BME Design-Spring 2020 - THOR LARSON
Complete Notebook

PDF Version generated by

JARETT JONES

on

Apr 29, 2020 @03:15 PM CDT

Table of Contents

Team contact Information

JARETT JONES - Apr 29, 2020, 12:08 PM CDT

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Project description

CARSON GEHL - Apr 04, 2020, 12:26 PM CDT

Course Number: BME 301

Project Name: Global Health: Prevention of diabetic foot ulceration and amputation

Short Name: Ulcer Detector

Project description/problem statement:

Diabetes is becoming an international epidemic with India being tagged the Diabetic capital of the world in recent years. It is estimated that anywhere from 50-90% of Indian diabetics are undiagnosed in rural areas of the country, leading to costly complications of diabetes, of which the most common is the development of a diabetic foot ulcers leading to lower limb amputation.

There is currently no way of identifying which patients are at greatest risk or on the brink of ulceration. If it was possible to identify and perhaps predict which patients are at greatest risk for developing an ulcer, healthcare costs and the incidence of amputation could greatly be reduced. The client, through a thermal imaging study of over 250 patients feet in India, has shown that thermal imaging could be used to reveal which diabetic patients had patches of inflammation perhaps indicating an impending ulcer. Primitive data analysis of the images shows that this could be a novel method of determining which patients are on the brink of ulceration, and implementations of AI algorithms could further strengthen the interpretation and predictive power of these images.

The client proposes a thermal device to streamline a way of measuring temperature from the feet of diabetic patients to serve as a diagnostic tool in Indian hospitals as well as an app-based software to further interpret the images collected by the client as well as the thermal maps that the team will collect with their instrumentation. Specifically, the client would like to develop an artificially intelligent algorithm to be able to categorize which patients are at greatest risk of ulceration based on the thermal scans of their feet.

About the client:

Kayla Huemer is a recent graduate of the UW - Madison BME department; she now works as an engineer at Exact Sciences in Madison. During her undergraduate studies, Kayla traveled to India as a SN Bose Scholar to work on medical research abroad. This led her to go on and work in India following her graduation on a Fullbright Fellowship. She began developing prototypes to aid in ulcer prevention as it relates to diabetes. She has now brought her work to us to continue the project in hopes of creating a diagnostic tool for diabetic foot ulceration.

2/3/20 - Client Meeting 1

THOR LARSON - Feb 03, 2020, 6:35 PM CST

Title: Client Meeting 1

Date: 2/3/20

Content by: Thor Larson

Present: Team

Goals: Record notes on the first client meeting of the semester.

Content:

Reflection for the past semester:

- Focus on conveying the statistics better in future presentations later in the semester
- Last semester there wasn't a seamless way of going between the box/picture to the app/analysis

New direction for this semester:

- Could stay with the FLIR camera and recreate a native FLIR app to work with our algorithms
- Could make a homemade IR system with bluetooth Arduino that would remote take a picture and analysis would be on the mobile app

Additional thoughts:

- Think about privacy/security concerns with collecting data during research
- Homemade IR system would allow the team to have more design opportunities
- Think about voltage changes between America and India --> do research

Conclusions/action items:

- Work on the PDS with the team
- Split up future tasks among the team
- Start researching on Arduino IR components

02/14/20

TAMARIN TANDRA - Apr 10, 2020, 2:02 PM CDT

Title: Advisor Meeting 3

Date: 02/14/20

Content by: Tamarin Tandra

Present: All

Goals: Picking out sensors, design matrix, preliminary presentation preparation

Content:

- Find more details (accuracy might not be for the whole temperature range)

- There might be other sensors with narrower temperature range but more accuracy (because we are measuring difference)

- MLX90640 that we are looking at has decent accuracy of 1^{o}C in 0-100^{o}C operating temperature.

- Design matrix based on thermal sensors.

- Practice preliminary presentation together as a group.

Conclusions/action items:

3/27/20

CARSON GEHL - Apr 04, 2020, 12:13 PM CDT

Title: Advisor Meeting

Date: 3/27/20

Content by: Carson Gehl

Present: All

Goals: Establish new plan going forward due to campus shutdown

Content:

We determined we could still get a lot done this semester with the given situations. It sounds like we will be able to get a hold of the department FLIR camera which we can then use for testing with our camera. Getting some images and being able to perform some testing of our camera will be the main priority for the rest of the semester.

