Global Health: Prevention of diabetic foot ulceration and amputation

Carson Gehl, Jarett Jones, Thor Larson, Jan Wodnicki, Kelson Rauser
Advisor: Dr. Willis Tompkins
Client: Ms. Kayla Huemer

Abstract

Some diabetic patients suffer from ulceration in their feet which, in an extreme, can result in amputation of the foot. In order to detect ulceration, others have employed a thermal imaging system paired with image processing software in order to detect statistically significant changes in temperature due to ulcer development. The team has been tasked with designing an imaging device along with image processing software and an algorithm for early-stage detection of ulceration. The device proposed is an insulated box that is foldable in order to increase portability. Image processing software will comprise of grayscaling and pixel extraction; the client has already performed calculations that have been implemented into an algorithm to place individuals in a class based on risk level. Integration into a mobile software for ease of use has been developed and will continue to be improved upon more data collection and testing.

Problem Statement

Motivation:

- Over 60 million in the population suffer from the disease [1]
- Diabetic patients often suffer from peripheral neuropathy as a result of diabetes, meaning that they lose feeling in their peripheries
- The repeated shear forces acting on tissue over time can cause inflammation and tissue damage, regardless of the magnitude of the forces being minimal [2]
- Many patients develop foot ulcers which, if not properly taken care of, may become infected and ultimately end in the amputation of the foot

Background:

- Thermal imaging has proven to be an effective technique in early-stage ulcer detection in diabetic patients. Specifically, research has shown notthat an increase of 2.2 ℃ is associated with the beginning of ulceration [3].
- Existing devices that utilize this temperature difference, such as temperature monitoring socks, which alert users when a given temperature threshold has been reached [4].
- A gap exists in the design of thermal imaging systems for low-resource settings. The team has been tasked with creating a thermal image acquisition device, as well as an algorithm that will be able to analyze thermal images and separate them into categories based on levels of risk for ulceration
- Goal is to create a low-cost system that will minimize the time spent by patients in clinic.

Acknowledgements

We would like to thank our client, Kayla Huemer, as well as our advisor Dr. Willis Tompkins for their continued support and design advice throughout our project.

Design Criteria

Client requirements:

- Mobile application to score thermal images for likelihood of ulcer formation
- Application should automate image analysis
- Apparatus to standardize thermal imaging
- Low-cost use in rural Indian hospital (<$150) and in-home use (<$5)
- Utilize variables such as typical ulcer location, typical ulcer size, temperature location, etc to improve accuracy
- Crowded hospitals require portability of the imaging device (easily carried with 2 hands).

Design requirements:

- Imaging device: ~$150 to be implemented in a rural hospital where cost is a main concern. May be achieved with validation of low-cost thermal camera in comparison to $315 gold standard (FLIR).
- The device needs to be able to travel overseas to India.
- Device needs prioritize sensitivity over specificity in detecting patients early-stage diabetic foot ulcers

Final Design

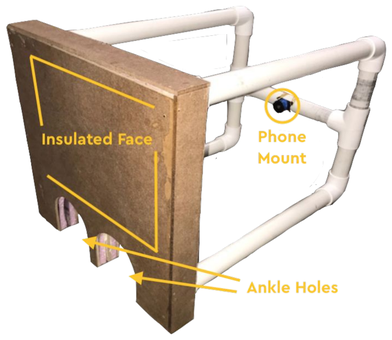


Figure Whole Box
The box includes two layers of foam with a small layer of airspace in between for insulation. The ankle slots were made large enough to accomodate any patient. A towel was added above the foot slots in order to cover any open area still remaining behind the ankles.

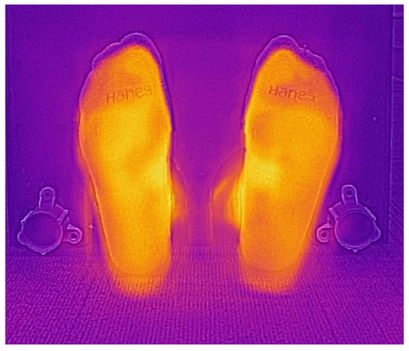


Figure Box Face (consistent background). The front face of the imaging booth was insulated with two layers of ¾” high-density foam encapsulating a pocket of air. This provides an even thermal background needed for automated analysis.

