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LOW COST AND EFFECTIVE FOOT PRESSURE ULCER DETECTION SYSTEM FOR DIABETICS PATIENTS

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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.

I. INTRODUCTION

Diabetic foot ulcer is a major complication of diabetes mellitus, and probably the major component of the foot. Wound healing is an innate mechanism of action that works reliably most of the time. A key feature of wound healing is stepwise repair of lost extracellular matrix (ECM) that forms the largest component of the dermal skin layer. But in some cases, certain disorders or physiological insult disturbs the wound healing process. Diabetes mellitus is one such metabolic disorder that impedes the normal steps of the wound healing process. Many studies show a prolonged inflammatory phase in diabetic wounds, which cause a delay in the formation of mature granulation tissue and a parallel reduction in wound strength. Sensor is a device that vibrates, measures a physical quantity and converts it into a signal which can be interfaced to a system. Loss of any kind of functions to leg leads deleterious to the patient and mostly to the diabetes patients. Diabetes mellitus (DM) is reported to be an important cause of diabetic ulcer disease. Diabetes related foot complications can be detected early through provision of education and appropriate foot care. SUDOSCAN: a noninvasive and quick method, PRESSURE detection: normalized peak pressure and pressure contact ratio are basic elements to prevent complications and amputations. It is also found that the foot pressure parameters are functions of the material properties of foot sole soft tissue and also different levels of sensation loss. The normal path way of monitoring is the painful to the patient. Energy harvesting and other applications of piezoelectrics has widely studied and used. Effective circuits, different concepts, integration of sensor with electronics have been investigated for better applications. Few companies developed only platform to avoid the numbness and foot ulcers. But, no feedback was being taken in the existed models.

Ignored and untreated, minor sores on the skin of the foot can turn into severe problems with potentially devastating consequences, namely, numbness which turn into foot ulcers in later stages so protective way and independent risk study was proposed as a simple monitoring system to predict the foot ulcers in patients. Related to this concept recent developments on security were done by researchers. Pressure points data can be easily noticed and record the data. Simple GUI based android electronic tool can warn the patient periodically.

II. NEUROPATHY MONITORING SYSTEM ARCHITECTURE

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 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.

Fig2.1. Polyvinylideneflouride material prototype infection with aerobes, especially in cases of deep tissue stress.

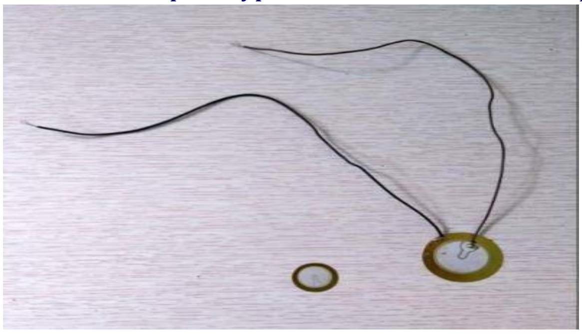

Fig2.2.PZT Sensor

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.

B. Fabrication of PZT:

We generally use the materials such as Phynox, Brass, Stainless steel (SS) for fabrication of a PZT sensor. 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 Aluminum (Al) metal. Aluminum coated area will act as positive and remaining area as negative plate. Hence, it acts as parallel plate capacitor.

C. 2N2222 NPN transistors:

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.

III. PROPOSED SYSTEM

The proposed system, a block diagram of which is shown in Fig. 3, 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. 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

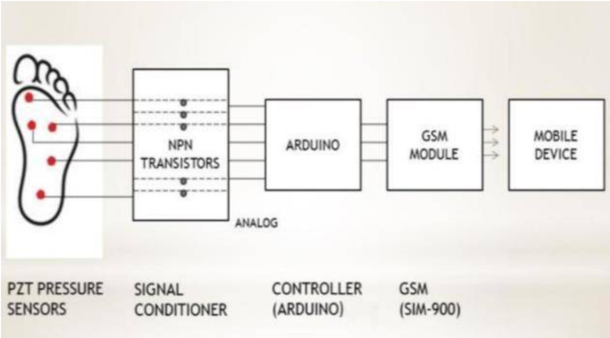

Fig 3.1 Block diagram of the proposed system communication system, making the task easier

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. 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. 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. 4. 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.

