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Intelligent pressure and temperature sensor algorithm for diabetic patient monitoring: An IoT approach

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ABSTRACT
The present study evaluated how an Internet of Things (IoT)-based innovative algorithm could employ feature values to identify distinct plantar foot locations. The proposed system could also assess static and dynamic plantar pressure conditions through an enhanced feature extraction method. This study emphasized the significance of intelligent systems in monitoring diabetic patients and their potential to improve patients' lives. The proposed IoT-centred approach offers a promising solution for accurately determining unique foot locations and plantar pressure parameters. The algorithm could predict potential diabetic issues in advance via an optimized feature extraction, aiding proactive interventions. Available systems need to be improved to provide real-time data. Furthermore, fundamental alerts might be a nuisance for the users. Consequently, this study proposes a more personalized and context-aware monitoring device. The findings provided insights into innovative sensor employment in diabetic patient care and underscored IoT's role in refining the system's accuracy and reliability.

Keywords: Internet of Things (IoT), Arduino UNO, Intelligent Pressure and Temperature Sensor Algorithm, Diabetic Foot Ulcer (DFU), Blynk

1. INTRODUCTION
Insulin is a blood sugar level-regulating hormone. According to the World Health Organization (WHO), diabetes is a chronic illness arising from either deficient insulin production by the pancreas or ineffective insulin usage by the body (American Diabetes Association, 2009). Uncontrolled diabetes commonly results in hyperglycemia, also known as raised blood glucose or sugar (American Diabetes Association, 2009). Over time, high

blood levels could severely harm numerous bodily systems, including the neurons and blood vessels (American Diabetes Association, 2009). In 2014, 8.5% of the population aged 18 years and older were diabetic (American Diabetes Association, 2009; Amin and Doupis, 2016).

In 2019, researchers directly linked the illness to 1.5 million mortalities, of which 48% were under 70 years old (American Diabetes Association, 2009; Amin and Doupis, 2016). Between 2000 and 2019, age-standardized diabetes fatality rates rose by 3%. Diabetes-related death rates also increased by 13% in lower-middle-income nations (American Diabetes Association, 2009; Amin and Doupis, 2016). Between 2000 and 2019, individuals between 30 and 70 experienced a 22% worldwide reduction in the likelihood of fatality from cancer, chronic respiratory diseases, diabetes, or cardiovascular disease (Amin and Doupis, 2016). Uncontrolled diabetes could lead to foot ulcers and amputation, potentially harming numerous bodily systems, including the neurons and blood vessels. Amin and Doupis, (2016) stated that anticipating diabetes reasonably in advance is essential, considering that the disorder severely affects people of all ages.

Accordingly, the researcher designed an algorithm utilizing smart detection pressure sensors for diabetic patients using the artificial neural networks (ANN) model (Abbott et al., 2019). Assessing walking intensity is crucial to determining the most appropriate exercise during rehabilitation therapies (Huchegowda et al., 2019; Bagavathiappan et al., 2010). Walking promotes healthier living in diabetic and peripheral artery disease patients (Alexiadou and Doupis, 2012). Nonetheless, continuous walking increases foot ulcer incidences from repeated stress on the plantar foot. Walking at a higher pace and for more extended periods also increases foot ulcer risks (Huchegowda et al., 2019; Alexiadou and Doupis, 2012; Amin and Doupis, 2016; Mazur et al., 2019). Diabetic shoes were more successful at alleviating the discomfort caused by neuropathy than conventional shoes, reducing foot ulcer risks (Alexiadou and Doupis, 2012).

Consequently, Huchegowda et al., (2019) suggested employing a wearable system to quantify plantar pressure while walking. A researcher set out to choose a set of pertinent static and dynamic features for plantar pressure by utilizing a feature selection method (Alexiadou and Doupis, 2012). Feature extraction could also reduce the number of attributes by integrating several features into new parameters (Alexiadou and Doupis, 2012). The researcher would define the range and threshold values for normal (healthy foot) and abnormal cases (feet with calluses) under various static and dynamic parameters, including standing still, walking, and running (Alexiadou and Doupis, 2012). The simulation results could compute each characteristic's values (Alexiadou and Doupis, 2012).

The deep learning algorithms suggested by could considerably improve the robust accuracy of radiological pictures by directly learning prediction attributes from the images. Several studies reported developing an intelligent algorithm utilizing feature sets, range, and threshold values to determine the variables connected to distinct parameter data (Abbott et al., 2019; Priya and Dhanaseely, 2018; Bus, 2016). The researchers also created an ANN-based algorithm to intelligently learn typical foot baseline or feature values within various static and dynamic settings, which vary from person to person (Priya and Dhanaseely, 2018; Bus, 2016). Currently employed systems are limited to measuring real-time data and providing alerts when specific thresholds are reached (Bus, 2016). Instances of pressure on the plantar foot exceeding the safe threshold set by the designers occur when walking (Bus, 2016).

The intelligent monitoring devices constantly alert the users that the plantar pressure on the foot is high (Bus, 2016). The scenario might be a nuisance or distraction to the user due to continuous notifications (Bus, 2016; Mickle et al., 2011). Diabetes is a chronic condition affecting millions worldwide (Pataky et al., 2003). Employing smart pressure sensors to monitor diabetic patients is becoming increasingly crucial (Malvade et al., 2017). This study highlighted the importance of developing intelligent systems that could respond to and perceive the world around them and how the systems could aid in improving the lives of diabetic patients. The proposed algorithm could provide accurate and reliable predictions to assist in reasonably anticipating the illness in diabetic patients in advance, utilizing feature values and optimized feature extractions.

