Implementation of early diagnostic device for diabetic foot using the thermal sensor

D.Enkhzul, D.Erdenechimeg, T.Amartuvshin, N.Chuluunbaatar, T.Enkhbaatar
Electronics Department, School of Information and Communication Technology, Mongolian University of Science and Technology, Ulaanbaatar, Mongolia
enkhzuld1002@gmail.com, chimeg@must.edu.mn, amartuvshin@sict.edu.mn, n_chuka@must.edu.mn, enkhbaatar79@gmail.com,

***Abstract*— This work presents a prototype design and an implementation of early diagnostic device for the diabetic foot. In the implementation we used an IR camera, an OV5640 CMOS camera, a TMP006 temperature sensors and an Exynos4412 embedded board with android OS and OpenGL software. Our final suggestion is first prototype of the commercial electro weight which is combined with an early diagnostic device of diabetic foot 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 ultra-low power, cost-effective, simple link multi standard wireless microcontroller CC2650. 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*— *diabetic, thermal image, IR camera, ARM Cortex-A9

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^{0}C the identical area of soles of right and left foot soles [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 early diagnostic device for the diabetic foot based on related work and previous studies. In the implementation we used a Lepton infrared camera, OV5640 CMOS camera, TMP006 temperature sensors and Exynos4412 embedded board with android 4.4.4 OS and OpenGL software. Our final suggestion is first prototype of the commercial electro weight which is combined with an early diagnostic device of diabetic foot and application for the smart devices such as wearable device, mobile phones, smart watches, tablets and pads.

Our system works with two steps for monitoring of diabetic foot. In the first step, consumer or patients use our system like an electro weight that shows weight and the status message of the foot monitoring in the wearable device via Bluetooth connection. To show the status message of foot monitoring, the system measures and collects the temperature of fixed twelve points of the right and left sole of the foot using the TPM006 contactless temperature sensors. 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. If the system identifies a critical spot in the sole of foot that has to alert to the consumer should take visible and thermal picture of sole of foot using the CMOS camera and infrared camera that are located in the front of the foot monitoring system. In this case consumer can see the detailed thermograph and visible picture of foot soles. Concurrently this pictures, information and thermographs will 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

An early diagnostic device of diabetic foot is implemented on the ARM Cortex A9 Quad Exynos4412 MCU base embedded board with android 4.4.4 OS with the several sensors and modules such as two CMOS cameras, the thermal cameras with servo motors, CC2640 BLE 4.1 and RTL8188 wireless modules. The general system architecture of an early diagnostic device of diabetic foot is shown in the Fig. 1.

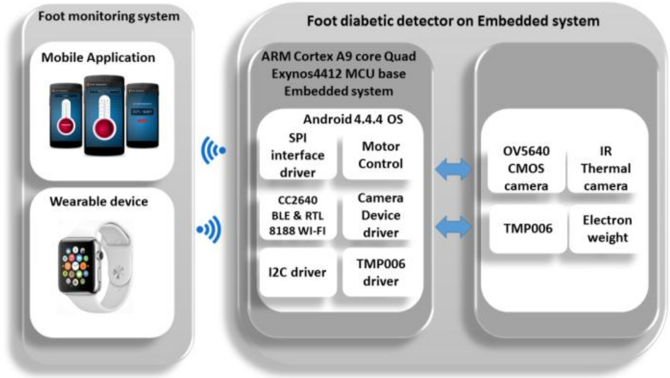


Fig. 1. System architecture

The wearable device is not commercial watch which is also implemented in CC2650 simple link multi standard wireless microcontroller with 1.8 inch LCD display which is a wireless MCU targeting Bluetooth Smart, ZigBee and 6LoWPAN, cost-effective, ultralow power, 2.4-GHz RF devices. The CC2650 includes the 32-bits ARM Cortex-M3 processor that runs at 48 MHz [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 cameras and other sensors for the accurate measurements temperature of foot soles, human weight, infrared and visible image capturing. The second part is a hardware implementation of the early diagnostic devices for diabetic foot.

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

A. Prototype design

In daily life our system has to inform information of human weight and status message of diabetic foot monitoring in the wearable device to the consumer via Bluetooth connection. Therefore we need to combine the electro weight and signal processing unit with infrared temperature sensors and Bluetooth.

Based on related work and our experiment of infrared temperature sensor, we made six holes for each foot sole in the electro weight. Reason is that the temperature sensor couldn't measure real temperature of foot sole through the glass or plastics. To accurate measurement of temperature of foot soles we need to choose the optimal hole size and distance between the object (our case foot sole) and the sensor. To choose these parameters we calculated following equations.

$$r = d * \tan(\theta) \ \ [cm] \qquad (1)$$

$$\theta = arctan\left(\frac{r}{d}\right) \qquad (2)$$

Here d- is a distance between the object and sensor, r – is a radius of field of view.