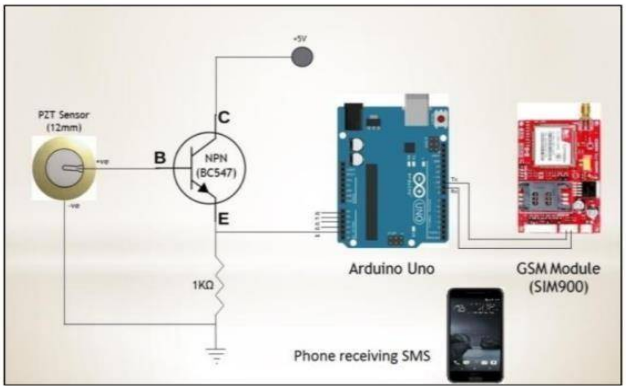

Fig 3.2. Schematic diagram of the working of a single sensor

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 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, 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. SYSTEM DESIGN

The proposed system in this paper contains 5 modules including: 1) Piezoelectric sensors, 2) Foot platform, 3) Microcontroller, 4) Bluetooth module, 5) Android based smartphone.

A. Design of the sensors platform:

Foot placing platform consists of 3 layers (soft silicon – sensor mounting rubber-hard silicon) which are shown in Figure 5(a) and total assembly has 5 mm thickness, in which top and bottom layers are silicon sheets. Mid layer is a rubber sheet, which is attached to the bottom layer. In the mid layer grooves are made at preferred pressure point locations using specific cutting tool 13 mm diameter. Figure 5(b) shows grooves, piezoelectric sensors are placed and also proper path is cut to take wiring sensor and analog inputs of microcontroller.

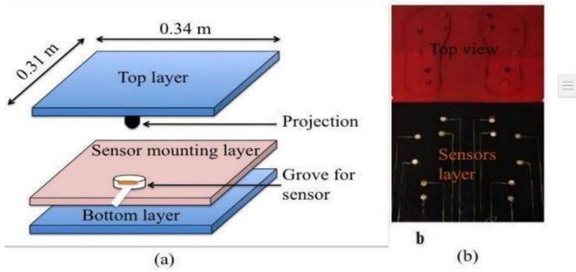

Fig4.1 (a)sensor mounting view (b)Developed platform for sensor placement (inside view and top view)

Total 6 grooves are made at each side of the platform i.e., for left foot and right foot. The piezoelectric sensors are of 12 mm diameter, total 12 sensors are placed at 12 grooves. In the top layer, 13 mm, extrudes are made and each extrude will fit into the grooves of the mid layer.

B. Overall System Representation:

Wires from each sensor of each side of platform are connected to the respective Arduino board analog I/O pins, which is shown in the figure 5.1(a). Bluetooth module is connected to the RX and TX pin of the Arduino board respectively and remaining pins are connected as indicated on the datasheet. Placement of sensor to measure the foot pressure distribution suggested are 6. These six areas are heel, metatarsal head 1 (MTH1), metatarsal head (MTH) (high pressure areas), toe and arch 1 (medium pressure areas), arch 2 (low pressure area). We have identified four locations to give optimized pressure distribution and complexity of sensing system. Figure 6(b) shows the layout of the sensors placement in order to measure the pressure distribution of the foot.

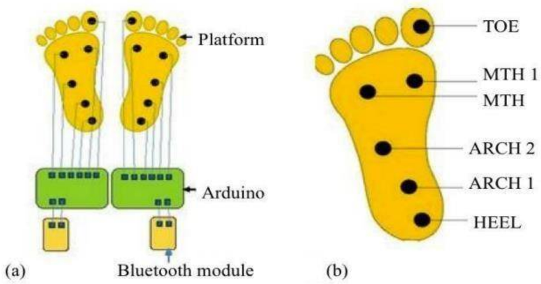

Fig. 4.2 (a)Complete system model representation including the data transmission to handheld devices. (b) Nodes representation on the foot used to place sensors.