The Internet of Things (IoT)-based method proposed in the present study offers a potential solution for identifying unique plantar foot locations. An optimized feature extraction algorithm could also determine static and dynamic plantar pressure parameters. Consequently, the intelligent monitoring device designed in this study could provide more personalized and context-aware alerts. The findings also provided valuable insights into employing innovative pressure and thermal sensors in monitoring diabetic patients. Furthermore, the author of this paper discussed the potential of ANN to improve the accuracy and reliability of diabetic monitoring systems.

2. METHODOLOGY

Figure 1 illustrates the project implementation of the overall system proposed in the present study. The current research meticulously selected the required hardware and software, designed a computer model of foot structure, performed finite element analysis (FEA), and developed a foot pressure and temperature detection device prototype. The device's performance was extensively assessed and analyzed under different conditions, such as standing and walking. Finally, the author evaluated the results and recorded data for further analysis.

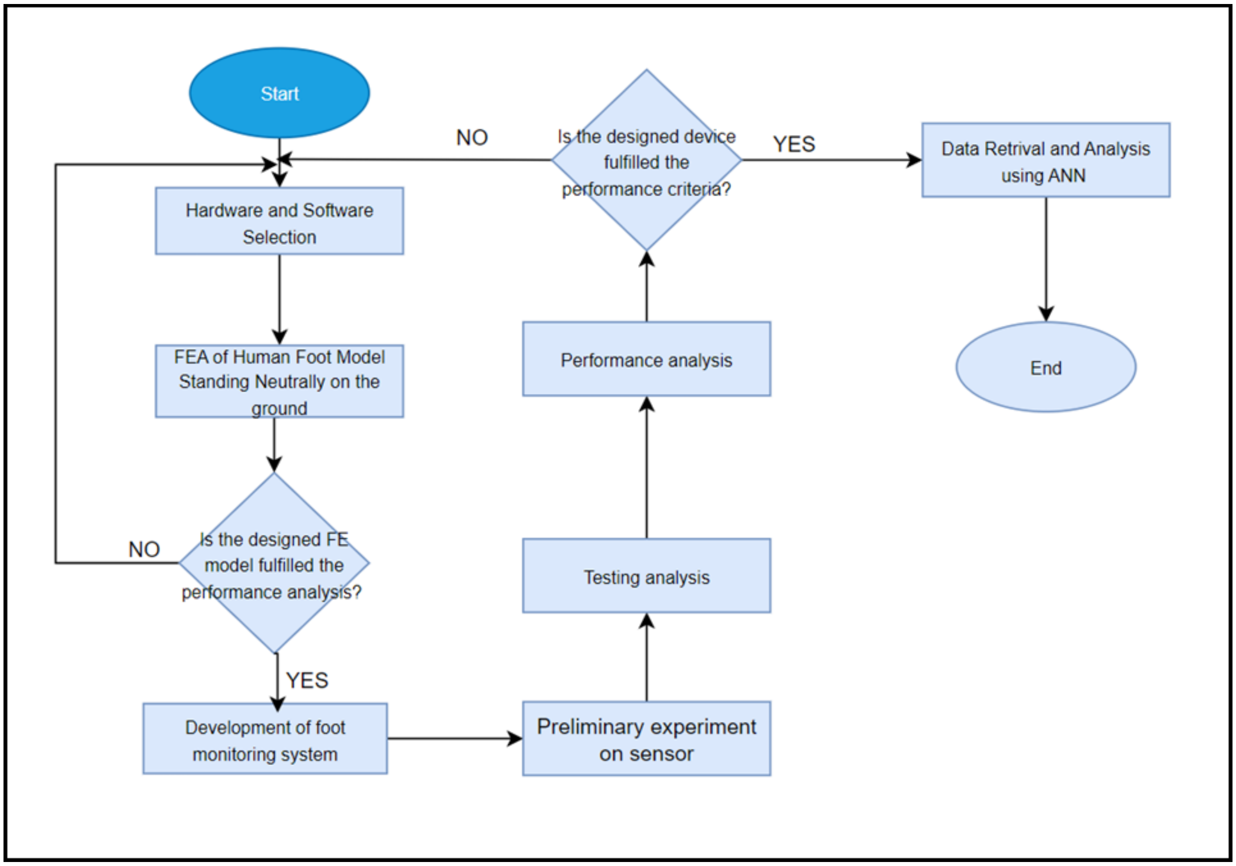

Figure 1 The flow of the implementation of the proposed system

The optimal performance of the system manufactured in this study relied on meticulous hardware and software choices. Pressure and temperature sensors were also carefully selected to suit the insole. The researcher employed an Arduino UNO as the central control unit and utilized an ESP8266 Wi-Fi Shield to transmit data to smartphones. Foot temperature and pressure monitoring were performed by an LM35 and FSR 402 pressure sensors, respectively. The Arduino IDE programmed the system to synchronize the smartphone's display and sensor data. The Blynk application and IoT linked the microcontroller and smartphone via the Internet. This study also employed software applications such as SolidWorks to produce foot models and Ansys for pressure distribution analysis. The author utilized the FEA based on FEM to simulate foot structure under neutral stepping conditions. The results facilitated plantar foot pressure data derivation during optimal sensor placement determinations.

The proposed system device

Sensor positioning and insole design

The present study utilized four pressure sensors to collect pressure data. The researcher situated the sensors at significantly critical spots: One at the big toe, two at the metatarsal head, and one at the heel. Based on the FEA results, the locations recorded the highest pressures. An LM35 was placed on the area with the thickest insole space to avoid affecting the foot condition when a user steps on it (Figure 2). The equipment was employed to obtain temperature readings, considering that foot temperature could signal the initiation of foot ulcers.

