Prototype Design of Smart Diabetic Shoes with Lora Module Communication

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***Abstract*—Diabetes is a disease that affects many people in the world. Diabetes mellitus is a type of metabolic disease in a person who suffers from blood glucose levels with extreme conditions, namely insufficient insulin production in the human body. Monitoring diabetes is an important concern for researchers because it can be useful for improving the quality of the nursing service system. One of the common conditions in diabetic patients is ulceration which is difficult to detect on time. Technology can minimize the total cost of monitoring chronic diseases such as Diabetes continuously and on time. This research focuses on solutions to produce IoT-based smart diabetic shoes that utilize pressure sensors and the temperature of the feet of people with diabetic feet. Smart diabetic shoes are made using the Lora E32 module to be applied to areas with poor internet connections. The results of the testing carried out for 60 seconds in this study succeeded in detecting the area of the foot that experienced the greatest pressure, which was located on the rear footrest with a portion of pressure of around 25 – 28% of the total body weight. The patient's foot temperature increases when the pedestal load is greater. The Lora E32 module also functions as a media transmitter and receiver at a distance of 2.2 km in sending sensor data.**

Keywords—Diabetes, foot, ulcers, IoT, Lora

I. INTRODUCTION

Diabetes is one of the diseases that many people suffer. This is evidenced by data showing an increase in sufferers from 537 million people in 2021 to 783 million in 2045 [1]. This disease is a serious threat to global public health [2] [3]. Diabetes mellitus is a type of metabolic disease in a person who suffers from blood glucose levels with extreme conditions, namely insufficient insulin production in the human body. [4]. There are at least 40 types of Diabetes, and it turns out that people worldwide are not aware of the complications that occur due to under-resourced health systems [5].

As reported by the official website of the Ministry of Health, in 2021, Indonesia will be ranked 5th out of 10 countries with the highest number of diabetics in the world. Increasing the number of sufferers in Indonesia is an important task requiring patients to have better access to nursing [6].

Based on international and national guidelines, there is self-management of disease and optimal quality of diabetes control or disease prevention efforts in the form of patient education in blood glucose management [7]. Prevention can also be done by monitoring 3 times a day to determine glucose levels in the body [8].

Various types of technology that focus on Diabetes include Glucose monitoring, Continuous subcutaneous insulin infusion, Closed loop systems, Electronic teaching and applications for smart devices, and Automated bolus calculators [7]. These technologies can collaborate with the Internet of things (IoT) [9]. Diabetes can be monitored at any time within 24 hours by utilizing sensors that are integrated into the IoT [10].

Monitoring diabetes is an important concern for researchers because it can be useful for improving the quality of the nursing service system [11]. It is known that the traditional method of pricking the fingertip to check glucose levels makes patients psychologically depressed and can lead to infection [8]. This certainly encourages researchers to make better tools for monitoring this disease.

One of the common conditions in diabetic patients is ulceration which is difficult to detect on time [12]. Diabetic foot is very at risk of injury, infection to ulceration in patients [13]. The high risk of recurrence of the diabetic foot also exacerbates this condition. Abnormal lower extremity movements and changes in plantar biomechanics cause this recurrence. Excessive foot pressure also damages the skin on the soles and instep, thus compromising the patient's condition, which has the potential for ulcer recurrence and amputation. [13].

Advances in technology open up new opportunities for the concept of nursing and improving digital-based health services [14]. Technology can minimize the total cost of monitoring chronic diseases such as Diabetes continuously and on time [15]. Besides, technology is getting higher accessibility to smartphones and fast Internet, and patients are using mobile apps to handle multiple medical requests. [15].

The application of special technology for monitoring diabetic feet based on IoT has been made by several researchers, including Ganesh [16], which implements cost-effective monitoring of foot pressure and blood flow by wireless communication and collects real-time data for physician analysis. Escoffier has also conducted similar research in making smart shoes for Diabetes that offer possibilities to support prevention, diagnostic screening, and therapeutic decisions. [14]. Research conducted by Kularathne creates an innovative, mobile-based plug-and-play device that can be applied to any diabetic shoe to treat foot ulcers and prevent them from breaking down while monitoring the patient's temperature, humidity, weight, and step count. [17].

