

# Wireless monitoring method for diabetic foot temperature

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**Abstract**— This work presents a wireless monitoring method for diabetic foot temperature. In the implementation we used an FLIR infrared camera, a BME280 temperature sensor and an embedded board. Our final suggestion is prototype of the wireless monitoring device of diabetic foot temperature and its mobile application for the smart devices such as wearable device, mobile phones, smart watches, tablets and pads. To develop the fully independent embedded system we also developed the wireless wearable device using the ARM7EJ-STM RISC processor cored MT2502 RePhone Kit Create. Hence our device is implemented on the powerful embedded platform, we can suggest daily or short and long term monitoring for the consumer and clinical usage.

**Keywords**— *diabet, thermal image, IR camera, foot ulceration, rephone kit create*

## I. INTRODUCTION

Diabetes is one of biggest health problem of the world population. Many studies and researches are concerning to this problem with two main trends. First one is an improvement of early diagnosis of diabetic foot, and another one is a reduction of ulcer occurrence and amputation of diabetic foot [1, 4].

The reduction of ulcer occurrence and amputation of diabetic foot is a work of medical or Nano and biotechnology fields [5, 6]. Therefore we are working on the implementation and improvement of the early diagnosis device for diabetic foot.

One common indication of diabetic foot is an inflammation. In the early stage inflammation can be invisible in the sole of foot. For the detection and monitoring the new and emerging inflammation of diabetic foot has not contactless and costless friendly solution in the medical field yet [1, 2, 6].

Previous studies and research works show the relation of temperature and foot complication for the emerging inflammation of diabetic foot [1-6]. That relation is a difference of 2.2°C the identical area of soles of right and left foot [1, 3, 6]. Therefore in the last few years many researches intensively study and investigate the accurate and optimal analyzing solution and idea, implementation of monitoring of diabetic foot from the ICT or Electronic fields.

Here we present a prototype design and an implementation of wireless monitoring device for the diabetic foot based on related work and previous studies. In the implementation we used a Lepton infrared camera, BME280 temperature sensor

and embedded board. Our final suggestion is first prototype of the wireless monitoring device of diabetic foot and application for the smart devices such as wearable device, mobile phones, smart watches, tablets and pads.

When a consumer or patient puts feet in the wireless monitoring device, an infrared camera captures the thermal image of foot soles. Also thermal image can be shown in the 10.4 inch LCD of the wireless monitoring device. Using this thermal image, a microcontroller identifies or collects of the temperature of fixed twelve points of the right and left foot sole. Based on processing and comparison of temperature for right and left foot soles, system sends the status information for foot monitoring to the wearable device via Bluetooth [10]. Concurrently this pictures, information and thermographs will be able to automatically send to the web server of hospital and doctor via wireless technology.

We arranged our work following structures. Section 1 is introduction of study, Section 2 presents the general architecture of our system, Section 3 demonstrates our prototype design, an implementation and some important details of system hardware, Section 4 shows experimental results and finally we conclude our work.

## II. GENERAL ARCHITECTURE OF SYSTEM

A wireless monitoring device of diabetic foot temperature is implemented on the embedded board with several sensors and modules such as the thermal camera, temperature sensor and BLE 4.0 modules. The general system architecture of wireless monitoring device of diabetic foot temperature is shown in the Figure. 1.

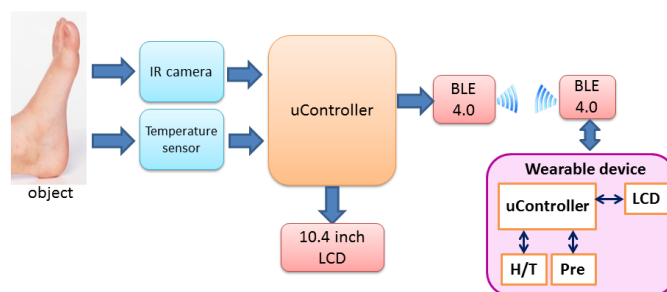


Figure. 1. System architecture

The wearable device is not commercial watch which is also implemented in an open source modular phone kit

MT2502 RePhone Kit Create. It provides a new form of phone customization, and the easiest solution to wearable/IoT development. [7].

### III. IMPLEMENTATION

The implementation is separated into the two parts; first part is the mechanical construction of the prototype model that must satisfy convenient placement of camera and other sensors for the infrared image capturing of foot soles. The second part is a hardware implementation of the wireless monitoring device of diabetic foot.

The forepart explains the mechanical construction of the prototype model, and the explanation of the hardware implementation is continued.

#### A. Prototype design

Our system has to inform the status message of diabetic foot monitoring in the wearable device to the consumer via Bluetooth connection based on the processing and comparison of temperature for right and left foot soles. Therefore we need to place infrared camera and BME280 environmental sensor in the comfortable or appropriate position of the wireless monitoring device.