Geometry definition of Field of view for TMP006 temperature sensor is illustrated in Fig.2.

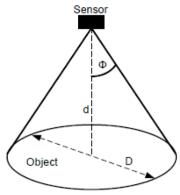


Fig. 2. Field of view Geometry TMP006 sensor

Fig.3 is shown our chosen size of the hole and distance between the object and sensor.

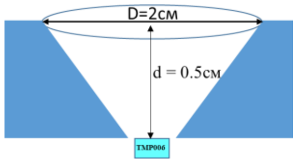


Fig. 3. Hole size of the prototype and distance between the object and sensor

When a consumer stands to the electro weight who can see own weight and a status message of diabetic foot monitoring in the wearable device via Bluetooth which is shown in Fig.4. Based on processing and comparison of temperature for right and left soles of foot, system sends the status information for foot monitoring to the wearable device via Bluetooth.

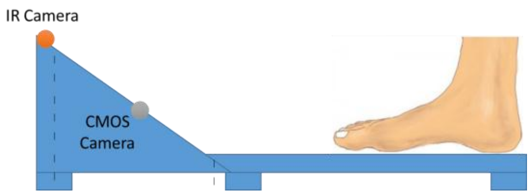


Fig. 4. Protoype model (side view).

Fig.5 shows top view of prototype model and position of TMP006 IR temperature sensors in the back side of the electro weight. In the front side of the electro weigh OV5640 visible CMOS camera and two IR cameras are shown.

Fig. 5. Protoype model (top view).

If the system identifies a critical spot in the sole of foot that has to alert to the consumer should take visible and thermal picture of foot sole using the CMOS camera and thermal camera that are located in the front of the foot monitoring system. In this case consumer should change position and capture the detailed thermograph and visible picture of foot soles. Concurrently this pictures, information and thermographs will send to the web server of hospital and doctor via wireless technology.

One limited or restricted parameter is our 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 shown following equations and geometry:

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

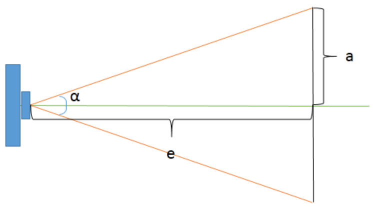


Fig. 6. Geometry of the angel and distance

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 electro weight or foot monitoring system prototype which is shown in Fig. 7.

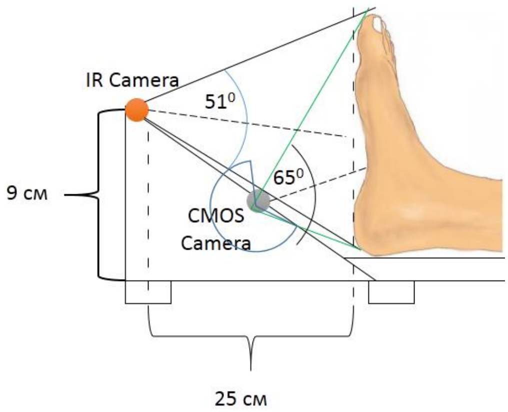


Fig. 7. Protoype model (side view).

B. Hardware design

The main processing unit of the early diagnostic devices for diabetic foot is the ARM Cortex A9 Quad Exynos4412 microcontroller which has been widely used in modern embedded systems for the various fields. This powerful microcontroller includes many hardware peripherals, such as TFT 24-bit true color LCD controller, Camera Interface, MIPI DSI, CSI-2, System Manager for power management, MIPI slim bus interface, MIPI HSI, four UARTs, 24-channel DMA, Timers, General I/O Ports, three I2S, S/PDIF, eight IIC-BUS interface, three HS-SPI, USB Host 2.0, USB2.0 Device operating at high speed (480Mbps), two USB HSIC, four SD Host and high-speed Multimedia Card Interface, Chip to Chip interface, and four PLLs for clock generation. It gave us good opportunity to integrate all system's components and interconnection in the one schematic and PCB.

Fig. 8 is shown our hardware design of device block diagram of the system interconnections.