Indonesia has a relatively low internet speed, so it can't be maximized in implementing IoT [18]. There are still many areas that have bad connections. IoT-based diabetes shoes cannot be fully implemented in areas with slow connection power.

This is a problem to be solved in this research. Our contribution to this research is to make smart diabetes shoes that utilize the Lora module to be applied to areas with low connections. Lora is used as a solution to the problem of a wireless communication connection that has not been maximized [19].

II. Diabetic Foot Ulcer Indicators

A. Temperature

Diabetic foot ulcers (DFU) are characterized by an increase in temperature on the skin of the patient's feet caused by inflammation and autolysis enzymatic tissue due to an imbalance in pressure activity, repeated stress, neuropathic sensory loss, and biomechanical abnormalities. [20]. An increased temperature on the patient's feet above 2.2°C can indicate the risk of ulcers that will occur soon [21]. Skin thermometry can identify inflammation in the form of early signs to prevent DFU events and reduce serious complications that lead to amputations and even death. [22].

There is no specific range available to measure this condition because the body temperature of each sufferer varies greatly [23]. This problem can be overcome by comparing one body part with the opposite part, which is symmetrical under normal circumstances [24]. Increased temperature in the diabetic foot area and local pressure can exacerbate the condition of the patient's wound. Several investigators use thermometry as a measuring tool to diagnose occult neuropathic fractures in diabetic patients [22].

B. Pressure

Pressure has a major influence on the condition of patients suffering from diabetic foot [25]. The high plantar pressure causes additional pressure on the underlying soft tissue and causes tissue damage and ulceration [26]. The most common location of the highest plantar pressure is the middle of the forefoot [27].

Significant literature shows a relationship between ulcer formation and increased foot pressure [17]. In a study conducted by Altayyar, it was shown that foot pressure was also affected by the patient's weight [28]. In this condition, men generally have higher plantar pressure than women because men generally weigh more than women [28].

The use of pressure sensors can also be used to measure foot pressure in diabetics [29]. The resulting pressure values are widely used to investigate the results of biomechanical features in individuals with high-risk diabetes [29].

III. Technology Investigation and Selection

A. Pressure Sensor

The pressure sensor used is the Walfront DF9-40 resistance type which is waterproof, thin film, flexible, and made with nanometer pressure-sensitive material equipped with an ultrathin film substrate. This sensor is very sensitive and flexible in detecting very small changes in pressure. The pressure value is taken as an analog value [30]. When no pressure is applied to the sensor, the resistance is greater than 10 MΩ. The pressure sensor has a response time of 1 ms, a recovery time of less than 14 ms, and a test voltage of 3.3 V. The sensor can detect pressure values within a 9.0 mm diameter area. [30].

B. Temperature Sensor

NTC stands for "Negative Temperature Coefficient" The NTC thermistor is a resistor with a negative temperature coefficient, which means that the resistance decreases with increasing temperature. They are commonly used as resistive temperature sensors and current limiting devices. Resistor This coefficient of resistance changes with changes in ambient temperature. Thermistors consist of 2 or 4 metal oxides of iron, nickel, cobalt, manganese, and copper, being shaped and sintered at high temperatures (1200 ^{0}C to 1500 ^{0}C) [31].

C. Lora E32 Module

Lora is an IoT-enabling technology especially suitable for low-data rate applications [32] [33]. Lora, through wireless modulation, enables end nodes to establish remote communication, while LoRaWAN refers to the communication protocol and system architecture [34]. The main feature that differentiates LoRa from other wireless WAN technologies is that it is transmitted over long distances with low power consumption. Lora supports low-bit rate applications with fewer demands on mobility and reliability. Lora technology was developed to support a wide area network type of wireless telecommunication as it is known that Lora technology can be an alternative to IoT [35].