C. Working principle:

The person who suffering from diabetic neuropathy is being asked to stand on the platform, pressure gets applied on the sensor due to the projections on the top layer. Signals are generated in the form of pulse. These signals are received by the analog I/O pins of microcontroller and processes the signals.output of the Arduino board are fed to Bluetooth module. Data was serially transmitted to the smartphone and displayed in the designed GUI application.

V.SIMULATIONS AND MODELING

With applied load on the PZT sensor, we observed noticeable change in the signal. The model of sensor structure was estimated/simulated with ANSYS tool. Simulation results shown in Figure 5.1 with distribution load and point contact load. In simulation tool the sensor material was taken as copper with young's modulus / elastic modulus was 110 GPA. We tested at different load conditions and shown in Figure 5.1 (a), (b), (c) i.e. 40kg, 60kg, 80kg respectively. Also a point contact test with load of 50kg (figure 5.1(d)) was done and it shows significant change w.r.t uniform load distribution. Point load is taken into consideration as the application of pressure on the solder over the sensor. Due to the solder contact, more pressure can act over the sensor.

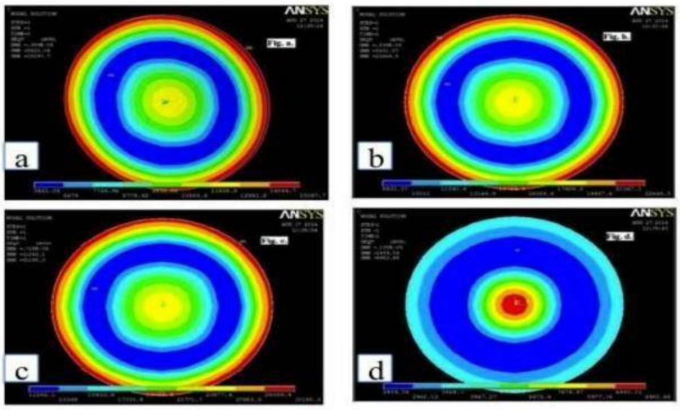

Fig 5.1 Load distribution on sensor model metalInsulator-metal. (a), (b), (c). Uniform load distribution, (d). Point load distribution.

After applying uniformly distributed load and point load, the maximum stress was observed at the edges of the value 15097.7, 22646.5, 30195 upon applying 40 kg, 60 kg, and 80 kg respectively. For point load the maximum stress value of 6982.68 upon applying 50kg. Different forces acting on sensor are being computed with the help of stress and strain relations. The stress acting on the sensor is being calculated with the below relation. Stress = (load/cross sectional area) = and the axial deformation is calculated using.

VI. RESULT AND DISCUSSION

A person step on the platform, the pressure applied to all the sensors was not the same, thus the output from each sensor will be different. The observed output from PZT sensor is shown in below Figure 8.

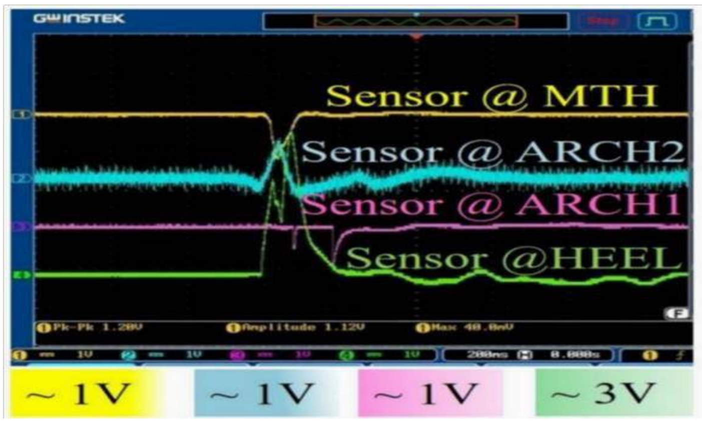

Fig. 6.1. PZT responses with respect time as we apply the load.