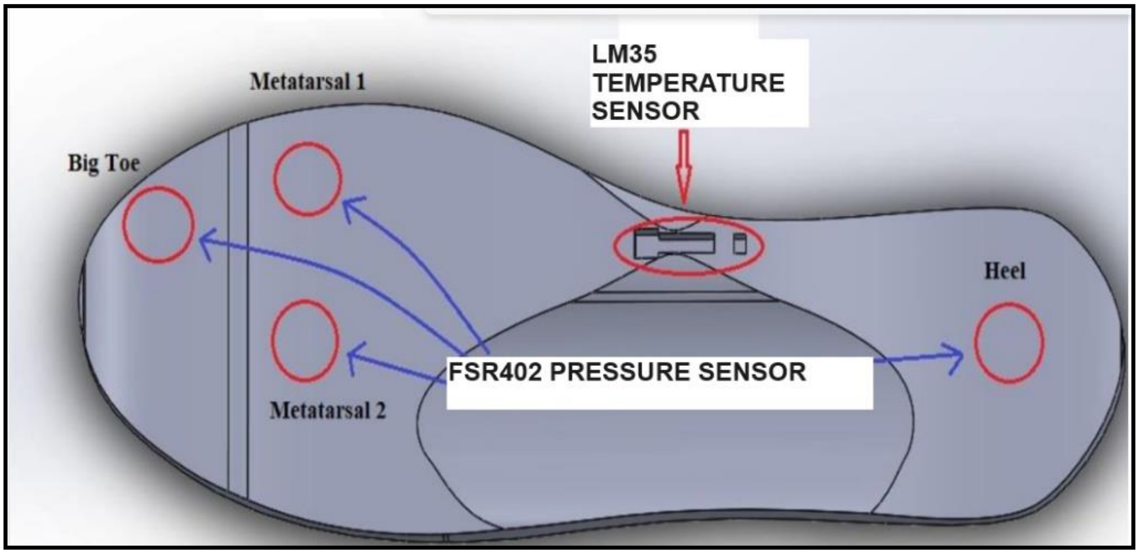

Figure 2 The sensor placements and insole design

System operation

The system proposed in the current study assessed diabetic patients' foot pressure and temperature levels. First, the microcontroller, Arduino UNO, installed in the system would obtain the pressure and temperature sensor data. A HC-05 Bluetooth module would then transmit the information to a Bluetooth receiver on smartphones. The Blynk application on the smartphone would display data from the sensors in real-time. Figure 3 demonstrates the system design.

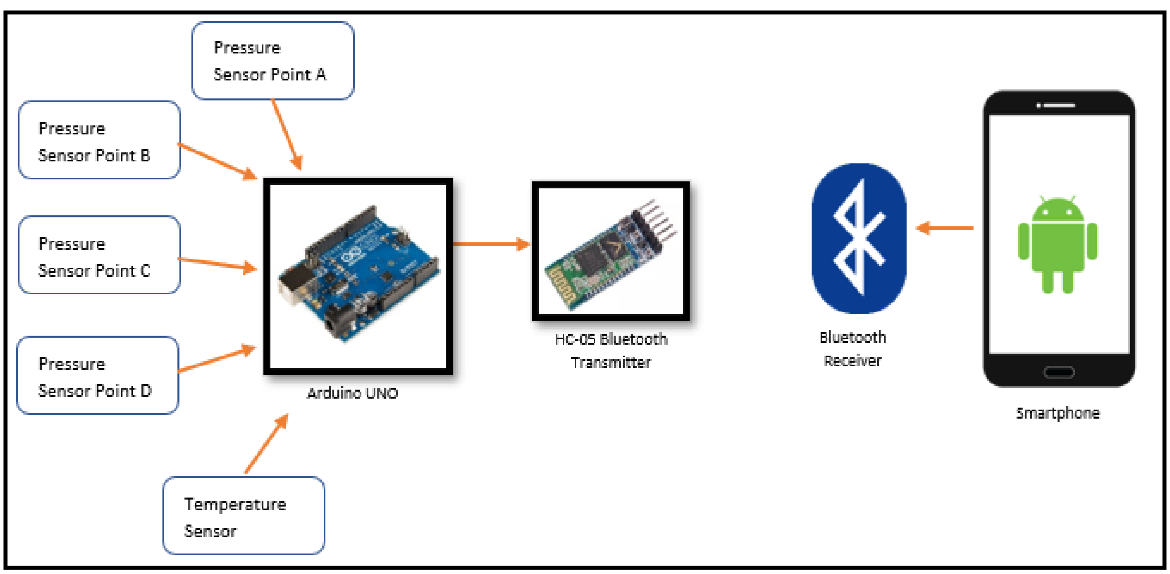

Figure 3 The architecture of the proposed system

For software implementation, this study employed Arduino IDE to design the coding for the sensors to obtain optimal foot pressure and temperature detection performance. This study also utilized the Blynk application as the monitoring system interface on smartphones. The application would display the data provided by the sensors. The primary control (processing) unit, Arduino UNO, was suitable for the system proposed in this study. The circuit employed six sensors connected to six input ports on the microcontroller. The Bluetooth module was connected to the transmitter and receiver ports of the microcontroller (Figure 4).

In this study, the researcher applied the voltage divider method to enable conversions of the resistance value recorded by the sensors to an output voltage by the force-sensitive resistance (FSR) sensor. According to its working principle, FSR resistance diminishes when a load force is applied [16]. The researcher utilized a 10 K ohm resistor in the proposed system circuit to reduce the FSR's total resistance from the maximum to the minimum resistance, 10 K ohm, when full load force is applied to the sensor.

