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Diabetic Foot Neuropathy Monitoring System

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----------ABSTRACT----------

In today's world, the use of sensor technology to make portable devices can help patients in detecting or monitoring diseases. One such problem is the onset of foot ulcers in diabetic patients. Diabetes often leads to improper circulation of blood to a person's feet, which results in diabetic foot ulcers. This leads to gangrene formation and loss of sensation in the patient's foot. If ignored, leads to lower leg amputation. The proposed system is a device which is developed and evaluated to identify the patients who are likely to develop diabetic foot ulcers at an early stage. This is accomplished by fixing pressure sensors in five pressure points of the foot. The foot pressure readings are converted into corresponding voltage output by the sensor. These voltage readings are amplified using an amplification unit. The voltage data are read using a data acquisition device. The output of the device decides whether the person has the probability to develop diabetic foot ulcer or not.

Keywords: *Diabetic Foot Ulcers, Proposed System, Arduino Uno, Piezoelectric Transducer, GSM Board and GSM AT Command Set,*

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I. INTRODUCTION

Diabetic mellitus is a group of metabolic disease characterized by high blood sugar levels that result from defects in insulin secretion or action. These ulcers are red sores that can occur most often on the pad of the foot or the bottom of the big toe as illustrated in Fig. 1. They occur due to various factors, such as mechanical changes in conformation of the bony architecture of the foot, peripheral neuropathy, and atherosclerotic peripheral arterial disease, all of which occur with higher frequency and intensity in the diabetic population. Diabetic foot lesions are responsible for more hospitalizations than any other complication of diabetes. Diabetes is the leading cause of non-traumatic lower extremity amputations in the United States, with approximately 5% of diabetics developing foot ulcers each year and 1% requiring amputation. Physical examination of the extremity of having diabetic ulcer is divided into examination of the ulcer and the general condition of the extremity, assessment of the possibility of vascular insufficiency, and assessment for the possibility of peripheral neuropathy.

In order to diagnose this problem according to the American Diabetes Association, all patients with diabetes should be screened for loss of protective sensation in their feet (peripheral neuropathy) when they are diagnosed and at least annually thereafter, using simple clinical tests such as the Semmes-Weinstein monofilament exam. A 10-g Semmes-Weinstein monofilament, as shown in Fig. 2, is used. The patients who cannot feel the monofilament on their feet are termed "insensate" and are 10 times more likely to develop a foot ulcer than their "sensate" counterparts are. Neuropathy usually starts in the first and third toes and progresses to the first and third metatarsal heads. It is likely that these areas will be the first to have negative results with the Semmes-Weinstein monofilament exam. Altogether, the monofilament is incapable of detecting all the pressure points. Routine ulcer care, treatment of infections, amputations, and hospitalizations cost billions of dollars every year and place a tremendous burden on the health care system.

This paper proposes a system, which uses a pressure mat consisting of PZT pressure sensors, to measure the foot pressure value of diabetic patients and alert them the corresponding output values. These values are transmitted to the doctor through the wireless communication module for the diagnosis of the foot ulcer. Doctors can receive data and analyze it remotely.

II. NEUROPATHY MONITORING SYSTEM ARCHITECTURE

The architecture of diabetic foot neuropathy monitoring system is described below:

A. Sensor Specifications:

A PVDF (polyvinylideneflouride) sensor, as shown in Fig. 1, was initially picked to design a prototype. It is not suitable because the readings from the sensor were inaccurate and very low. To overcome this problem, an alternative material was thought of to replace the PVDF pressure sensors, PZT pressure sensor.

A PZT sensor (piezoelectric sensor), as showcased in Fig.2, is a device used to measure pressure, acceleration, force, temperature, or strain by converting them to electrical charge, using piezoelectric effect. In Greek language, *piezo* means to press or squeeze. These are versatile tools for measurement of various processes and used for process control, quality assurance and for research and development in many industries. Piezoelectric effect is the property of a certain material to generate electrical charge in response to applied mechanical participate in a mixed infection with aerobes, especially in cases of deep tissuestress.