Conclusions/action items:

Find out who needs to do what and divide tasks. Also try and get the FLIR camera from Dr. P.

4/3/20

CARSON GEHL - Apr 04, 2020, 12:18 PM CDT

Title: Advisor Meeting

Date: 4/3/20

Content by: Carson Gehl

Present: All

Goals: Run over testing plans; touch base.

Content:

Sounds like we will be able to get the FLIR camera from Dr. P, but Dr. Rogers will have to deliver it from Dr. P to us. Should hopefully have sometime early next week. Also went over some ideas for a testing plan:

- Compare accuracy and precision of our camera to FLIR camera. Can test for actual temperature readings and additionally the ability of our camera to detect the 2.2 degree Celsius difference in foot temperature.

- Another idea is to use something like a series of metal cans and put water in them with varying temperature levels. Measure the temperature of the water with some sort of thermometer and then take a picture of all the cans with our camera and see how it compares.

Conclusions/action items:

Get FLIR camera from department and start taking some images. Thor and Tamarin should communicate on getting the raspberry pi + camera together. One of them will also need to get the FLIR camera when possible as Jarett and I are not in town.

04/10/20

TAMARIN TANDRA - Apr 10, 2020, 2:00 PM CDT

Title: Advisor Meeting

Date: 04/10/20

Content by: Tamarin Tandra

Present: All

Goals: Talk about our progress this week (testing plans, poster preparation)

Content:

- We have successfully acquire the department's FLIR camera to aid in testing.

- Various surface can give us various contrasts --> can be a problem in testing.

- We can proceed with our current testing protocol as long as we can keep everything constant.

- For poster presentation: Making an actual poster is preferable but if not possible we can make it into powerpoint format.

- Some components that "should" have happened this semester can be put into future work in greater detail. --> part of grading

Conclusions/action items:

04/17/20

TAMARIN TANDRA - Apr 17, 2020, 2:20 PM CDT

Title: Advisor Metting

Date: 04/17/20

Content by: Tamarin Tandra

Present: All

Goals: Finish testing, data analysis, working on poster presentation

Content:

Screen resolution: correlates to the number of pixels

Temperature resolution: the smallest change in temperature that can be detected by the camera

- Take images as something is cooling then you have bunch of different temperature point.
- Different temperature might give you different resolution (for example 200^{o}C may give you different resolution).

Testing methods:

1. How close it is to the thermometer à give you accuracy
2. Heating different temperatures and capture à give you precision
3. The ability to see a difference if temperature is changed to a degree à give you resolution

- If you put it to grayscale mode, it has gray level. Each gray level corresponds to a change in temperature.
- See how much change in temperature that you have to make to see a change in color.
- Can take several measures, put it in a graph and see the linear correlation / slope.

Conclusions/action items:

Design Materials

JARETT JONES - Apr 29, 2020, 12:01 PM CDT

Title: Design Materials

Date: 04 - 29 - 20

Content by: Jarett Jones

Present: N/A

Goals: Outline the materials that were utilized throughout the design process.

Content:

Image Capturing Materials:

Thermal imaging was done using an MLX90640 camera coupled with a standard Raspberry Pi. Additionally, USB-C power supply was necessary for the Raspberry Pi microcontroller. Connections at microcontroller pinouts were done using a Qwiic adapter and a breadboard jumper. Lastly, in future semesters we hope to create a casting to house the camera and microcontroller, this casting will likely be printed using polyactic acid.

Imaging Studio Materials:

The imaging studio, used for standardizing the image capturing process was constructed. Materials necessary for this construction included 1/4" thick particle board for the face of the box, construction adhesive, half-inch polystyrene foam (insulation). These materials were used in construction of the face of the imaging studio to achieve standard temperature background. Lastly, 1.25" diameter PVC pipes were purchased as supports for the imaging studio.

Conclusions/action items:

Outlining the materials that were utilized throughout the design process is necessary to document progress, purchasing, and to aid in future replication of designs. Additionally, this information will be essential to include in the final deliverables.