The E32-433T20DC is a LoRa module from Ebyte that uses the SEMTECH SX1278 RF chip and a UART interface for communication with the MCU. The E32 can also be connected to a PC using USB-TO-TTLUART [36]. In general, Lora type E32915T20D has 7 core pins that are used in the sensor node manufacturing process, namely M0, M1, RXD, TXD, AUX, Vcc, and GND [37]. There are 3 modes in sending sensor data to Pin M0 and M1, namely Wake up mode (mode 1), if M1 and M0 = 1, then Power-saving mode (mode

2) if M1 = 1 and M0 = 0 and Sleep mode if M1 = 1 and M0 = 1. Dimensions WirelessModule LoRa E32 915T20D has dimensions of 21x36 mm [37]. Lora E32 can be used as a data transmitter and receiver model [38].

D. *Microcontroller*

There are two microcontrollers used in this study. We use Arduino Uno as a data transmitter medium, and NodeMCU as a data receiver medium. Each microcontroller is connected to the Lora E32 module. NodeMCU was chosen because of its ease of connecting data sent by sensors in a web server, making it easier for IoT developers to display sensor data in the form of client applications such as websites or mobile [39].

IV. METHODS

This research aims to monitor the condition of patients with diabetic feet. Smart diabetic shoes are a diabetic shoe design that is integrated with several sensors and IoT supporting modules. This shoe is equipped with a pressure sensor to determine the pressure of diabetic foot sufferers. This shoe is also equipped with a temperature sensor to determine the temperature of the feet of people with Diabetes. We built an IoT-based system that utilizes Lora technology as a communication tool, namely a transmitter and receiver, which can be used as an alternative IoT connection in areas with poor internet signals. The design of the system built can be seen in Fig. 1.

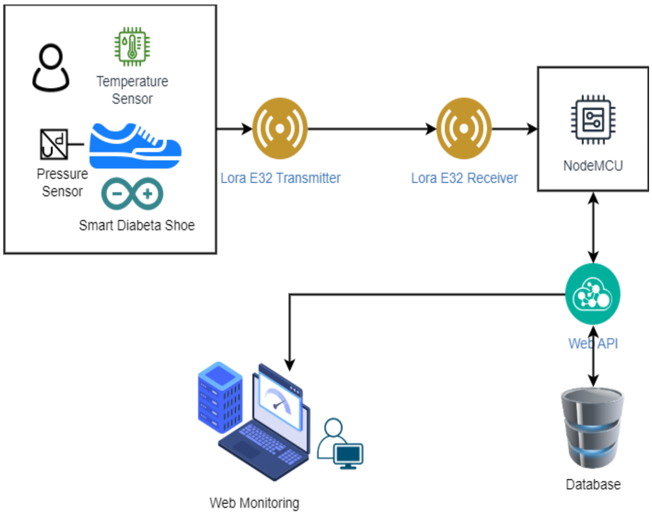


Fig. 1. System Flow

Based on Figure 1, the smart diabeta shoe works from the patient's side, sending pressure and temperature sensor data using the Lora transmitter module. Sensor data is then received by a receiver that utilizes NodeMCU so that the data can be stored in the database. The stored data is processed using web services to appear on the web client as media monitoring.

A. *Smart Diabetic Shoes as Transmitter*

Smart diabetic shoes are a media transmitter that uses the Lora E32 module. This module will send pressure sensor data and patient temperature to the media receiver. Specifically, the pressure sensor is placed in the shoe's middle following the recommendations from Wibowo's research [40]. When humans stand upright, the two hind feet bear the burden of 60% of the body's weight [40].

The design of smart diabetic shoes can be seen in Fig. 2. The prototype utilized 1 Arduino Uno, 3 types of pressure sensors, 1 temperature sensor, and 1 Lora E32 module as the sensor data sending medium. The wiring between Arduino Uno and the pressure sensor can be seen in Table 1. In contrast, the wiring between Arduino Uno and the temperature sensor can be seen in Table 2, and the wiring between Arduino Uno and Lora E32 can be seen in Table 3.