Fig 1. PolyvinylIdeneflouride material sensor prototype

In 1880, Pierre Curie discovered this effect, but manufacturers began to use this effect in industrial sensing application around 1950s. Since then the measuring principle has become a mature technology. These devices are used in applications such as nuclear instrumentation, aerospace, medical and as a tilt sensor in consumer electronics or in the touch pads of mobile phones as pressure sensors. The sensor technology is insensible to radiations i.e. it provides measurement under harsh condition and electromagnetic fields. The only drawbacks of such sensors are they are not fit for truly static measurements. A static force results in a fixed amount of charge on the PZT material. In conventional readout electronics, imperfect insulating materials and reduction in internal sensor resistance causes a constant loss of electrons and yields a decreasing signal.

Fig 2. PZT Sensor

B. Fabrication of PZT:

We generally use the materials such as Phynox, Brass, Stainless steel (SS) for fabrication of a PZT sensor as in Fig 2. For this model, we fabricated the sensors using Stainless steel material. The materials other than SS have very low melting point, so an SS is preferred for fabrication over the other materials. An SS material of diameter 27mm is prepared and placed in an oven at a temperature of 410°C. The SS material is covered with 10 layers PZT powder, where the powder acts as an insulator. This material is kept at the same temperature for about an hour. Finally, the material is coated with Aluminium (Al) metal. Aluminium coated area will act as positive and remaining area as negative plate. Hence, it acts as parallel plate capacitor.

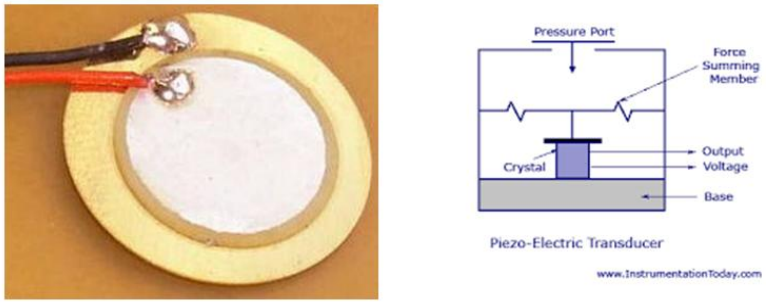

Fig 3. Piezoelectric sensor

C. 2N2222 NPN transistors:

As shown in Fig. 4, it is a common NPN bipolar junction transistor (BJT) used for general-purpose switching and low-power applications. The transistors hold the properties such as low power, medium voltage, and low to medium current. They can operate at high speeds. They use TO-18 metal for fabrication. All variations have a beta or current gain (hFE) of at least 100 in optimal conditions. It is used in a variety of analog and switching applications.

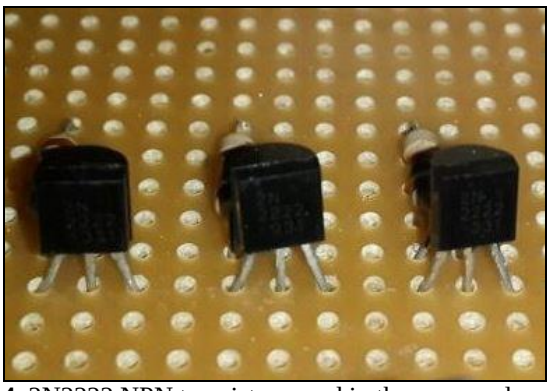

Fig 4. 2N2222 NPN transistors used in the proposed system

III. FUNCTIONING OF PROPOSED METHODOLOGY

The proposed system, a block diagram of which is shown in Fig. 6, consists of five PZT pressure sensors placed at different parts of the model. These sensors are placed such that the pressure from each part of the foot is taken into account when a person walks or steps on a floor while wearing the proposed model. These sensors are incorporated inside a PDMS (polydimethylsiloxane) material, which can be seen in Fig. 5. This material is chosen over other alternatives because of various reasons. The material is light and easy to handle. It is flexible and can hence be fitted into any footwear, giving us an option to use the product multiple times or to reuse it. The general idea is to take the readings from the sensors when a person walks. Based on these readings, the doctor can guess whether the person is walking normally, applying equal pressure on all parts of the foot, or whether there is something wrong with his movement. If there is something wrong, there is a chance of a diabetic ulcer being present in that part of the foot. These readings are transmitted to the doctor using a wireless communication system, making the task easier. The doctor and the patient do not need to be present together at the same place at a given time, making it an easy and viable option.