Material Expenses

TAMARIN TANDRA - Apr 29, 2020, 12:01 PM CDT

Title: Materials Expenses

Date: 29 April 2020

Content by: Tamarin Tandra

Present: N/A

Goals: To document the total expenses for this semester's design

Content:

[redacted]

Thermal Imaging							
MLX90640 110_{o} FoV	Used for thermal imaging	Sparkfun	SEN-14843	02/23/20	1	$69.95	$69.95
Qwiic Adapter	Used for adapter	Sparkfun	DEV-14495	02/23/20	1	$1.50	$1.50
Qwiic Cable - Breadboard jumper	Used for connection	Sparkfun	PRT-14425 ROHS	02/23/20	3	$1.50	$4.50
Tax (5.5%)							$4.19
Raspberry Pi 3 Model B+ Project Board	Used as microcontroller	Amazon		03/02/20	1	$42.00	$42.00
Motor Apparatus							
Linear Sliding Guideway (400 mm)	Used as sliding rail	Amazon		03/02/20	1	$21.99	$21.99
GT2 timing belt + wheels	Used for nonslip rotation	Amazon		03/02/20	1	$8.99	$8.99
Bottom drawer slider	Used for slider for the box	Grainger	1HEV9	03/02/20	1	$8.55	$8.55
L293D Dual H-Bridge Motor Driver	Chips that control DC step motor	Newark	53W6277	03/02/20	1	$2.95	$2.95
Stepper motor with cable	Used for control	Sparkfun	ROB-09238 ROHS	03/02/20	1	$15.95	$15.95
TOTAL:							**$180.57**

Conclusions/action items:

The total cost for this semester is $180.57. However, a lot of the purchased materials were unused since we didn't have access to several machinery. These can be retained for next semester.

4/14/20 Testing Protocol

CARSON GEHL - Apr 14, 2020, 5:33 PM CDT

Title: Testing Protocol

Date: 4/14/20

Content by: Carson Gehl

Present: N/A

Goals: Outline the procedure we plan on using for testing

Content:

Accuracy Test

If a thermometer is available, use it as a control; otherwise, use the FLIR camera as a control. Heat up 5 cans or cups of water to varying temperatures of 10 degrees Celsius, 20 degrees Celsius, 30 degrees Celsius, and 40 degrees Celsius. If a thermometer is available, measure the temperature of each sample. Take a picture with the FLIR camera as well as with the MLX + raspberry pi camera. Sample at least 5 pixels to determine the average temperature of the water from each image as well as standard deviations; this will allow for a comparison of the accuracy of the camera.

Specificity Test

Heat 5 cans or cups of water so that their temperature differences are as close to 2.2 degrees Celsius as possible. The temperatures should also be as close to typical bodily temperatures as possible (i.e. one can/cup should be close to 35 degrees Celsius, another should be close to 37.2 degrees Celsius, etc). If a thermometer is available use that as a control.Take an image with the MLX + raspberry pi as well as with the FLIR and sample at least five pixels from each can/cup to determine average temperature values and standard deviations. If successful, there will be a difference of 2.2 degrees Celsius between each sample with minimal error.

Conclusions/action items:

Get to testing (the team has planned to meet tomorrow, 4/15/20 via zoom)

04/18/20 FLIR Water Testing

TAMARIN TANDRA - Apr 29, 2020, 3:15 PM CDT

Title: FLIR Water Testing

Date: 18 April 2020

Content by: Tamarin Tandra

Present: N/A

Goals: To show how the thermal images were processed to get the temperature data

Content:

As described by the Testing Protocol, water was heated to a certain temperature degree and pictures were taken with the FLIR camera. They were then converted to grayscale and the temperature of a point was calculated using MATLAB code.

