Method to Measure Plantar Perfusion

Adam Junck; Daniel Mercer; Jack Davidson; Mustakim Rahman

Schulich School of Engineering, University of Calgary

ABSTRACT

Technologies were researched to determine which, if any, were suitable for measuring blood perfusion on the plantar surface of the foot. Of the technologies explored, three were identified as promising candidates for approximating blood perfusion. Doppler Ultrasound which uses ultrasound to measure blood velocity in vessels, infrared (IR) oximetry which uses infrared light to measure concentrations of haemoglobin to determine specific oxygen content (SPO_2), and experimental microwave sensing which uses microwave antennas to measure changes in permittivity that correlate to changes in water content associated with decreased blood flow. Of the three, microwave and IR sensing were determined to be the most promising solutions to produce proofs of concept based on early testing, research, and input from advisors and sponsor. A prototype design for an IR system on a PCB was produced as well as a proof of concept demonstrating technical feasibility of the microwave sensing option.

SPONSOR

Orpyx Medical Technologies Inc.
Michael Purdy
Travis Stevens

ADVISORS

Dr. Laura Curiel
Dr. Zahra Abbasi

Adam Junck—adam.junck@ucalgary.ca
Daniel Mercer—daniel.mercer@ucalgary.ca
Jack Davidson—jack.davidson1@ucalgary.ca
Mustakim Rahman—mustakim.rahman@ucalgary.ca

INTRODUCTION

Peripheral neuropathy is a complication of diabetes that can cause lack of sensation in the extremities and particularly the feet. Without this sensation, individuals with peripheral neuropathy are at risk of developing foot ulcers without the ability to feel that they are there. Being able to measure perfusion in the feet is a critical indicator for predicting and preventing diabetic foot ulceration. The focus of this project was to research different technologies that are suited to solving this problem, and provide a proof of concept for how the technology might be implemented to measure blood perfusion in the feet.

PROCESS

Research into available technologies began with exploration into clinical procedures for measuring blood perfusion such as doppler ultrasound and pulse oximetry. We then explored experimental methods that could be leveraged to approximate blood perfusion and discovered Dr. Zahra Abbasi's research on chip-less microwave sensing. These were the three technologies that were evaluated in the next phase of the project which was initial feasibility testing. Representatives of the technology were procured to get a feel for how the technology could be implemented, risks and pitfalls associated with the technology, and suitability of the technology for solving the problem. A fetal ultrasound was purchased to evaluate doppler signals, this was used to listen to arteries and get explore the process of acquisition and processing; an infrared oximetry development kit that used the MAX30101 Heart Rate and Pulse oximetry module was purchased to test acquisition of oximetry data on the foot; and a microwave sensor was manufactured in Dr. Abbasi's lab to evaluate the microwave sensing. These tests informed the next stages of the project which involved a proof of concept for the microwave sensor design and a PCB prototype for the infrared oximetry technology. Based on results from initial testing, Ultrasound doppler was removed as an option in favour of pursing IR oximetry and microwave more diligently. A PCB implementation of an IR oximetry prototype was designed in Altium based around the MAX30101 SPO_2 and Heart Rate Sensor, and the MAX32664 Biometric Sensor Hub. Microwave proof of concept was developed through design and testing of various tissue phantoms and accompanying data collection.

RESULTS

Ultrasonic Doppler

Initial testing of the ultrasonic doppler showed potential difficulties associated with implementing it. Placement and angle of the probe is crucial in order to acquire blood velocity measurement. In addition to that, the smaller the vessel size, the lower the flow and the more difficult it is to measure. For these reasons, it was decided not to go forward with ultrasonic doppler.

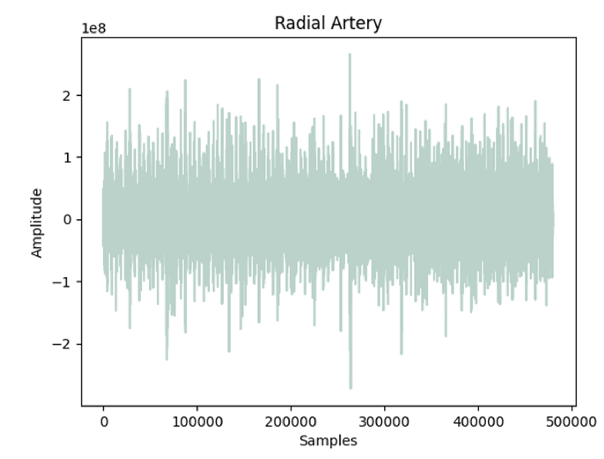

Figure 1. Ultrasound recording from radial artery.