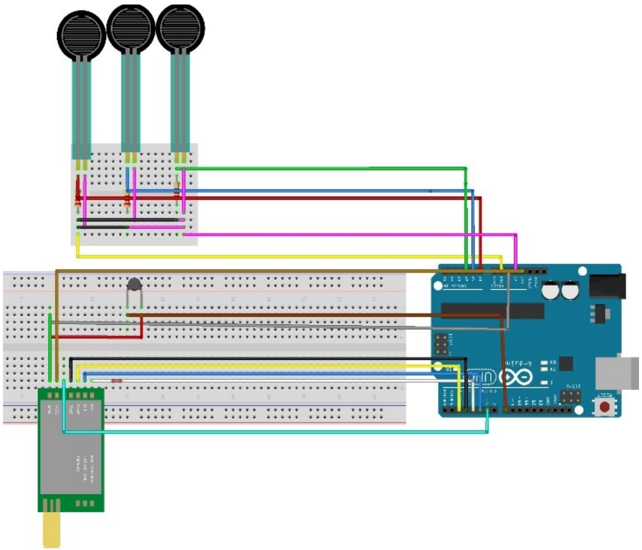


Fig. 2. Smart Diabeta Shoe Design

TABLE I. WIRING ARDUINO AND PRESSURE SENSOR

Arduino Uno	***Pressure Sensor***
GND	Left Pin + Resistor Pull Down 10 kΩ + Analog Pin
3v3	Right Pin

TABLE II. WIRING ARDUINO AND SENSOR TEMPERATUR

Arduino Uno	***Temperature Sensor***
GND	Terminal 0
D8	Terminal 1

TABLE III. WIRING ARDUINO AND LORA E32

Arduino Uno	***Lora E32***
GND	GND
VCC	3v3
Digital 2	RX
Digital 3	TX
Digital 4	M0
Digital 5	M1
Digital 6	AUX

B. *Receiver*

The media receiver only uses NodeMCU and the Lora E32 module. This media captures pressure and temperature sensor data sent by smart diabetic shoes. NodeMCU will then display sensor data on the client web application media as a web server. The design of the receiver media can be seen in Fig. 3. Wiring between NodeMCU and Lora E32 can be seen in Table 4.

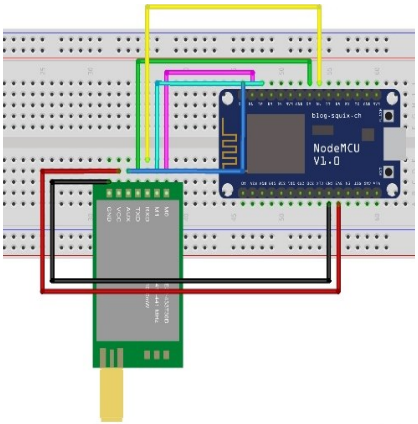


Fig. 3. Lora E32 as Receiver

TABLE IV. WIRING NODEMCU AND LORA E32

Node MCU	*Lora E32*
GND	GND
VCC	3v3
Digital 6	RX
Digital 5	TX
Digital 1	M0
Digital 2	M1
Digital 0	AUX

C. System Testing

The system was tested using several scenarios: three people with underweight, normal, and overweight BMI standing for 60 seconds. Underweight BMI weighs 40 kg and is 155 cm tall. A normal BMI weighs 60 kg with a height of 160 cm, and an overweight BMI weighs 80 kg with a height of 170 cm. Testing the sensor results in this study has not implemented a calibration process.

V. RESULT AND DISCUSSION.

A. Prototype Smart Diabeta Shoes

The implementation of the application of pressure and temperature sensors is going well. Pressure sensors are placed on the bottom layer of diabetic shoes at three important points, namely on the foot's front, middle, and back [41]. Fig. 4 shows the pressure sensor placement on special shoes for Diabetes.

Fig. 4. Installation of Pressure Sensors

The prototype results of the entire series of smart diabeta shoes are presented in Fig. 5. We assemble all the main components, namely the pressure sensor, temperature, and the Lora E32 module installed on the Arduino Uno. The hardware wiring process can run well.