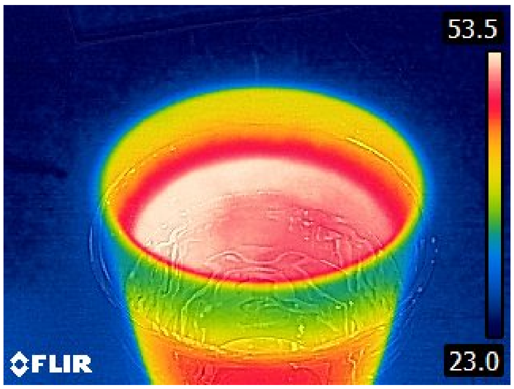


Figure 1: Thermal image captured by FLIR

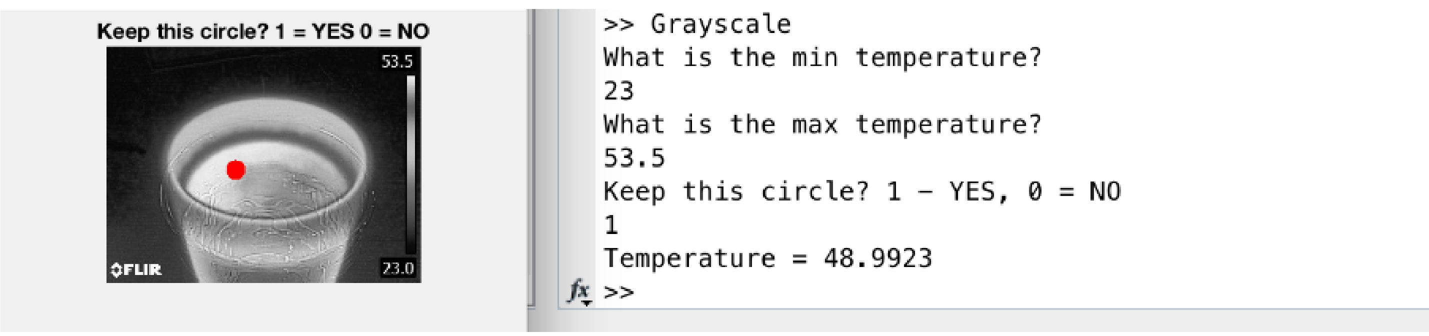


Figure 2: Thermal image processed in MATLAB

Conclusions/action items:

Taking an average temperature of the whole water surface instead of a single point may improve the accuracy of the measurement. This can be done by modifying the MATLAB code.

4/18/20 FLIR Ulcer Testing

CARSON GEHL - Apr 29, 2020, 12:02 PM CDT

Title: FLIR Ulcer Testing

Date: 4/18/20

Content by: Carson Gehl

Present: N/A

Goals: Test spatial resolution of FLIR camera by simulating ulcers on feet

Content:

Jarett took nine pictures with the FLIR E5 in which he simulated an ulcer by heating up a coin in 49 degree water for either 1, 3, or 5 minutes and then pressing it against his foot in three different hotspots on the foot (1st metatarsal, 5th metatarsal, and heel). He then had an image taken of his feet. I used MATLAB code to detect the difference in temperature from the hotspot on one foot to that same spot on the opposite foot. From the nine images, an average temperature difference of 2.89 +/- 0.76 degrees Celsius was detected.

Conclusions/action items:

We are quite pleased with the ability of the FLIR camera to detect hotspots on the foot, thus demonstrating excellent spatial resolution.

2/26/20 - MLX90640 Thermal Camera

THOR LARSON - Feb 26, 2020, 9:18 AM CST

Title: MLX90640 Thermal Camera

Date: 2/26/20

Content by: Thor Larson

Present: Individual

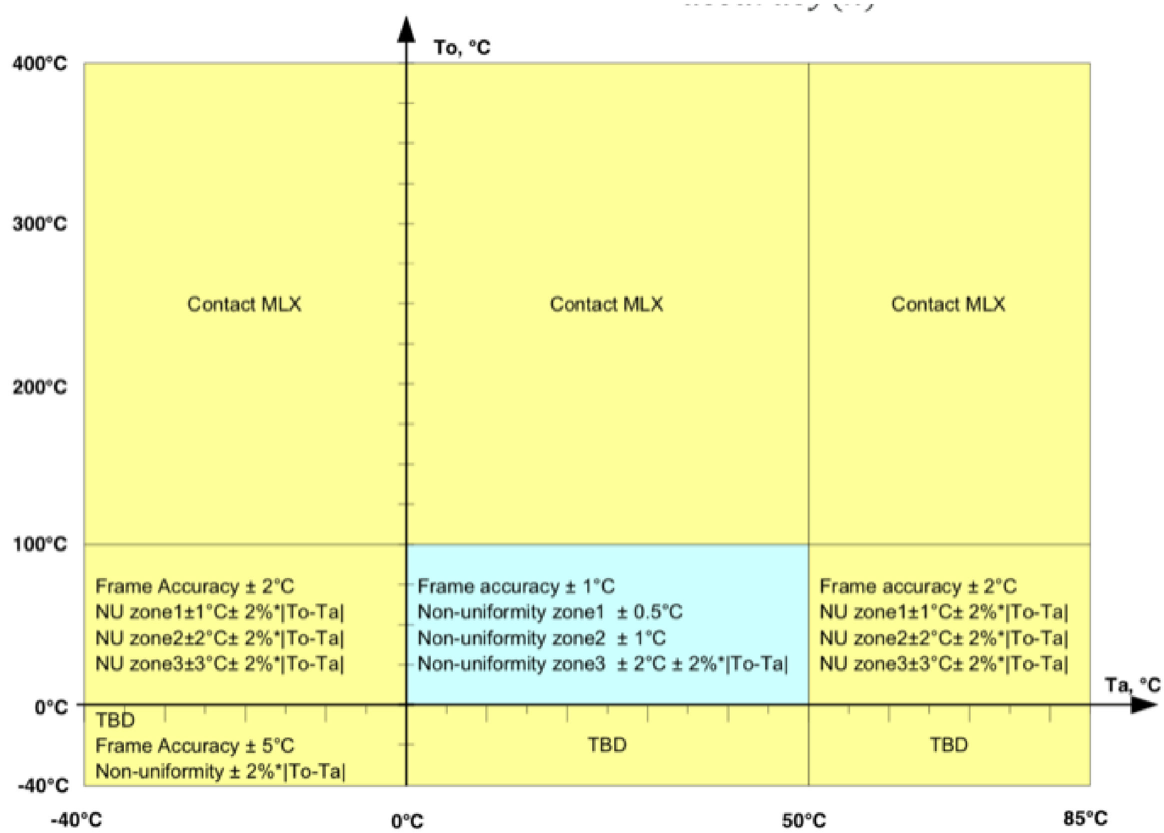
Goals: Compile research on the MLX90640 Thermal camera, a proposed option for the thermal camera module for the project