Infrared Oximetry

Feasibility testing of IR oximetry was done using the MAX86140 which was selected because of its ease of use out of the box. This testing showed potential for measuring signals on the plantar surface but did not have the capability to measure SPO_2. Testing with the SEN15219 development board from SparkFun allowed measurement of SPO_2 values with modifications to the settings. The components on the SEN15219 were eventually incorporated into a final PCB prototype design done in Altium and printed at PCBWay.

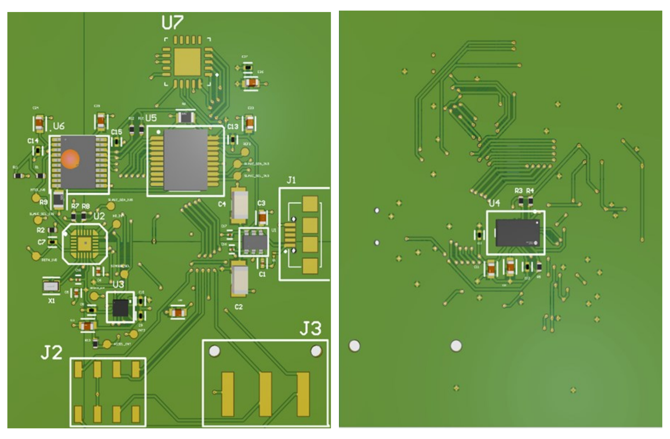

Figure 2. Finished IR PCB design.

Microwave

Testing of the microwave sensors began with manufacturing a sensor based on an existing design of Dr. Abbasi's. This sensor was able to detect small changes in water applied to a paper towel. This proved that the sensor could be a valid solution to the problem. Testing using tissue mimicking phantoms, and then ground beef and chicken skin showed that the microwave sensors were capable of detecting small changes in water volume inside tissues.

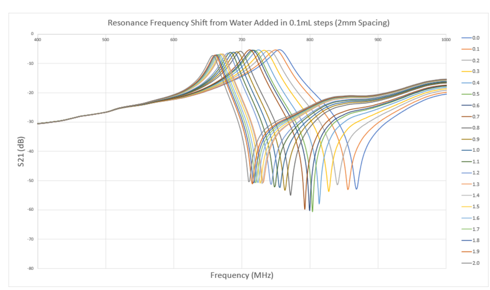

Figure 3. Graph showing the change in resonance frequency with addition of water.

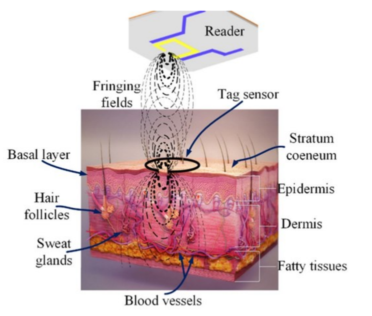

Figure 4. Image showing the interaction of microwave sensor with issue.

DISCUSSION

The solution to this problem is non trivial and has not been effectively solved before. This meant that a substantial amount of literature research and expert consultation was required at the outset of the project. Considerable effort was put into defining the project and determining potential avenues long before any design work was conducted. The original plan was to evaluate a collection of technologies and then narrow that list down to one technology that would be used to design a proof of concept prototype. There was a shift from this plan once it became apparent that there was merit in both the IR oximetry and microwave sensing options. IR represented the more documented solution with clinical uses on other parts of the body, while microwave represented a more "blue sky" solution. The microwave sensors are not commercially available and represent an area with considerable further research opportunity.

CONCLUSIONS

Preventing diabetic foot ulcers is an enormous motivation for preventing amputations. Throughout this project we researched many different technologies both experimental and with clinical precedent. We conducted effective tests to determine how well the technologies performed for our specific application. We made educated decisions about feasibility based on our test results to create a plan for moving forward. We executed that plan using knowledge that we have gained throughout our engineering education and with support and guidance from our sponsor and academic advisors. We have proven the potential for these technologies to be adapted into a system to monitor and help prevent diabetic foot ulcers. Completion of the project has provided the sponsor with valuable insight towards the further development of solutions that leverage these technologies.

REFERENCES

[1]S. Li, E. Fear, and L. Curiel, "Breast tissue mimicking phantoms for combined ultrasound and microwave imaging," Physics in Medicine & Biology, vol. 66, no. 24, p. 245011, Dec. 2021, doi: https://doi.org/10.1088/1361-6560/ac3d18.

[2] N. Barrie Smith and A. Webb, Introduction to Medical Imaging, Cambridge: Cambridge University Press, 2011.

[3] M. Baghelani, Z. Abbasi, M. Daneshmand, and P. E. Light, "Non-invasive continuous-time glucose monitoring system using a chipless printable sensor based on split ring microwave resonators," Scientific Reports, vol. 10, no. 1, Jul. 2020, doi: https://doi.org/10.1038/s41598-020-69547-1.