There was output change in each sensor according to the pressure level and noticeable change in the heel part sense area of the foot. This was the basic test done to optimise the sensor result for further process. Repeated tests shows the comparatively similar responses. Green marked line shows the heel part data at high peak response. MTH, ARCH1, ARCH2 points have a reasonable response and it is less than the heel point response. Several experiments with many sensors conducted and recorded in the digital CRO.

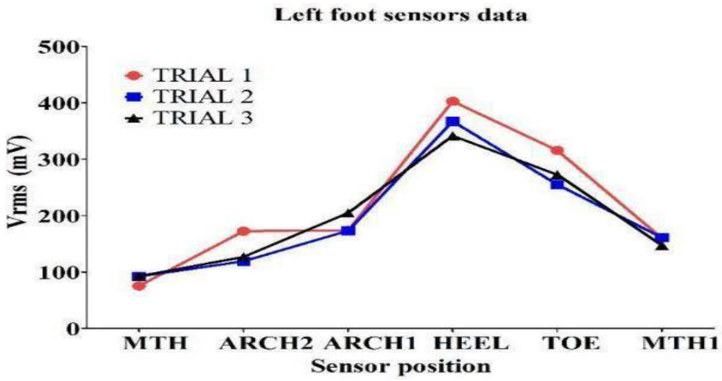

Fig. 9. Left foot sensor data in three trials

All analog input pins read values when we step onto the developed platform. Graph was computed for 6 sensors data taking in X-axis and response of sensor (voltage) in the Y-axis. Three trails has been conducted to notice the repeatability of the system. left foot and the right foot responses in multiple tests with the same platform. In the data the heel pressure point has recorded consistent values for several trials. This data shows the stability in sensors and system performance.

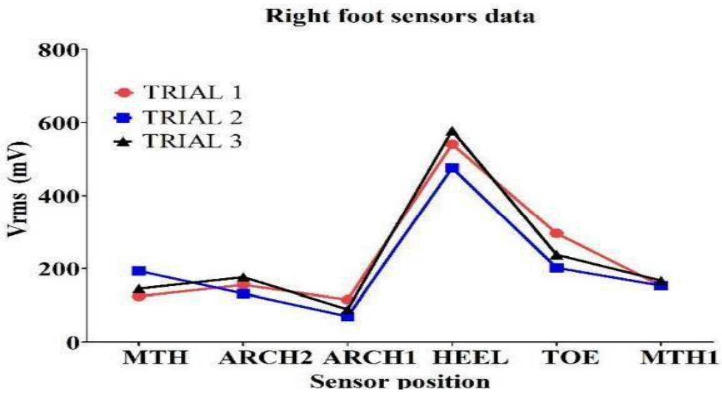

Fig. 6.2. Right foot sensor data in three trials

From both, results we observed that HEEL exhibits more pressure. When we step on MTH sensory point, which read as a least pressure point. Figure 8 shows the Digital oscilloscope reading of the MTH, ARCH 2, ARCH 1 and HEEL sensory points. The green line data in indicates the HEEL sensory point and has high output response compared to the other sensory points. These repeatable data can be used to optimize the platform and system can perform better.

VII.CONCLUSION

Foot pressure sensing platform system is developed using piezo-electric sensors to early detection of foot ulcer caused by diabetic conditions. This system used to measure pressures on foot at HEEL, MT, MT1, TOE, ARCH1 and ARCH2 locations. The result shows the comparisons of the pressure distribution on foot with different trials to detect the numbness and avoid the foot ulcers. This system can aid in deciding suitable foot wear for diabetic patients and walking style for a given time based on the data read sensor and shown in the hand held device. It is envisioned that the said technique, developed and tested is effective biomechanical system to diagnose various disorders related to foot. Remotely, data can be accessible using inbuilt gsm module is a trend to resolve many of the medical problems.

VIII. 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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