Fig 5. 5 PZT sensors encased in PDMS material

PZT pressure sensors generate a feeble analog signal when they detect a pressure being applied to them. The value of this signal depends on the size of the sensor and the pressure being applied.

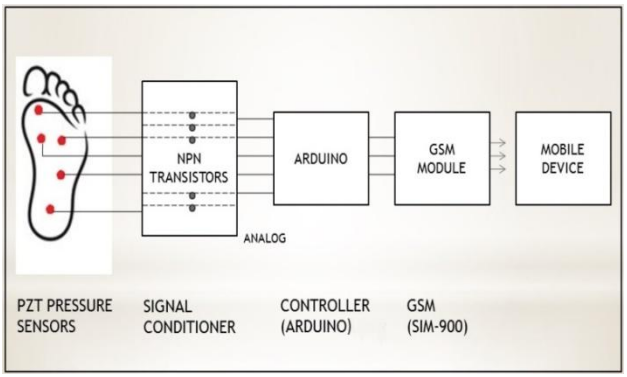

Fig 6. Block diagram of the proposed system

For any useful return of this value, we need to amplify it such that it can be read using the right equipment. To amplify the signal for the need of the system, NPN transistors like 2N2222 or BC547 are used. The 2N2222 NPN transistor is used in the proposed system; the working of which can be easily explained by Fig. 7. It is designed for low to medium current, low power, medium voltage, and can operate at moderately high speeds. This amplified analog signal then needs to be converted to a digital form to be sent wirelessly to the receiver.

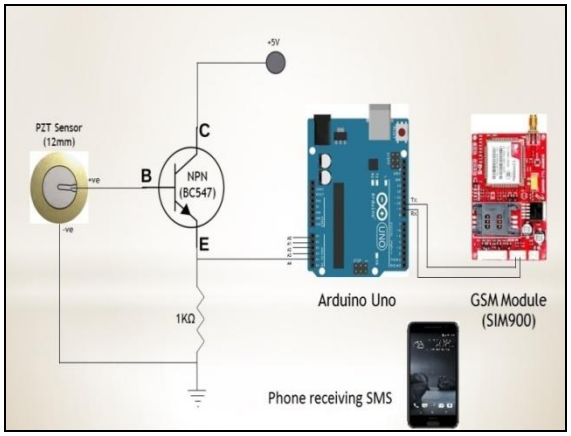

Fig 7. Schematic diagram of the working of a single sensor

An Arduino Uno microcontroller is selected for this purpose, as it is small in size, and has 5 in/out pins required to convert analog to digital signals for the 5 PZT sensors. The digital value which is to be transmitted to the receiver after the conversion is given by the formula:

Digital Reading = 1023 x (Analog voltage in volts)/5 (1)

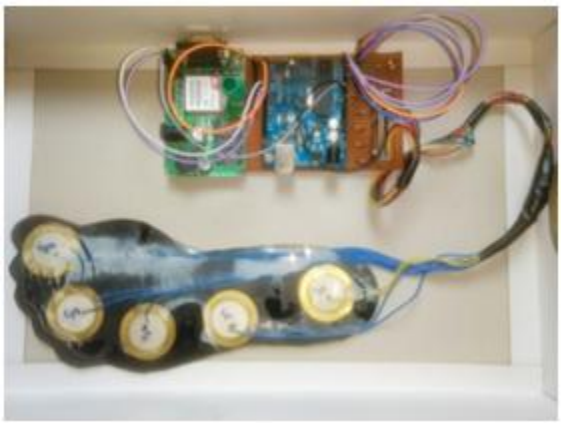

Fig 8. Diagram of diabetic foot ulcer detection & transmission system

To wirelessly transmit the data, a GSM module is used. SIM900A is used as it supports the basic frequency bands used worldwide. The Arduino board is coded to take the help of this GSM module to transmit the readings from the 5 sensors to a predefined mobile number as and when required in the form of a SMS. This number will in most cases belong to the doctor who is looking after the patient. Based on these readings sent by the proposed system, as seen in Fig. 8, the doctor can treat the patient.
The above mentioned method showcases the working of the system proposed in this paper to detect an early onset of foot ulcers in diabetic patients.

