Temperature Monitoring Footwear: Detecting Early Signs of Diabetes-Related Complications

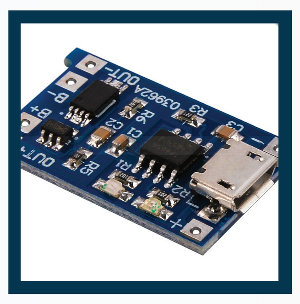
SACRAMENTO STATE

Thermistors

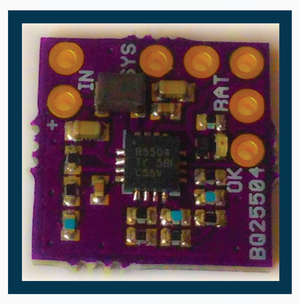
Bluetooth Low Energy SoC

GSM Module

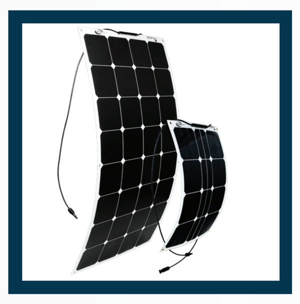
USB Charger



Ultra-Low Power Boost Converter



Thin-Film Solar Panel



Abstract:

There are 29 million people in the United States (9.3 percent) that have diabetes, and 1.7 million people aged 20 years or older were diagnosed with diabetes in 2012. Experts suggest that around 10 percent of people with diabetes develop foot ulcers at some point in their life. While early detection is crucial to mitigate the injury and suffering caused by foot ulceration, this often does not occur because many diabetics also experience loss of sensation due to nerve damage (Peripheral Neuropathy). This means that preventable problems can quickly escalate in severity, may require amputation, or even become life threatening. The objective of this project is to measure and compare temperature at several locations on each foot, and if there is a sizable and persistent difference trend of at least 2-3 degrees, then the data will be uploaded to a database for further analysis.

Project Description:

We use twelve low-power thermistors that are suitable for placement at sites in the shoe insole. We use small Bluetooth Low Energy (BLE) chips in the left and right shoes, one we call Central and the other Peripheral. The shoe with the Peripheral BLE chip also contains a compact mobile telephony (GSM) module. The BLE chips sample the thermistor temperature values, and the Central chip wirelessly communicates with the Peripheral chip to allow comparison of temperatures between the left and right feet. If there are signs of inflammation, the GSM module uploads relevant data to an online database, and also provides the means to notify a physician. Our system operates on a thin, light lithium ion polymer power cell, and we recharge it via an intelligent USB charger. To supplement the power cell, we use small, thin-film solar panels connected to ultra-low power energy-harvesting converters.

Thermistors:

101JT-025 NTC (Negative Temperature Coefficient) thermistors are designed for applications in the milliwatt power range, and are only 500um thick, which makes them perfectly suitable for placement inside the shoe insole.

Arduino Primo Core:

The PRIMO CORE is a compact device using a Nordic nrf52832 chip with Bluetooth smart (BLE 4.0) and NFC-A tag functions, and also integrated motion and environmental sensors. The low power consumption permits powering the Primo Core with a coin cell battery. Data transfer is very accurate with a BLE sensitivity level of -96dBm. Operates on 1.7V to 3.6V, and is suited for power-efficient applications.

GSM Module:

The SIM800H is a quad-band 850/900/1800/1900MHz GSM module, which uses TCP/IP and GPRS to send and receive data. Its compact footprint make it ideal for our application.

Thin-Film Solar Panel:

We utilized flexible solar panels made by PowerFilm Inc. With their ultra-thin profile, they are easily integrated with devices for solar recharging or direct powering. They are rated for 3v, 22mA.

USB Charger:

The TP4056 is a complete constant-current/constant-voltage linear charger for single cell lithium-ion batteries. The TP4056 can interface with both, a mini USB connector, and a solar panel that is rated for 4.5V - 5.5V. The charge voltage is fixed at 4.2V, and the charge current can be programmed externally with a single resistor. The TP4056 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

Battery:

Lithium ion polymer batteries are thin, light and powerful. The output ranges from 4.2V when completely charged to 3.7V. This battery has a capacity of 2500mAh for a total of about 10 Wh. The battery includes protection circuitry to keeps the battery voltage from going too high (over-charging) or low.