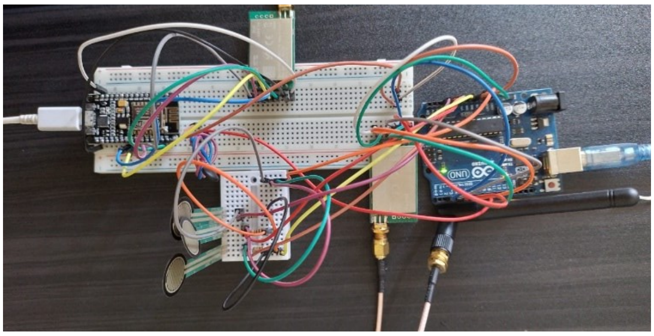


Fig. 5. Prototype System Smart Diabeta Shoe

B. Sensor Test

Pressure testing is carried out on 3 sensors installed on diabetic shoes. We tested it within 60 seconds while the user was standing. The results of testing people with an underweight BMI can be seen in Table 5, normal in Table 6, and overweight in Table 7.

TABLE V. UNDER WEIGHT SENSOR TEST

Time (Seconds)	*Back (gr)*	*Middle (gr)*	*Front (gr)*	*Temperature (ºC)*
5	10775.22	4037.66	6017.56	21.41
10	10790.56	4249.78	6222.81	23.64
15	10952.44	4162.9	6450.14	23.88
20	11062.38	4047.54	6419.46	22.34
25	11081.98	4195.32	6453.75	21.33
30	10957.18	4286.98	6533.29	20.98
35	11909.45	4378.08	6444.46	24.01
40	11308.37	4399.48	6630.87	25.45
45	11822.72	4414.01	6558.89	24.03
50	11927.94	4422.23	6674.34	25.23
60	11987.19	4469.56	6654.21	25.25

TABLE VI. NORMAL WEIGHT SENSOR TEST

Time (Seconds)	*Back (gr)*	*Middle (gr)*	*Front (gr)*	*Temperature (ºC)*
5	15400.98	6000.76	9000.27	20.34
10	15442.85	6004.75	9033.24	21.19
15	15455.86	6042.55	9085.50	22.58
20	15540.83	6047.49	9094.62	21.53
25	15543.96	6066.37	9098.81	22.20
30	15635.18	6067.78	9093.12	22.41
35	15707.67	6070.65	9091.97	22.43
40	15760.19	6081.77	9097.24	23,73
45	15729.04	6094.61	9115.05	24.21
50	15747.83	6093.08	9112.49	24.27
60	15760.15	6198.98	9121.43	24.5

TABLE VII. OVERWEIGHT SENSOR TEST

Time (Seconds)	*Back (gr)*	*Middle (gr)*	*Front (gr)*	*Temperature (°C)*
5	20200.55	8000.67	12000.19	21.98
10	20736.78	8069.85	12191.18	22.27
15	20718.06	8073.39	12198.72	23.29
20	20931.26	8079.67	12201.14	23.06
25	20857.04	8068.42	12224.96	24.55
30	20907.07	8076.43	1223.53	24.70
35	20917.31	8088.09	12257.39	24.81
40	20952.54	8085.56	12261.39	24.90
45	20967.45	8088.04	12276.63	24.23
50	20974.26	8093.70	12287.54	25.33
60	20981.55	8100.88	12293.22	24.95

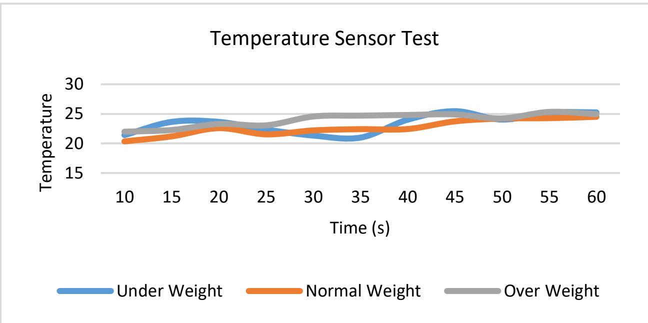
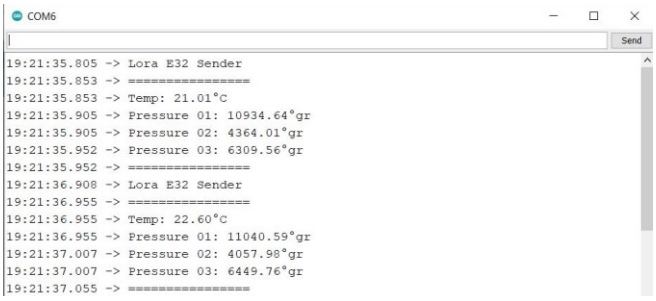