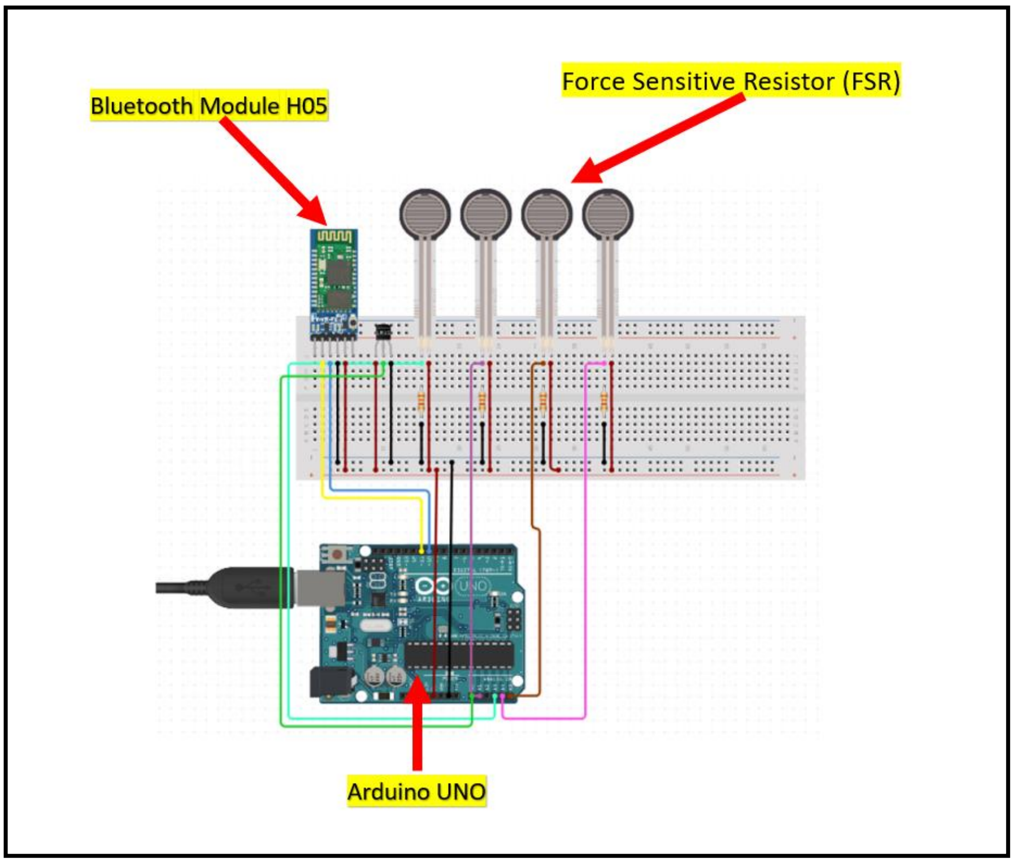

Figure 4 The circuit connections

The hardware setup

The researcher connected the circuit and components of the proposed system, including the sensors, to a breadboard placed in a blue 16 cm × 10 cm plastic box (Figure 5). A 9 V battery supplied the power to the Arduino UNO, while the Bluetooth module HC-05 acted as a data transmitter. To ensure safety, the researcher covered the prototype's insole and FSR sensor with ESD (Electrostatic Discharge) material to avoid short circuits and maintain user comfort. The intelligent insole could replace standard shoe insoles. The user can wear the device attached to the intelligent insole on their calf and tighten it with the provided belt. Figure 6 illustrates the smart insole setup and demonstrates how to wear the device.

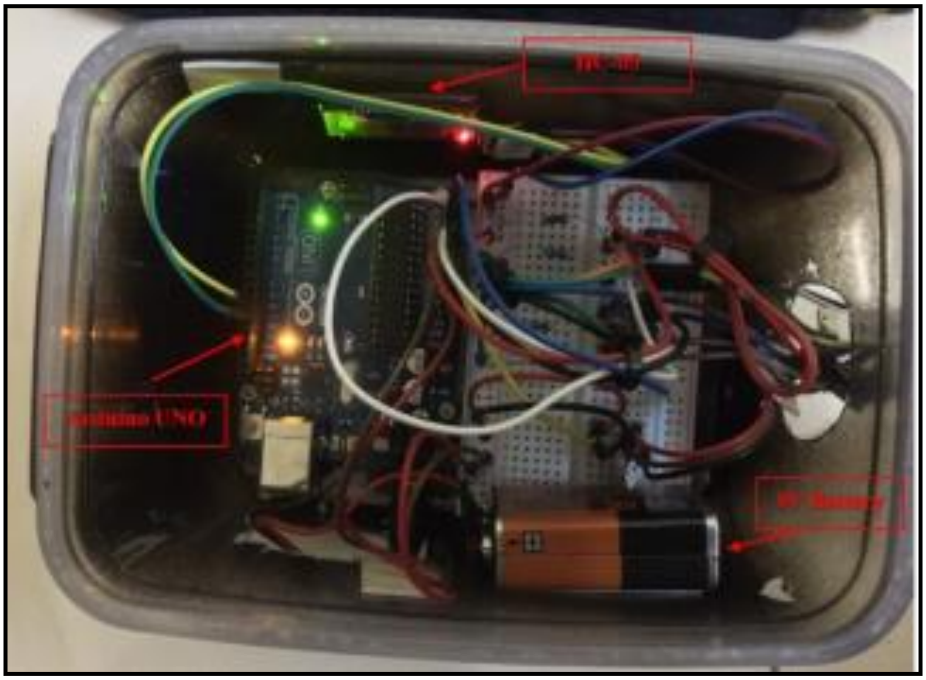

Figure 5 The components inside the blue box

Figure 6 The intelligent monitoring system prototype

The Blynk application setup

Blynk is a platform that permits application creation for controlling Arduino boards connected to a personal computer (PC). Using a smartphone, users can control the boards from anywhere worldwide with Internet access or a Bluetooth connection. Blynk also has a digital dashboard enabling graphic interface production by dragging and dropping widgets. After downloading and installing the Blynk application Google Play (for Android) or Apple Store (for iOS), a user needs to install the Blynk library in the Arduino IDE library folder to interface it with Arduino UNO. Subsequently, the user has to create a new account before logging in to establish a new project. The researcher selected the Arduino UNO hardware with a Bluetooth communication type for the project proposed in this study.