IV. RESULTS AND CONCLUSION

Using a prototype of the above proposed system, digital simulation values were generated on the software, which can be seen in Fig. 9. Changes in pressure on the PZT sensors resulted in digital values being displayed according to the formula mentioned previously. Each sensor has an output port assigned to it, which leads to five different values being displayed on the simulation screen. The change in pressure on any of the sensor results in the value corresponding to it being changed. Based on these values obtained on the simulation software, readings were transmitted wirelessly using the GSM module to a mobile device assigned to one of the testers. In the microcontroller and GSM code, the number of the receiver is pre-assigned such that an SMS is received as soon as the person puts on the device and walks.
Each sensor is assigned variables from S1 to S5. Each of these variables shows the value of change in the respective sensor. The SMS contains a reading for a change in each of the sensor values.
When a person walks with normal steps, all 5 points receive equal distribution of pressure and a reading on each sensor accordingly. But in other cases, when the disease is present, some values vary largely compared to the rest, showing a fallacy. In such cases, the doctor can detect the disease when there are abnormally low values or no reading at all. Fig. 10 shows a screenshot from the mobile device where multiple SMS were received, some showing changes in the pressure, while other showing no value when the device was left idle.

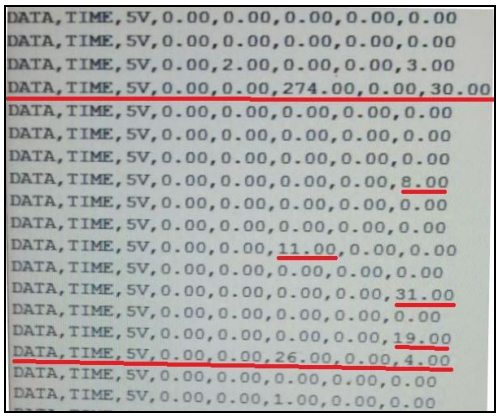

Fig 9. Sensor values as seen on the simulation software

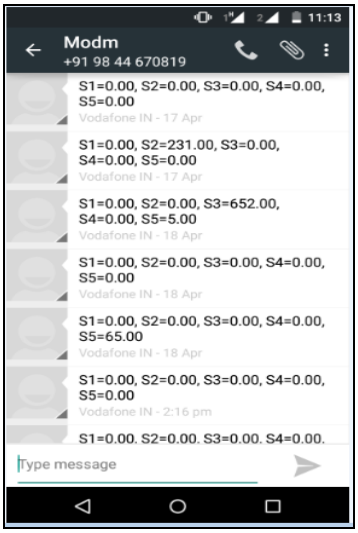

Fig 10.Sensor values sent by the system to smartphone

The idea of the system is to detect foot ulcers at an early stage or without the need to physically visit a doctor which can be time consuming and cumbersome. The use of PZT pressure sensor makes it easy to detect the pressure on a foot when a person walks. The system is efficient and not a hassle to use. It is portable and requires very few prerequisites. It can be used by just about anyone and consumes very less power to drive itself. A wireless communication system means that the data is transmitted fast, with ease and multiple times if need be.
In the current scenario of the world, a device which uses pressure sensors, electronic components and wireless communication to detect a disease, and makes it easier for the doctors as well as the patient, is the right step forward in digitizing the methods to detect and cure diseases. The benefits of such systems outweigh the drawbacks by such a huge margin that their use will become a major industry changer.

V. FUTURE WORK

In this system, only the pressure readings from a person's foot are taken into account. A future idea may be conceived such that depending on the walking pattern, the size of a foot, and the rate of occurrence of an ulcer in a patient, an algorithm can be figured out such that it detects the onset of the disease even before it happens. This would of course mean that the person wears the system over a period of time to enable the collection of data required, but in the long run, it will help multiple patients by, in layman's terms, looking into the future.

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