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Design of Wireless Telemetric Sensor System for Advanced Monitoring and Treatment of Chronic Diabetes

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***Abstract*—** Diabetes mellitus (DM) is one of the most general causes of chronic wounds. To prevent the wounds from worsening, appropriate treatments are needed, one of which is by monitoring the temperature and humidity of the wound area. The aim of this research is to design an improved sensor system which is able to monitor the chronic wound's' advancement condition in patients with diabetic foot. The working principle of this sensor system is to measure the temperature and humidity around the wound's area and transmit the results to an Android-based application, and, when the temperature and humidity reaches the threshold set beforehand, the system will send an alert to the Android application so that further treatment can be done. Based on the results of the research, wireless telemetric sensor systems that have been developed that can be used for management of diabetics' chronic wounds.

Keywords— chronic wounds, wound grades, temperature, humidity

I. INTRODUCTION

Chronic wounds, such as the wounds suffered by diabetic patients, or venous leg ulcers have become financial threats to health systems globally [1]. Indonesia is placed fourth in the numbers of diabetic patients and 25% of the patients suffer diabetic foot ulcers, which leads to amputations in 85% of the patients. In 2000, Indonesia had 8.4 million diabetic patients, and this is predicted to increase to 21.3 million in 2030 [2].

In various grades of wounds, chronic wounds have different physical characterizations around the wound area. The easiest factors to identify the wounds in order to classify them are the temperature, humidity and visual conditions of the wound [3]. Temperature and humidity are key factors that could change the wound's condition, and also could worsen the wound by factoring in bacterial growth.

Chronic wounds can be monitored non-invasively using sensors and wireless technology. The developments of wireless systems as monitoring devices can improve the quality of chronic wound treatments. The main problems for previous researches have been low sensor accuracy, no clinical tests to patients, the inability to place the system inside the wound's covering, and the need of transmission cables [3].

This research is aimed to design a wireless sensing system that could measure and transmit information on temperature and humidity in a wound's area accurately and in real time. The information transmitted can hopefully be used as the basis on which medics can decide the level of severity in a patient's wound and what appropriate treatments can be given. This research aims to design and develop a wireless telemetric sensing system for the management of diabetic chronic wound patients.

Chronic Wounds and their Classifications

Chronic wound is a type of wound that is not easy to heal. Chronic wound occurs for a long time, with indications of pathology factors and a long inflammation period. Chronic wound can also cause other complications to its patient [4], such as ulcers and amputation [5]. Diabetic foot ulcer is also one of the most common causes of chronic wound. This wound appears on the patient's lower extremities and can complicate treatments for diabetic patients, with possible other complications. The risk of neuropathy, arterial diseases, and foot deformation is also possible in diabetic foot ulcer [6].

Chronic wounds are classified in grades. To describe each grade, the most commonly used by medics are Wagner's classification and the University of Texas's classification [7]. These classifications are needed to help decide the appropriate treatments for the patients according to the wound's severity. Table 1 shows Wagner's six grades in of classification.

Table 1 Wagner-Meggitt's Classification on *Diabetic Foot* [7]

Grade 0	Foot symptoms like pain
Grade 1	Superficial ulcers
Grade 2	Deep ulcers
Grade 3	Ulcers with bone involvement
Grade 4	Forefoot gangrene
Grade 5	Full foot gangrene

Wagner's classification still has its shortcomings, because this system is limited. In Wagner, the grade of infections and

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inflammations are not classified clearly and superficially infected wounds are unclassified. Temperature and humidity in a wound's area are used as parameters because they are directly factored in the development of chronic wounds and in influencing infection rates in chronic wound's higher grades. By maintaining the condition of infected area to control the infection, bacteria's growth is restricted [8]. Rapid growth of bacteria is factored by humid environment, high temperatures and high oxygen level. One of the methods to maintain the condition of an infected area is to use wound dressings and changing the bandages periodically [9][10]. By maintaining the condition of an infected area, bacteria will not grow easily and are easier to handle, the wound is also not worsening.

II. METHODS

A. Sensor

The main sensor used in this research is DHT-11, a temperature and humidity sensor.

B. Arduino Uno

Arduino Uno is the microcontroller unit used to integrate the sensor with the transmitter (Bluetooth HC-05) and is used as analog to digital converter (ADC).

C. Bluetooth HC-05

The transmitter for data measured by the sensor is Bluetooth HC-05, which is compatible with Arduino Uno.

D. Android Inventor

Software used to make an Android application in this research is MIT App Inventor, a free web-based app inventor studio using block diagrams as its basic programming language. Android application is used as data display and data processing. Generated software is an application with **.apk* extension, which then installed in an Android smartphone

The hardware and software of this system is integrated as to be able to transmit real-time results of the sensor's reading for a long period. The design diagram is shown in **Figure 1**.

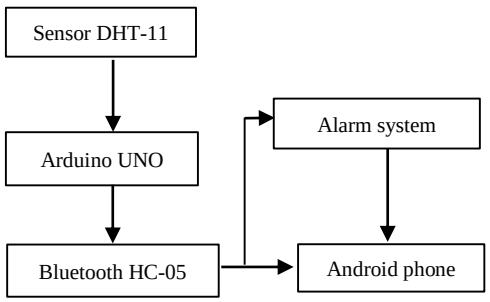

Fig 1. Block Diagram of Sensor System

There are two softwares created in this research and both are applications for Android smartphones. The first software is used as initial monitoring to determine the threshold of optimal temperature and humidity in a patient. The second software is used to display measured temperature and humidity and has a warning system, in which the threshold is determined by the results of the first software. Basically, the software for the sensor system is divided into two parts, which are data receiver and the software's interface.