The developer procured the auth token via an email account to set up a project before designing the Blynk application. Upon confirmation, the developer set up each button widget with personalized settings. Figure 7 illustrates the data obtained from the pressure and temperature sensors. Blynk application will display the information result. The researcher provided One temperature and four pressure displays for the different areas of the foot. The coding installed calculated the actual temperature reading. Conversely, the FSR sensor could not directly present pressure values in Pa, considering that its output is in voltage converted from resistance value, which was a limitation.

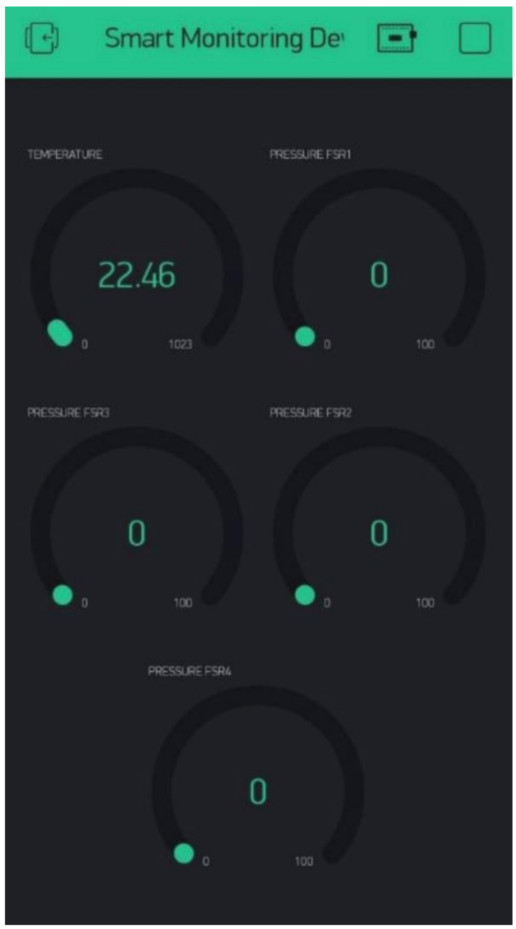

Figure 7 The assessment analysis

The system proposed in the present study provided real-time data reading from the sensors, enabling smartphone display. Consequently, the researcher evaluated the Bluetooth data communication employed to assess its effectiveness in achieving the goal. Furthermore, the researcher estimated the synchronization between the serial monitor in Arduino IDE and the result in Blynk. Identical values were displayed simultaneously (Figure 8).

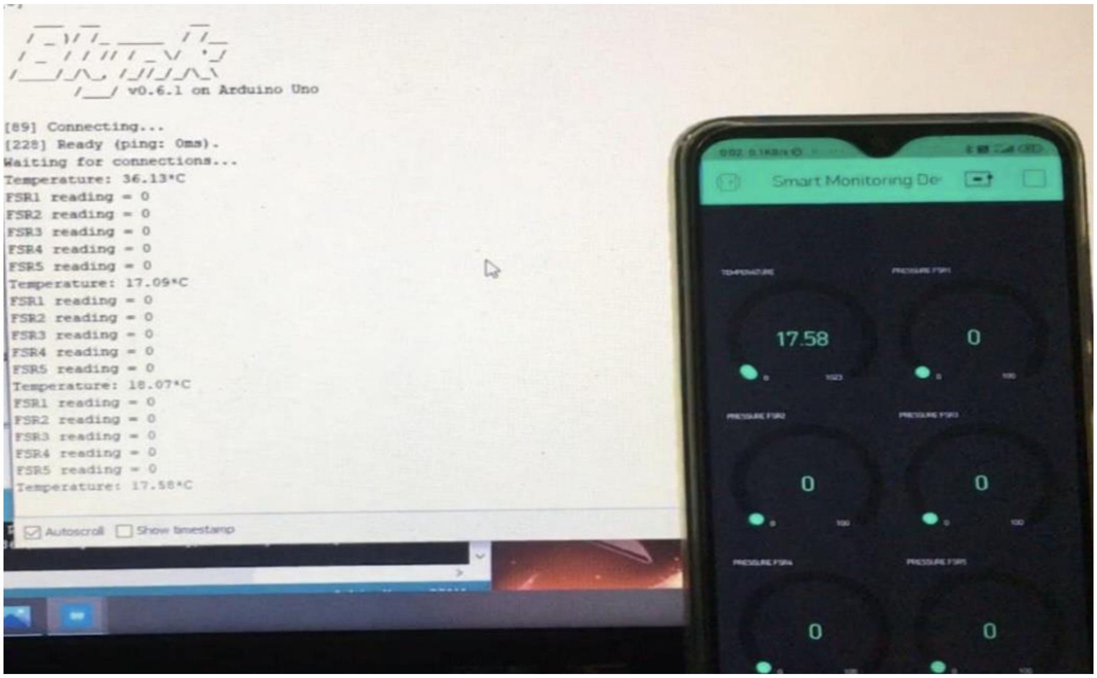

Figure 8 Synchronisation between the serial monitor and Blynk

The researcher applied the same code to obtain the readings from all five sensors without delay. Nevertheless, the results indicated that reading the sensors without delay could have been more feasible. Consequently, the researcher added a 0.2-second time delay in the coding for each sensor to send the data to Arduino UNO, ensuring real-time measurements with a short delay. The researcher illustrated the results in (Figure 9). The serial monitors displayed "Packet too big", indicating that the system was not stable enough to run with the short time delay. The researcher found that a little delay was necessary for the data transmission to be durable and usually run.