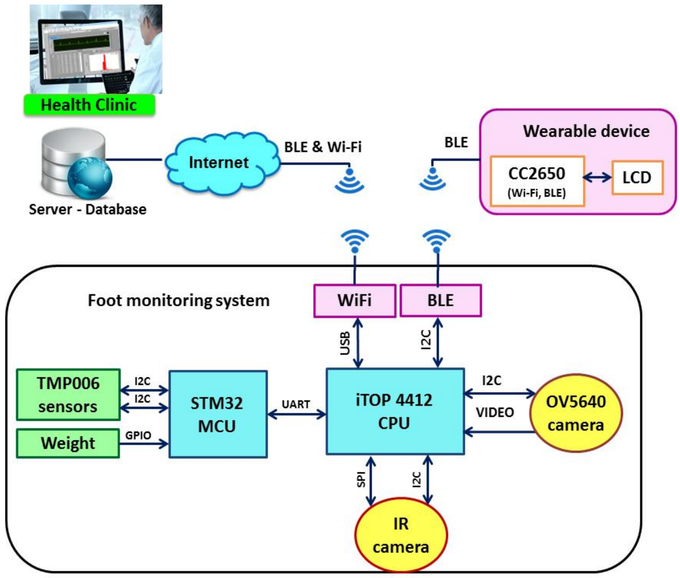


Fig. 8. Hardware design of device block diagram of the system interconnections

For the data acquisition of temperature of 12 spots of left and rigth foot sole, we used the twelve TMP006 sensors which are connected to the SMT32 microcontoller via two I2C interfaces with different addresses. Once our prototype is an electro weight, weight sensor also is connected with STM32 microcontroller via GPIO interface.

The comparison and preprocessing of the all information temperature and weight is performed in the of STM32 microcontroller then it transmits results to iTOP 4412 central processing units via serial interface.

If the diabetic foot monitoring process is going on the first step iTOP4412 transmits the convenient data to the wearable device and the web server via Bluetooth and wireless connections, respectively.

Further if the consumer need to capture or got alert of critical spot of foot sole, consumer will capture a thermograph and a visible image of foot soles using the IR camera and OV5640 camera and their mobile application.

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].

For the contactless temperature measurements, we used a TMP006 temperature sensor which is a fully integrated MEMs thermopile sensor that measures the temperature of an object without having to be in direct contact. The thermopile absorbs passive infrared energy from an object at wavelengths between 4um to 16um the end-user defined field of view [9].

The corresponding change in voltage across the thermopile is digitized and reported with the on-chip die thermal sensor measurement through an I2C and SMBus-compatible interface. With this data, the target object temperature can be calculated by an external processor. The Infrared thermopile sensor is specified to operate from –40℃ to +125℃ [9].

In addition to capture visible image of foot sole we used an OmniVision5640 CMOS camera that is a low voltage, high-performance, 1/4-inch 5 megapixel CMOS image sensor that provides the full functionality of a single chip 5 megapixel (2592x1944) camera using OmniBSI™ technology in a small footprint package. It provides full-frame, sub-sampled, windowed or arbitrarily scaled 8-bit/10-bit images in various formats via the control of the Serial Camera Control Bus (SCCB) interface [10].

The OV5640 has an image array capable of operating at up to 15 frames per second (fps) in 5 megapixel resolution with complete user control over image quality, formatting and output data transfer. All required image processing functions, including exposure control, gamma, white balance, color saturation, hue control, defective pixel canceling, noise canceling, etc., are programmable through the SCCB interface or embedded microcontroller [10].

IV. Experimental Results

To design schematic and printed circuit board (PCB) of the whole system first we need to test and operate all hardware and sensors, separately. As an example here we present the sub PCB which is drawn us and used for temperature sensor. Fig.9 shows our experimental PCBs.

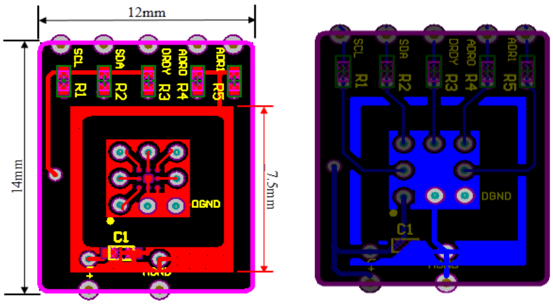


Fig. 9. PCBs of temperature and thermal sensors.

We tested an IR camera using the Rasp Berry Pi development board. The connection IR camera and development board and result are shown in Fig.10.

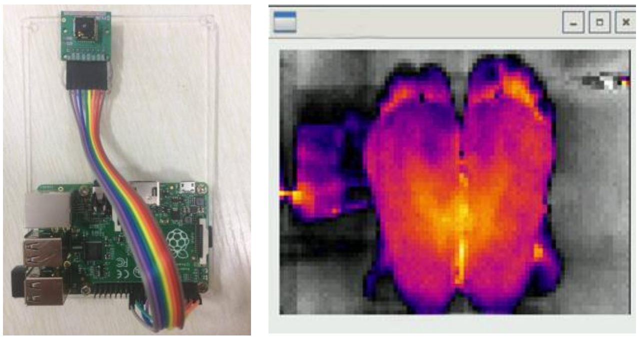


Fig. 10. IR camera experiment

Fig.11 illustrates experimental setup of placed temperature sensors and first prototype which is made by wood.

