyzing software which collects data from Doppler ultrasound and is analyzed using specialized software to quantify popliteal venous blood velocity.

IV. HARDWARE DEVELOPMENT AND TESTING

After getting the desired simulation result, the prototype of the automated paralysis patient health care system was developed. In this part of the report sensing and circuit development are discussed.

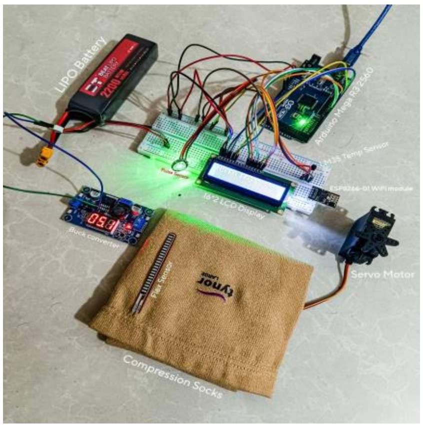

Fig.5. Development prototype **of Compression Socks** with **Sensor for Proper Blood Circulation.**

A. *Hardware Development of the System*

The circuit is mounted with all the required components. The LIPO battery was supplying the power. The Arduino ATmega2560 was used to insert logical code.

A code was inserted after the circuit was finished. And on the LCD monitor, the desired information, including temperature and BPM . The formula for converting Fahrenheit to Celsius is-

$$C = 5/9(F-32) \tag{1}$$

The formula for converting number 0-1023 from the ADC into 0-5V is-

$$Vout = (reading\ form\ ADC) * (5/10240) \tag{2}$$

The formula for converting Volt to temperature is-

$$Temperature\ (°C) = Vout * 100 \tag{3}$$

The temperature, and flex sensor sensors must be connected to the body. The most suitable spot to attach the sensor is on the hand or chest. The LCD will begin displaying the actual data as soon as the sensor is attached.

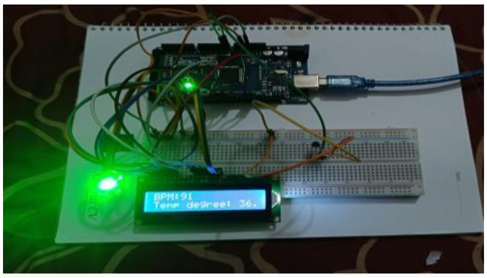

Fig.6. Hardware Testing using the components along with LCD.

B. *Experiment and Results*

The main objective of our project is to take proper blood circulation and use a health monitoring system in real life and this process was fully automated and used different sensors. To achieve the goal, we allotted several modules in our system which collects the data at real time and notifies the patient. Utilizing the linear relationship between temperature and voltage, the LM35 temperature sensor works. It is intended to provide an analog voltage proportional to temperature in degrees Celsius. The internal design of the sensor causes its output voltage to climb as the temperature rises. A microcontroller is typically used to measure this voltage to calculate the related temperature. The LM35 is a well-liked option for temperature monitoring and control applications due to its simplicity and precision. Both the temperature values, Celsius & Fahrenheit, are shown simultaneously on the I2C LCD. This helps with medical evaluation by enabling the monitoring and diagnosis of heart problems. The principle of resistance changes in response to bending governs how a flex sensor functions. It has a flexible substrate made of conductive substances. The resistance changes as the sensor bends because the spacing between the conducting components shifts. The degree of bending directly correlates with this change in resistance. The degree of bending of the sensor can be calculated by measuring the resistance, often using a microprocessor. This property makes the sensor ideal for robotics, gaming, and medical equipment. It is a GSM/GPRS communication device, the ESP8086-01 Wi-Fi module. To send and receive data, mostly text messages and calls, it connects to cellular networks. It interacts by sending AT commands through a microcontroller and connecting to a network using a Wi-Fi network. It employs protocols to create communication channels with mobile towers and runs on GSM frequencies. It is advantageous for IoT, remote monitoring, and communication applications since it enables remote data transfer, communication, and tracking.

TABLE.II TABLE OF SPECIFICATION

Components	Functionality	Testing Method	Weightage (%)	Pass/Fail Criteria
Arduino ATmega2560	Microcontroller and system control	Functional Testing	15	All system control functions work correctly.
LM35 Temperature Sensor	Temperature measurement	Calibration and Verification	10	Accurate Temperature Readings within an acceptable range.
Flex Sensor	Monitor Compression Level	Range and Sensitivity Testing	10	Responsive readings based on the patient's joint movements
Pulse Sensor	Detect the pulse rate	Sensor Integration and Testing	10	Accurate pulse rate readings within an acceptable range.
16×2 LCD Display	Real-time data display	Display Verification	15	Proper and legible display of patient data on the LCD screen
Servo Motors	Compression	Compression Testing	15	Socks compression achieved using one servo motor per sock.
Compression Socks	Compression Wear		5	
ESP8266 Wi-Fi Module	Wireless IoT Connectivity	Connectivity Testing	15	Successful data transmission to the server via Wi-Fi.

[1] Salzmann pressure measuring device MST MKIV, a sophisticated tool designed for the indirect in vitro evaluation of compression pressure. The air pump inflates the sleeve until the contacts open, allowing the pressure transducer to read and display the pressure digitally with 1-mmHg resolution, providing precise measurements at specific points.