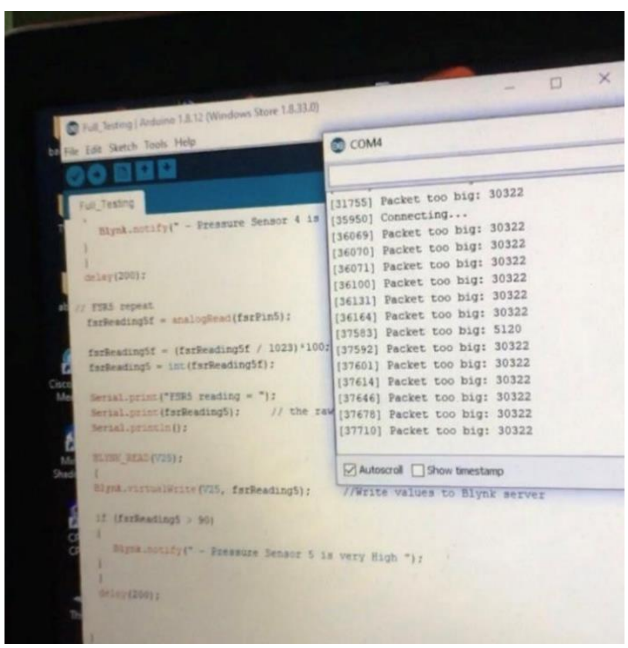

Figure 9 The Serial monitor results for the 0.2-second time delay

3. RESULT AND DISCUSSION

The author implemented two-time delays for each sensor during performance analysis: 1.0 and 0.6 seconds. The author also set a maximum threshold of 90 for the pressure sensors, ranging from 0 to 100. Pressure readings over the entire point were marked red, triggering the smartphone's vibration and a warning notification. The author set a 1.0-second time delay for each sensor to procure readings and allocated 1.0 seconds for each round. The researchers also evaluated the insole prototype manufactured in this study by standing on it for 60 seconds. The author summarized the results in (Table 1). Using the information, the author plotted a pressure range versus time graph (Figure 10). The pressure at the big toe altered dramatically during standing. The changes were due to the toe not staying at only one point, considering it maintains the body's balance while standing.

Table 1 The readings from the 60-second standing evaluation

Time (s)	Temperature (°C)	Pressure			
		At Big Toe	At Metatarsal 1	At Metatarsal 2	At The Heel
6	30.76	60	82	81	95
12	32.23	78	82	82	95
18	32.23	78	80	81	95
24	32.23	80	81	81	95
30	32.23	76	80	81	95
36	32.23	76	81	81	95
42	32.72	75	81	81	95
48	32.72	71	81	81	95
54	32.72	54	79	80	95
60	32.23	53	79	81	95