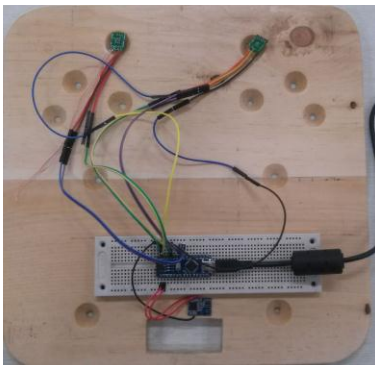


Fig. 11. Placement of temperature sensors and first prototype

The results of measured temperature are presented in Fig.12.

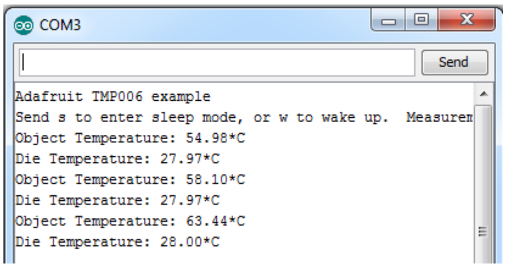


Fig. 12. Result of temperature sensor

The connection of OV5640 CMOS camera and iTOP development board, its result is shown in Fig.13.

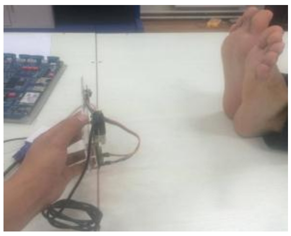
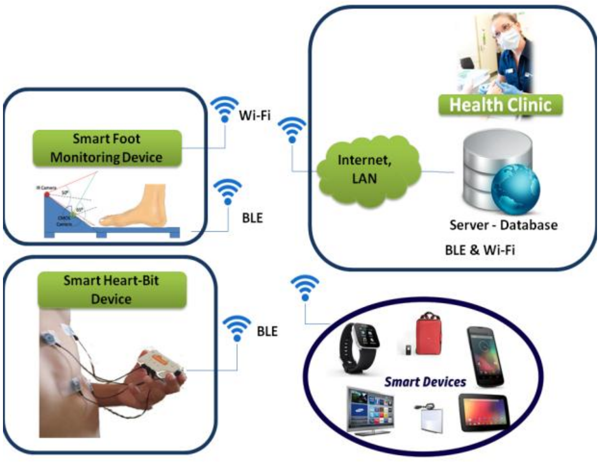


Fig. 13. Connection and result of CMOS camera

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 such as the weight and all temperature values of foot soles, the visible camera image and the thermograph.

Therefore in the future work to reach the optimal, analyzed, human friendly result and an interpretation, we will focus signal processing of all collected data using the OpenGL and matlab programming. In addition we will combine our proposed the diabetic foot monitoring device 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. The general architecture of our future complex healthcare device is depicted in the Fig.14.



.

Fig. 14. Future work

REFERENCES

[1] Luis Alberto Vilcahuaman Cajacuri. Early diagnostic of diabetic foot using thermal images. PhD dissertation, Universite d'Orleans, 2013.

[2] Liu, C. and Heijden, F. van der and Klein, M.E. and Baal, J.G. van and Bus, S.A. and Netten, J.J. van (2013) Infrared dermal thermography on diabetic feet soles to predict ulcerations: a case study, Advanced Biomedical and Clinical Diagnostic Systems XI, January 2013, San Francisco, CA, USA (pp. 85720N).

[3] Boulton AJ, Vileikyte L, Ragnarson-Tennvall G, Apelqvist J. The global burden of diabetic foot disease. Lancet. 2005;366(9498):1719–1724.

[4] Armstrong DG, Lavery LA, Liswood PJ, Todd WF, Tredwell JA. Infrared dermal thermometry for the high-risk diabetic foot. Phys Ther. 1997;77(2):169–177

[5] Armstrong DG, Holtz-Neiderer K, Wendel C, Mohler MJ, Kimbriel HR, Lavery LA. Skin temperature monitoring reduces the risk for diabetic foot ulceration in high-risk patients. Am J Med. 2007;120(12):1042–1046.

[6] Van Netten JJ[1], Prijs M, van Baal JG, Liu C, van der Heijden F, Bus SA, Diagnostic values for skin temperature assessment to detect diabetes-related foot complications. Diabetes Technol Ther. 2014 Nov;16(11):714-21

[7] Texas Instrument , CC2650 SimpleLink™ Multistandard WirelessMCU, SWRS158A –FEBRUARY 2015

[8] FLIR Proprietary-Confidential, FLIR LEPTON® Long Wave Infrared (LWIR) Datasheet, Version 1.2.3, October 15, 2014

[9] Texas Instrument, TMP006/B Infrared Thermopile Sensor in Chip-ScalePackage, SBOS518E–MAY 2011

[10] 1/4" color CMOS QSXGA (5 megapixel) image sensor with OmniBSI™ technology, product specification, version 2.03, may 2011