System Communication:

Each shoe contains a BlueTooth Low Energy-capable SoC. One SoC (the server) transmits collected data to the other (the client), which in turn calculates the temperature difference, and uploads the data to a MySQL database using a GSM.

Database:

The data stored in the database is received from the GSM module. There is a column for each temperature difference between the right and left shoes that are measured from the sensors, along with a column for the date and time of measurement. A script was written and placed on the webspace made available from Athena, which pulled the data from the tables, encoded the rows into javascript object notation, and used an open source chart libraries from C3 in order to provide a visual representation of each of the sensors with respect to the date and time. The script consisted of multiple programming languages such as php, mysql, html, and javascript.

Testing:

The primary area of concern was whether or not the thermistors would be able to detect a temperature change of 1 to 3 °C, which would be considered sufficient to detect local inflammation. The insole of the shoe with the embedded thermistors was placed on a Creality heated platform. A BK Precision temperature probe was used to verify the temperature. After stabilizing at 37 °C, the temperature was increased by 3 °C and measured.

Results:

The raw ADC values collected by the NRF52 microcontroller can be seen in the Figure 1. The ADC values are used to calculate thermistor resistances, and then the corresponding temperature values are determined via additional information provided by JT THERMISTOR, as can be seen in Figure 2. Figure 3 depicts the difference in temperature between both shoes from a different test—this information is intermittently uploaded to a MySQL database using the GSM module. The information from the database is displayed via an online interactive graph.

Conclusions:

We have demonstrated that despite the loss of sensation in the feet due to nerve damage, it is still possible to detect localized inflammation which is indicative of infection.

Results:

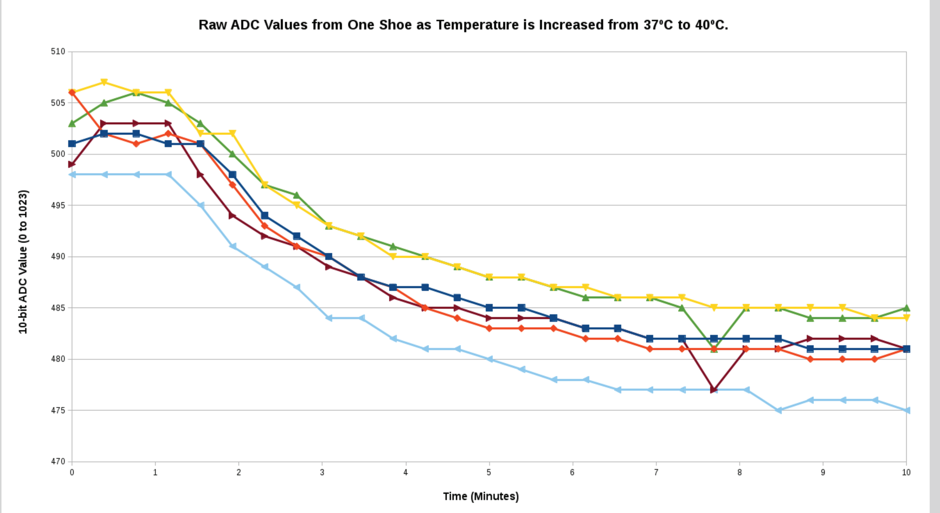


Figure 1

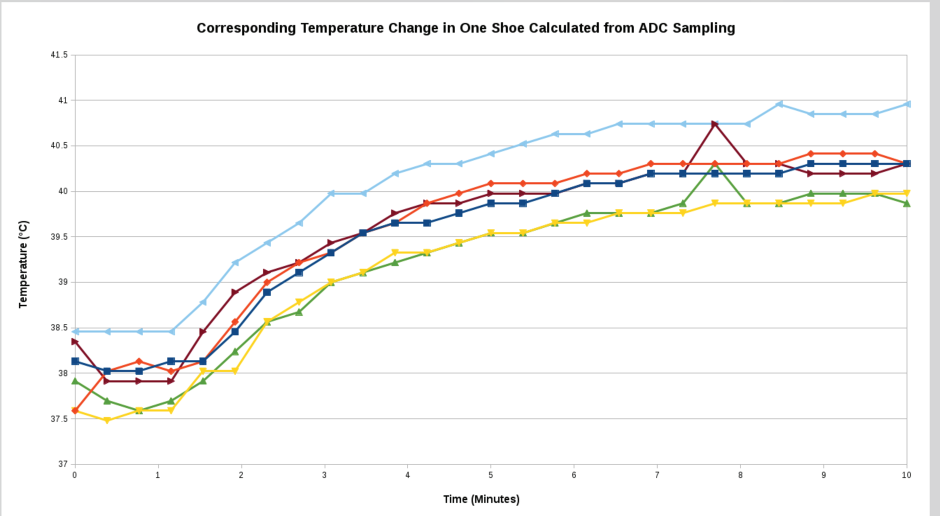


Figure 2

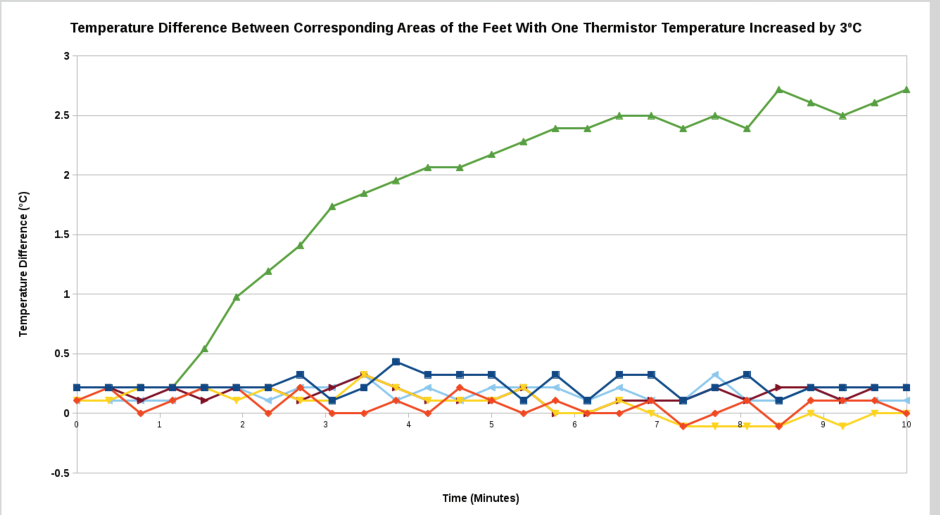


Figure 3

System Diagram:

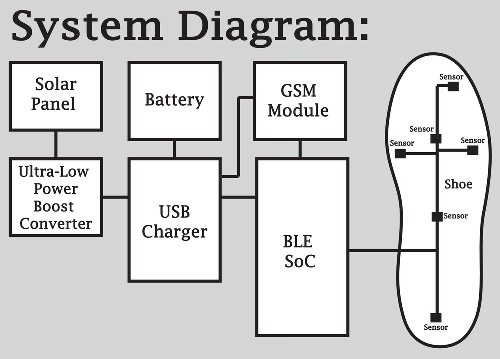


Image Source:
Netten, Jaap J. Diagnostic values for skin temperature assessment to detect diabets-related foot complications. Diagnostic Technology & Therapeutics. vol. 16, no. 11, pp. 714-721, 2014.

Future Research:

In order to obtain greater coverage of the feet, the sensor count should be increased.This will necessitate additional analog multiplexers. Increasing the resolution of the ADC from 10 bits to 12, 14, or 16, will also improve data accuracy. We utilized the readily available 5% tolerance resistors, however the accuracy of the system can be significantly increased by using <1% tolerance precision resistors.

Acknowledgements:

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