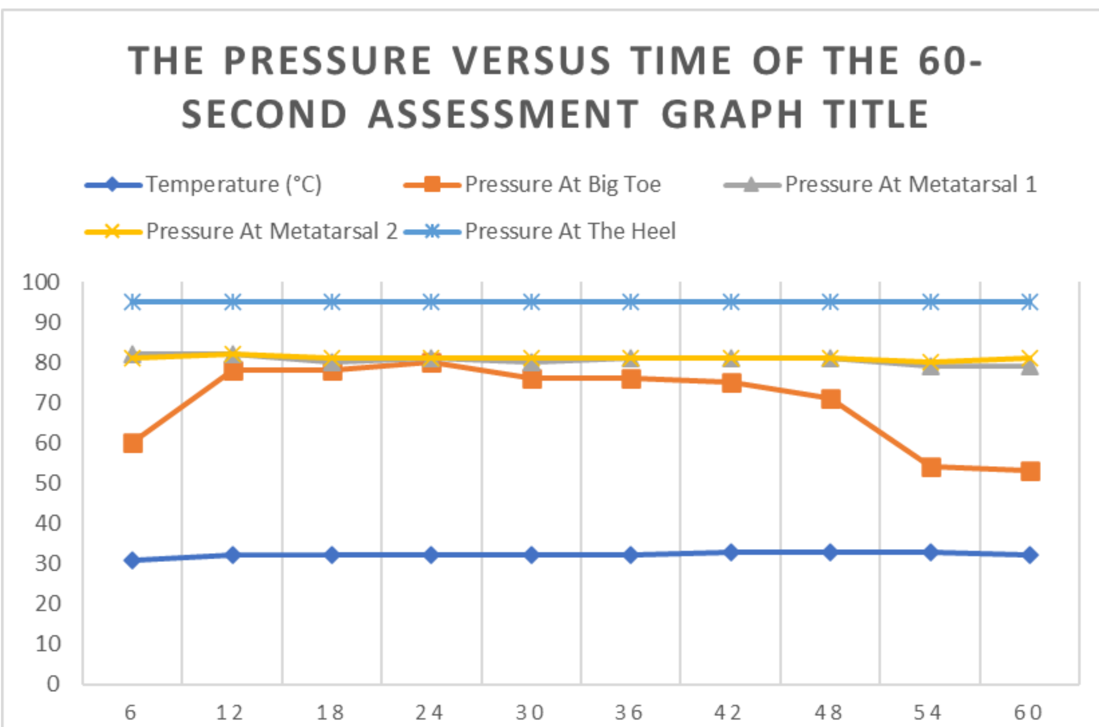

Figure 10 The pressure versus time of the 60-second assessment graph

Although the 1.0 second per sensor time delay results demonstrated good communication stability, it could have been more effective for innovative insole applications due to the extended data retrieval period. Consequently, the present study set a new time delay of 0.6 seconds for all sensors. The sensors procured data from the foot plantar every 3.0 seconds. Table 2 and Figure 11 exhibit the results and the pressure against time for 30 seconds of standing graph, respectively. Two areas of the foot recorded higher pressure than the threshold, the heel and metatarsal 1, initiating the delivery of warning messages to the user (Figure 12).

Table 2 The result of 30 seconds of regular standing

Time (s)	Temperature (°C)	Pressure			
		At Big Toe	At Metatarsal 1	At Metatarsal 2	At The Heel
3	20.51	69	92	88	95
6	22.46	70	92	88	95
9	20.02	68	92	88	95
12	19.04	57	92	88	95
15	20.02	64	92	87	95
18	20.51	51	92	87	95
21	21.48	52	92	86	93
24	18.07	48	92	87	96
27	21.00	40	92	87	95
30	20.51	46	92	87	95

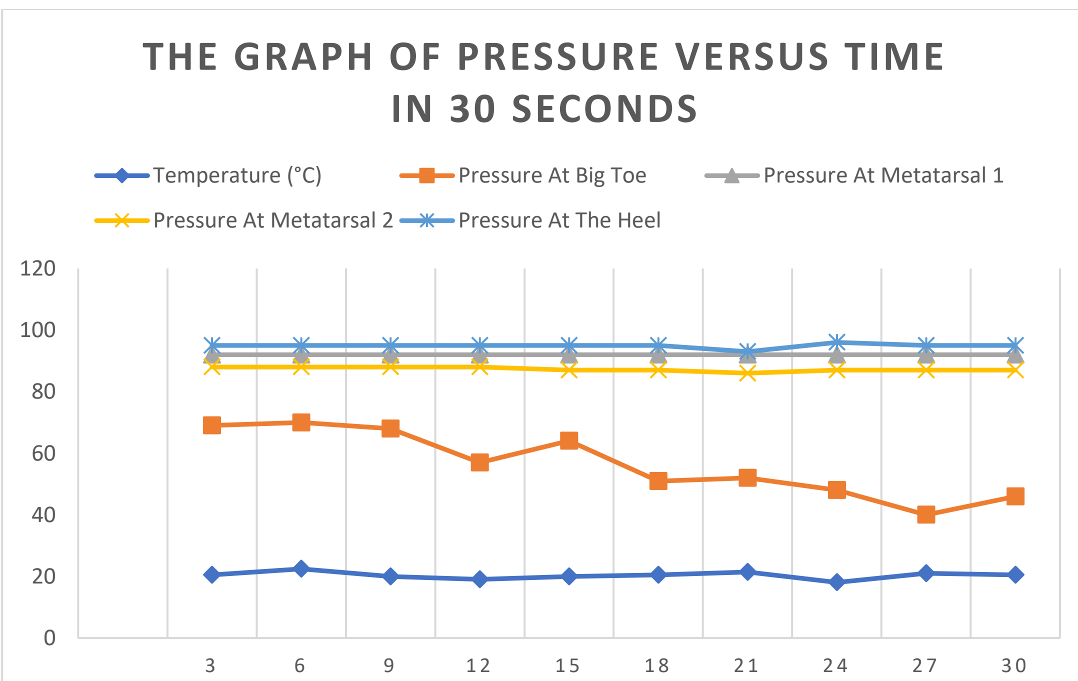

Figure 11 The graph of pressure versus time in 30 seconds

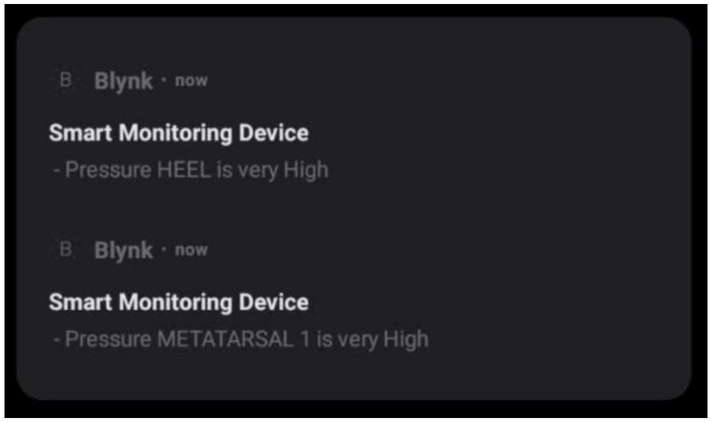

Figure 12 The warning notification received by the user

Based on the results, the big toe had the most negligible effect on plantar pressure distribution during standing compared to the metatarsals and heel. The pressure on the big toe was inconsistent in some periods because it supports the foot when it pushes off the ground during walking or running. The temperature results for the 30 seconds of standing evaluation fluctuated and changed dramatically. Although LM35 is a precise temperature sensor, several fluctuation output issues arose when connected to the Arduino UNO. The LM35 temperature sensor requires a capacitor connection for a stable temperature reading (Bus, 2016; Mickle et al., 2011).