The software is designed to send an alert when the condition of the wound is worsening, or when the measured parameters are above the threshold.

E. Testing And Data Gathering

Data are obtained by doing a test to various conditions in diabetic patients with chronic wounds. Conditions subjected to the test are healthy patients (do not suffer from chronic wounds) and diabetic foot patients from various grades (grade 1 to grade 5). Data gathering is done three times, once to healthy subjects, to diabetic foot patients in grade 1 to grade 5 to build a database of the wound's condition for each grade, and to diabetic foot patients using the database randomly obtained from the second test as a warning system.

The database of temperature and humidity in each grade is used to make the final software with the alarm system, so when the temperature or humidity in a patient's wound is above its threshold, the patient will receive immediate treatment. Data gathering is also done to observe the difference of temperature and humidity in each grade.

III. RESULTS AND DISSCUSSION

The using of wireless technologies and advancements in on-body sensor design can enable change in the conventional healthcare system, replacing it with wearable healthcare systems. Wireless monitoring systems can report continuous physiological data, as well as better information from the general health of individuals [11]. A wireless telemetric sensor system can be applied for advancement monitoring and treatment of chronic diabetes from temperature and humidity [12] [13]. The telemetric pressure and temperature sensor system can be used for medical applications [14] [15].

For the results of this study, data of temperature and humidity for each wound's condition are obtained. In healthy skin of subjects of age 45-50 years old, temperature is in the range of 31°C-34°C, while humidity is in the range of 60%-63% RH. Data gathering of healthy patients is needed for comparison between healthy skin and diabetic foot patient's skin. Figure 2 and 3 show the average of temperature and humidity measured in diabetic foot of patients.

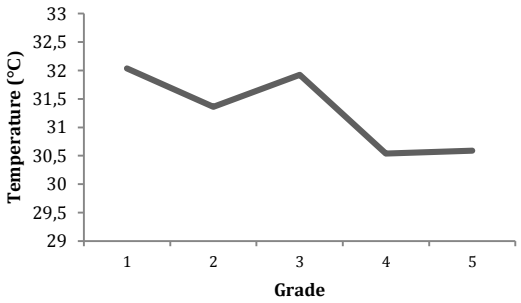

Fig. 2. Graphic average temperature measured in diabetic foot patients from grade 1 to grade 5

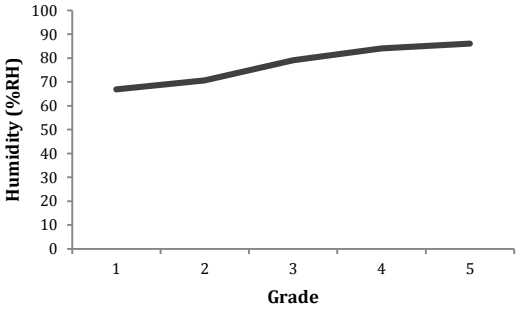

Fig. 3 Average humidity measured in diabetic foot patients from grade 1 to grade 5

The average result of temperature and humidity measurement in grade 1 chronic wound is 32.03°C and 66.90% RH. Grade 2 chronic wound has the average of 31.35°C and 70.60% RH for temperature and humidity, respectively. Grade 3 chronic wound has the average of 31.92°C and 79.11% RH. Grade 4 chronic wound has the average of 30.54°C and 84.04% RH, while grade 5 chronic wound has the average of 30.59°C and 86.06% RH. From the data in each grade, it is shown that lower grades tend to have higher temperature with low humidity. On the contrary, the higher the grade, humidity will increase while the temperature drops. It is also observed that temperature is not suitable for a threshold parameter, as the temperature for each grade doesn't differ significantly from the others.

In a warning system, a minimum value for each condition is required as a limit indicating that the desired condition is eligible to sound an alarm. When a measurement has reached a certain value, the warning system will automatically notify that the patient has entered a particular chronic grade of wound. In this research, the alert on the sensor system is set to humidity 68% RH in grade 1 chronic wounds, 72% RH for chronic wounds entering grade 2, 80% RH for chronic wounds entering grade 3, 85% RH for chronic wounds entering grade 4, and 87% RH for chronic wounds entering grade 5.

Based on the data from chronic wound patients, the minimum threshold for each grade is not linear with the others due to various factors, such as the patient's physical condition. In this research, data used for the threshold are the average temperature and humidity measured from each patient. Therefore, wireless telemetric sensor systems can be improved for application in chronic wound management through a temperature and humidity sensor.

IV. Conclusion

From this research, the designed hardware and software are able to measure temperature and humidity in a wound's area on diabetic foot patients and are able to give alerts correctly in each grade. The device and Android application as software can be used as a monitoring device for diabetic foot patients' wound advancement and as an aiding device for wound treatments. Based on the research results, wireless telemetric sensor systems can be improved and applied for chronic wound management through a temperature and humidity sensor.

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