Fig. 6. Temperature Sensor Test Graph

Based on the results of tests that have been carried out on the three types of BMI. It is also seen that the temperature has increased in the time range of 1 - 60 seconds as shown in Fig. 6. The increase in temperature is also affected by the temperature in the surrounding area. The biggest pressure load lies on the back of the foot, with a pressure portion of around 25-28% of the total body weight. The middle part of the foot, when viewed from the sensor data, shows a portion of about 10-15% of the total body weight, and the front shows a portion of 15-20% of the total body weight. The results of this pressure sensor test seem to be close to the results of research conducted by Wibowo [40].

C. *Lora Communication Test*

Communication tests that use the Lora E32 module to send pressure and temperature sensor data from the smart diabeta shoe are carried out at a distance of about 2.2 km. We did a test of the Lora transmitter and receiver. Before displaying it using a web client, this trial data is displayed on the Arduino Uno console. The display of transmitter and receiver serial monitor data in Fig. 7 goes well at a distance of 2.2 km.



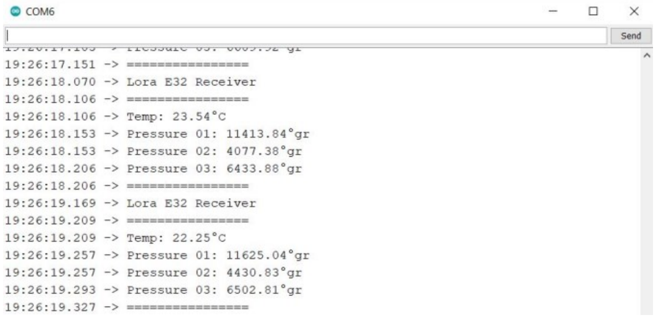


Fig. 7. Lora E32 Transmitter and Receiver Testing

D. *Web Client Test*

NodeMCU is a medium that can store data received by the Lora E32 module in a database server. Sensor data stored is then processed using the HTTP protocol to communicate between the server and the client. This study uses the GET request method so data can appear on a web client application built with the PHP programming language. Fig. 8 is a web user interface display for the smart diabetes shoe application, which can be used to monitor the pressure and temperature of patients with diabetic feet.

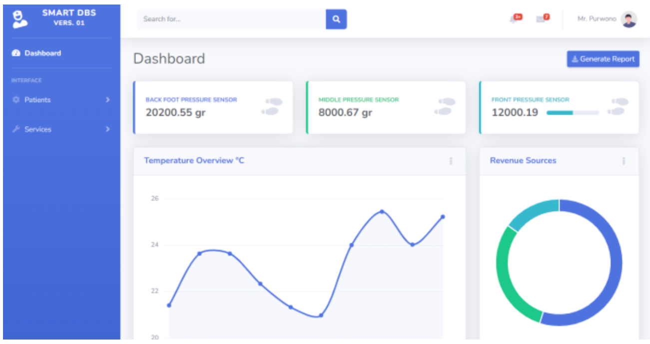


Fig. 8. User Interface Monitoring system

CONCLUSION

Based on the results of the research that has been produced, the smart diabetes shoe has succeeded in sending pressure and temperature sensor data via the Lora E32 transmitter module within a distance of 2.2 km. The pressure sensor shows that the three sensor points continue to increase when tested within 60 seconds. An ever-increasing foot temperature also followed this. The biggest pressure load lies on the back of the foot, with a pressure portion of around 25-28% of the total body weight. The middle part of the foot, when viewed from the sensor data, shows a portion of about 10-15% of the total body weight, and the front shows a portion of 15-20% of the total body weight. Receivers that utilize NodeMCU and Lora E32 have also successfully received sensor data that has been sent. The process of saving to the database server goes well. The web service method implemented with the GET request method can display the pressure and temperature sensor data on the web client to monitor the condition of patients suffering from diabetic feet.

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