The intelligent insole manufactured in the present study obtained a complete data set from eight men. The analysis compared the temperature and pressure values of eight individuals. Each person procured one reading. Table 3 demonstrates the assessment results. Table 4 summarises the primary standard standing data of the eight subjects. The average temperature was 22.95°C, significantly different from the expected 30.6°C. Nevertheless, the author accepted the value due to the influence of ambient temperature on foot temperature. On the other hand, the heel met the expectation of recording the highest pressure.

Table 3 The average standing values of the eight individuals assessed in this study

Individual	Temperature (°C)	Pressure at			
		The Big Toe	Metatarsal 1	Metatarsal 2	The Heel
1	20.51	51	92	87	95
2	23.44	73	79	80	96
3	22.46	71	76	82	96
4	28.32	79	91	88	92
5	20.02	82	92	84	95
6	22.46	70	92	88	95
7	24.41	71	69	77	96
8	21.97	68	76	76	95

Table 4 A summary of the normal standing foot pressure and temperature data of the participants

	Values across all participants		
	Average	Minimum	Maximum
Foot temperature (˚C)	22.95	20.02	28.32
Pressure at the big toe (%)	71	51	82
Pressure at metatarsal 1 (%)	83	69	92
Pressure at metatarsal 2 (%)	83	76	88
Pressure at the heel (%)	95	92	96

4. CONCLUSION

The present study successfully achieved its objective of developing an intelligent insole that could limit users' daily activity to prevent foot ulceration. The smartphone will display the data obtained from the foot plantar on users' smartphones. The proposed system could benefit the medical services in diabetic patient monitoring, given that the number of diabetic patients increases yearly. Furthermore, a properly engineered system design could provide diabetic patients with the best preventive measures for foot ulcers. The study produced the smart insole, an early detection device. Based on foot pressure and temperature, it alerts the user of a considerable foot ulcer possibility. The intelligent insole could also be employed as a standard insole replacement and is utilizable in different shoes.

First, users need to wirelessly connect the device to a smartphone via Bluetooth to utilize the intelligent insole acquired in the present study. Subsequently, users would have to open the Blynk app using the innovative system. The data transmitted by the intelligent insole would be displayed automatically. The method developed in this study employs a feedback system that could warn users immediately upon receiving data from the sensor. Furthermore, the researchers subjected the proposed approach to several assessments. Nevertheless, further investigations are necessary to ensure the stability and accuracy of the employed hardware.

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Ethical issues

Not applicable.

Informed consent

Not applicable.

Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES

1. Abbott CA, Chatwin KE, Foden P, Hasan AN, Sange C, Rajbhandari SM, Reddy PN, Vileikyte L, Bowling FL, Boulton AJM, Reeves ND. Innovative intelligent insole system reduces diabetic foot ulcer recurrence at plantar sites: a prospective, randomised, proof-of-concept study. Lancet Digit Health 201 9; 1(6):e308-e318. doi: 10.1016/S2589-7500(19)30128-1
2. Alexiadou K, Doupis J. Management of diabetic foot ulcers. Diabetes Ther 2012; 3(1):4. doi: 10.1007/s13300-012-0004-9
3. American Diabetes Association. Diagnosis and classification of diabetes mellitus. Diabetes Care 2009; 32 Suppl 1(Suppl 1): S62-7. doi: 10.2337/dc09-S062
4. Amin N, Doupis J. Diabetic foot disease: From evaluating the "foot at risk" to the novel diabetic ulcer treatment modalities. World J Diabetes 2016; 7(7):153-64. doi: 10.4239/wjd.v7.i7.153
5. Bagavathiappan S, Philip J, Jayakumar T, Raj B, Rao PN, Varalakshmi M, Mohan V. Correlation between plantar foot temperature and diabetic neuropathy: a case study by using an infrared thermal imaging technique. J Diabetes Sci Technol 2010; 4(6):1386-1392. doi: 10.1177/193229681000400613
6. Bus SA. Innovations in plantar pressure and foot temperature measurements in diabetes. Diabetes Metab Res Rev 2016; 32 Suppl 1:221-6. doi: 10.1002/dmrr.2760
7. Huchegowda R, Shruti A, Amarendra S, Shraddha T, Huchegowda C. Integrative studies to design and validate

wearable footwear among neuropathic patients. Diabetes Metab Syndr 2019; 13(3):2075-2079. doi: 10.1016/j.dsx.2019.03.038

8. Malvade PJ, Joshi AK, Madhe S. IoT based monitoring of foot pressure using FSR sensor. 2017 International Conference on Communication and Signal Processing (ICCSP), Chennai, India, 2017; 0635-0639. doi: 10.1109/ICCSP.2017.8286435
9. Mazur F, Swoboda B, Carl HD, Lutter C, Engelhardt M, Hoppe MW, Grim C. Plantar pressure changes in hindfoot relief devices of different designs. J Exp Orthop 2019; 6(1):7. doi: 10.1186/s40634-019-0173-9
10. Mickle KJ, Munro BJ, Lord SR, Menz HB, Steele JR. Gait, balance and plantar pressures in older people with toe deformities. Gait Posture 2011; 34(3):347-351.
11. Pataky Z, Golay A, Bounameaux H, Bobbioni-Harsch E, Assal JP. Relationship between peripheral vascular disease and high plantar pressures in diabetic neuro-ischaemic patients. Diabetes Metab 2003; 29(5):489-95. doi: 10.1016/s1262-3636(07)70062-9
12. Priya V, Dhanaseeley A. Health care footwear for monitoring diabetic patients. Int J Pure Appl Math 2018; 119(14):969-973.