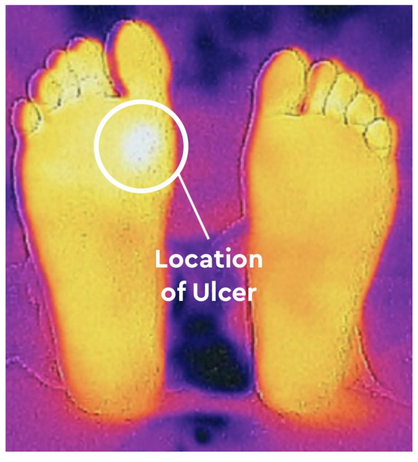


Figure IR pic of ulcer foot. A thermal image reveals a “hot spot” on the ball of the foot. This high temperature area correlates to the location of an ulcer, validating our assumption regarding the viability of thermal imaging to detect ulceration in diabetic feet.

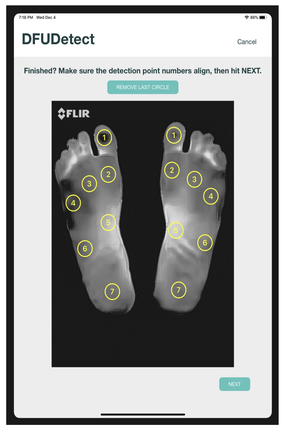


Figure App Screenshot (points selected). Application takes grayscale pictures as input and follows an analysis involving radius calculations and point selections to output ulceration risk. Data is saved to a database for future analysis.

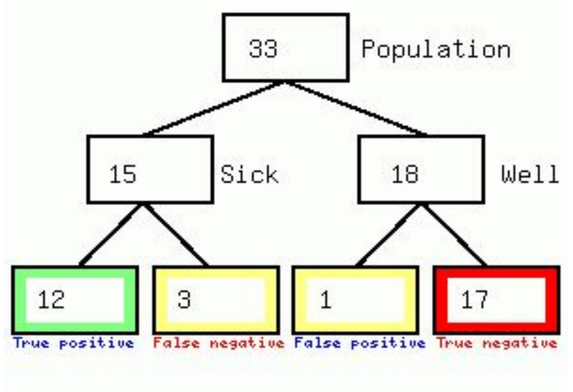
References

[1] S. Kaveeshwar, “The current state of diabetes mellitus in India,” *Australasian Medical Journal*, vol. 7, no. 1, pp. 45–48, 2014.
[2] BRAND PW (1989). Repetitive stress in the development of diabetic foot ulcers. The diabetic foot./4th edition./edited by ME Levin, LW O'Neal p83-90.
[3] Reyzelman AM, Koelewyn K, Murphy M, Shen X, Yu E, Pillai R, Fu J, Scholten HJ, Ma R “Continuous Temperature-Monitoring Socks for Home Use in Patients With Diabetes: Observational Study”, 2018.
[4] L. Fraiwan, M. Alkhodari, J. Ninan, B. Mustafa, A. Saleh, and M. Ghazal, “Diabetic foot ulcer mobile detection system using smart phone thermal camera: a feasibility study,” *BioMedical Engineering OnLine*, vol. 16, no. 1, Mar. 2017.

Progress/Results

Feasibility of Software

- Calculations carried out by client were implemented in a MATLAB code
- Client success rate of 93% in identifying patients that were at high risk
- MATLAB allowed ability to look at more accurate size of points on foot
- Tended to be on the low side due to normalizing temperatures and taking average of large amount of pixels
- Identified 80% of patients that had already ulceration
- Identified 94% of healthy patients
- MATLAB calculated scores varied from client calculated scores by average of 1.234



Future Directions

Imaging Box

- Mount phone to box
- Improve background consistency
- Correct foot orientation to avoid off-axis positioning

Imaging

- Use less expensive camera / mat alternative

Software

- Do not rely on max/min temps for normalization
- More images and data to improve accuracy
- Improve image processing and wholistic foot comparison
- Less user input

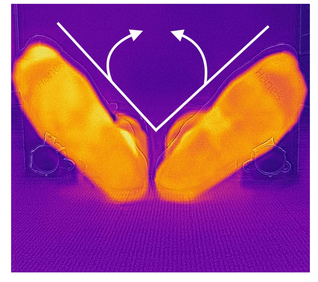


Figure Foot Rotation. Thermal image of incorrectly oriented feet. Without the ability to see the orientation of their feet, patients with neuropathy may find it difficult to correctly direct their feet for imaging.