The most limited or restricted parameters were pixel and coverage of IR thermal camera. Therefore we calculated distance and angle between IR camera and foot sole based on camera's parameters. Calculation is based on following equation:

$$e = \frac{a}{tg(\alpha)} \quad (1)$$

To experiment our system we used average foot size 24cm in the calculation of the distance and angle between IR camera and foot sole. Based on our calculation and visibility of camera image we designed a prototype of foot monitoring system which is shown in Figure. 2.

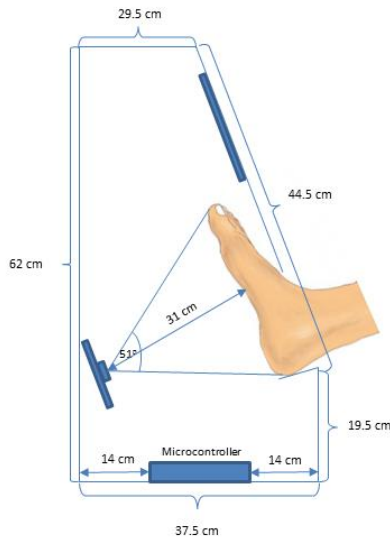


Figure. 2. Prototype model (side view).

#### B. Hardware design

The main processing unit of the wireless monitoring devices for diabetic foot is the Raspberry Pi which has been widely used in modern embedded systems for the various fields.

Figure. 3 is shown hardware design and system interconnections of our device.

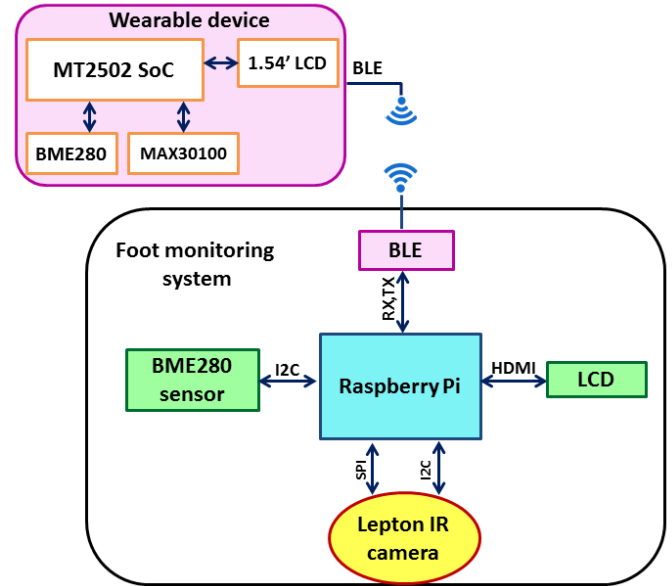


Figure. 3. Hardware design and system interconnections of wireless monitoring device

For the data acquisition of temperature of 12 spots of left and right foot sole, we used the infrared camera and BME280 temperature sensor which are connected to the microcontroller via two I2C interfaces. The comparison and preprocessing of the all information temperature is performed in the Raspberry pi microcontroller then it transmits results to wearable device via Bluetooth connection [11].

To capture the thermograph of right and left foot sole we used the Lepton thermal camera which is an infrared camera system that integrates a fixed-focus lens assembly, an 80x60 long-wave infrared (LWIR) micro bolometer sensor array, and signal-processing electronics [8].

To preprocess a temperature of foot sole we need a reference/environment temperature of foot sole. In order to measure this reference temperature we used a BME280 contactless environmental sensor which is as combined digital humidity, pressure and temperature sensor based on proven sensing principles. The sensor module is housed in an extremely compact metal-lid LGA package with a footprint of only 2.5x2.5mm<sup>2</sup> with a height of 0.93mm. The integrated temperature sensor has been optimized for lowest noise and highest resolution. The sensor provides both SPI and I2C interfaces and can be supplied using 1.71 to 3.6 V for the sensor supply V<sub>DD</sub> and 1.2 to 3.6 V for the interface supply V<sub>DDIO</sub>. Measurements can be triggered by the host or performed in regular intervals. When the sensor is disabled, current consumption drops to 0.1μA [9].

To compute temperature difference value from thermal image, our microcontroller performs several computation or procedures. Figure.4 shows general operation flow of foot temperature monitoring device.