Hardware includes a Doppler ultrasound system to measure popliteal blood velocity, while custom software analyzes the data**.**

The hardware utilized in the study includes specialized devices such as compression socks, sensors, data collected app for blood flow velocity measurement, ensuring accurate and reliable data collection. Additionally, participants may wear monitoring devices to track their adherence to wearing compression stockings.

This hardware facilitated the development of socks tailored to individual anatomical variations, optimizing compression efficiency.

The hardware utilized includes non-invasive monitoring devices to measure venous return and muscle blood flow, while the software employed is designed for data analysis and interpretation.

Near-infrared spectroscopy devices were utilized for non-invasive monitoring of muscle oxygenation. Vascular occlusion cuffs were applied to induce controlled ischemia during measurements**.**

V. Performance Analysis and discussion

In the realm of wearable health technology, performance analysis of the "IoT-based Compression Socks with Sensors for Proper Blood Circulation System" is presented. The assessment encompasses the accuracy, consistency, responsiveness, usability, scalability, and resilience of the system. The evaluation shed light on the system's efficacy in monitoring and improving blood circulation, making it a valuable contribution to wearable health technology.

A. *Temperature Monitoring:*

The LM35 temperature sensor, with an accuracy of ±0.5°C, provides precise temperature readings within a ±2-degree variations, contributing to the system's ability to monitor and respond to fluctuations in body temperature. The precise measurements, displayed on the 16x2 LCD display, empower both patients and healthcare professionals with essential health information.

B. *Muscle Activity Monitoring:*

The flex sensor demonstrated responsiveness to joint movements, allowing accurate monitoring of muscle activity. This capability is vital for adjusting compression levels in real-time, optimizing the system for personalized and effective blood circulation support.

C. *Pulse Detection:*

The pulse sensor integration successfully detected and displayed accurate pulse rates. This feature enhances the system's ability to assess cardiovascular health, providing valuable data for both patients and healthcare professionals.

D. *Compression Effectiveness:*

The flex sensor, servo motors, and compression socks collectively demonstrate the system's efficiency in maintaining proper blood circulation. The compression testing validates the capability of the system to adjust pressure levels dynamically, addressing anomalies such as reduced oxygen levels or abnormal temperatures to optimize blood flow.

E. *Connectivity:*

The system faced some difficulties with the ESP8266-01 Wi-Fi module during the testing. The module had some issues with the data transmission and the network connection. This need to be fixed to make the system work better in the real-world healthcare settings. The system used the hardware resources efficiently, and ran smoothly without any problems

F. *Challenges and Recommendations:*

The ESP8266 WiFi module, despite encountering challenges during testing, remains a crucial component for wireless IoT connectivity. Successful data transmission to the server via Wi-Fi ensures that healthcare professionals can remotely access and monitor patients' vital signs, enhancing the overall effectiveness of the system.

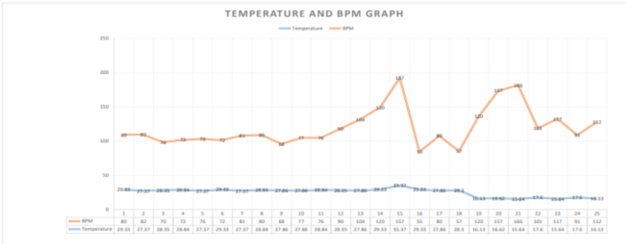

Fig.7. Real-time monitoring of temperature and BP.

The analysis validates the effectiveness and dependability of the "IoT-Based Compression Socks with Sensors for Proper Blood Circulation System." To enhance remote communication capabilities, further optimization of the SIM800L module's coverage range is recommended.

TABLE.III Basic features of the sample.

Pressure rating	**Thickness (cm)**	**Weight (g)**	**Transverse density (row/5cm)**	**Longitudinal density(row/5cm)**
Light	0.706	1.41	59	119
	0.707	1.45	72	116
	0.712	1.55	88	111.
Moderate	0.795	1.44	60	110
	0.729	1.41	76	106
	0.736	1.43	94	101
Strong	0.736	1.55	58	110
	0.735	1.60	72	107
	0.744	1.62	89	103

Table 3 presents data of socks thickness, transverse density and longitudinal density. It shows that pressure increases thickness weight increases and longitudinal density decreases slightly. Transverse density remains the same.

The performance analysis supports the successful integration of the system into real-world healthcare settings, meeting the requirements of both paralysis patients and healthcare professionals. These findings can help improve and make wearable health technology better over time.

VI. CONCLUSION

The research paper presents an innovative and effective solution for monitoring and enhancing blood circulation using IoT-based Compression Socks with Sensors. The comprehensive integration of temperature, pulse, and muscle activity monitoring, coupled with dynamic compression control, positions the system as a valuable tool for patients, especially those with compromised blood circulation.

The successful simulation and testing of the system validate its usability, reliability, and scalability. The user-friendly interface, real-time data display, and wireless connectivity contribute to its practical application in healthcare settings. The study acknowledges challenges with the Wi-Fi module and recommends further optimization, emphasizing the continuous improvement and refinement of wearable health technologies.

In conclusion, the "IoT-based Compression Socks with Sensors for Proper Blood Circulation System" presents a promising avenue for improving vascular health, particularly for individuals with conditions affecting blood circulation. The findings contribute valuable insights to the field of wearable health technology and pave the way for future advancements in remote patient monitoring and healthcare management.

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