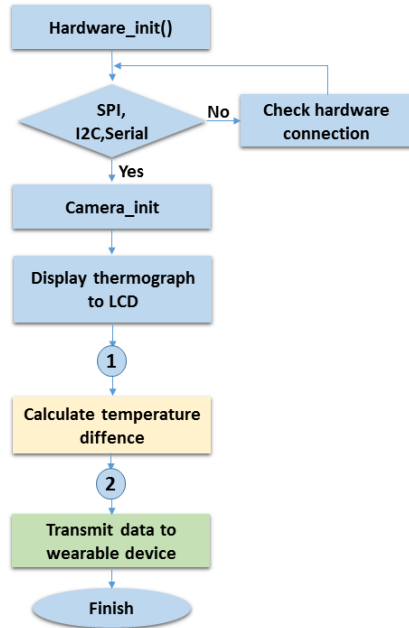


Figure. 4. Hardware operation flow of temperature monitoring device

The calculation of temperature difference is performed in the microcontroller and it consists of several processing that is illustrated in following flow.

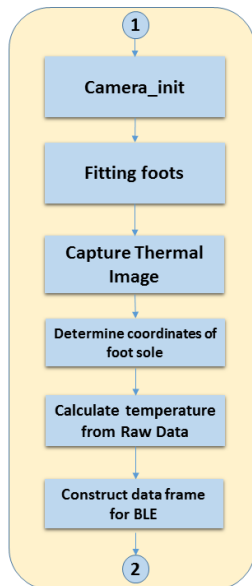


Figure. 5. Temperature difference value calculation flow of temperature monitoring device

The conversion of pixel value to temperature is calculated using Equation (2).

$$Tem [C^0] = slope * (raw - 8192) + ambTem \quad (2)$$

Here, ambTem is an environment temperature which is measured by BME280 contactless temperature sensor, raw is a pixel average value, slope is the temperature ratio of Fahrenheit and Celsius.

After calculation of temperature difference and packet construction device has to transmit processed data to the healthy wearable device via Bluetooth connection. This procedure is shown next flow chart of Figure.6.

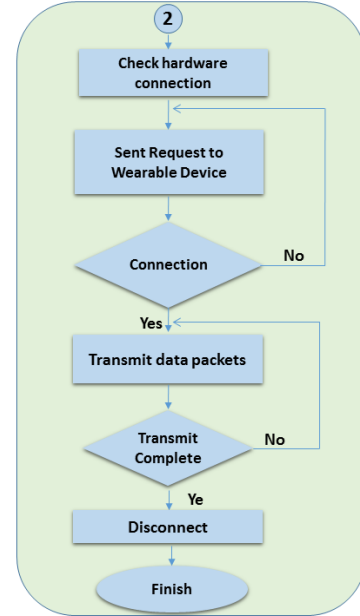


Figure. 6. Bluetooth transmission flow of temperature monitoring device

After receiving these differences from wireless monitoring device, healthy wearable device should be display information to consumer in the own LCD.

#### IV. EXPERIMENTAL RESULTS

Our experiment covers ten volunteers. Figure.7. shows our experiment setup and prototype of the wireless foot temperature monitoring device.



Figure. 7. Experimental setup

To clarify our measurement, we show points of foot sole in the Figure.8.



Figure. 8. Points of foot sole

Table.1 shows the pixel value, temperature of each points and temperature difference of right and left foot sole corresponding points.

Table. 1. Temperature difference of right and left foot sole points

| Points | average value of pixel | Ceils | $\Delta T$ |
|--------|------------------------|-------|------------|
| R1     | 8335.56                | 29.59 | 0.08       |
| L1     | 8338.69                | 29.67 |            |
| R2     | 8339.38                | 29.68 | 0.15       |
| L2     | 8345.38                | 29.83 |            |
| R3     | 8337.13                | 29.63 | 0.13       |
| L3     | 8342.38                | 29.76 |            |
| R4     | 8333.44                | 29.54 | 0.17       |
| L4     | 8340.06                | 29.70 |            |
| R5     | 8331.13                | 29.48 | 0.15       |
| L5     | 8337.13                | 29.63 |            |
| R6     | 8332.06                | 29.50 | 0.30       |
| L6     | 8344.19                | 29.80 |            |

All calculated temperature differences are transmitted to the wireless healthy wearable device via Bluetooth connection. This status information and difference is displayed in the wireless wearable device display. User interface of wireless wearable device is illustrated in the Figure.9.



Figure. 9. User interface of healthy wearable device for monitoring of foot temperature

## V. CONCLUSIONS

The results and experiments are shown us our proposed system architecture and hardware design are the consumable for the system integration and development. Especially we could collect all necessary data from sensors using our system. IR camera is possible to use temperature monitoring of diabetic foot.

For the future work to reach the optimal, analyzed, human friendly result and an interpretation, we will focus signal processing of all collected data using a Matlab programming. In addition we will combine our proposed the wireless monitoring device of diabetic foot with the daily health care wireless monitoring device. The daily health care wireless device can able to detect the fall, motion type and calculate heart rate.

## ACKNOWLEDGEMENT

The research funding was provided by the "L2766-MON: Higher Education Reform" project financed by the Asian Development Bank and executed by the Ministry of Education, Culture, Science and Sports of Mongolia.

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