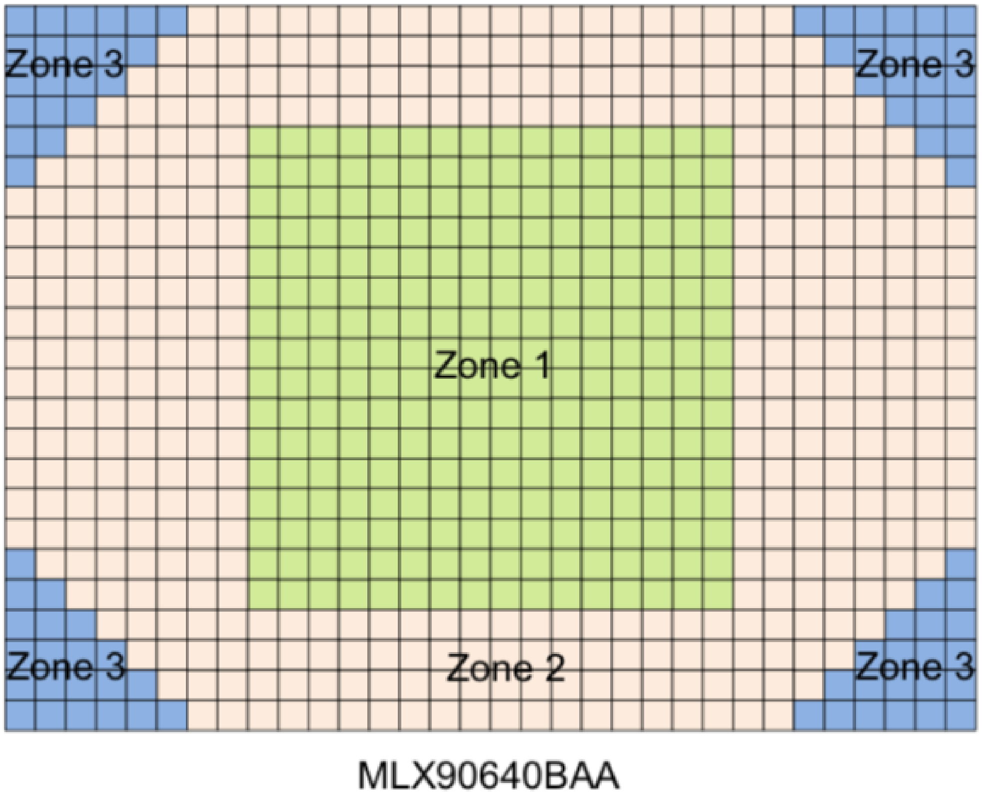
Content:

Link: https://www.adafruit.com/product/4469

Technical Specifications --> Attached PDF data sheet

- *Cost: ~$60*
- *Resolution*: 24 x 32 array, 768 individual infrared temperature readings





- Image can be accurate up to ±0.5°C in Zone 1 in the range of 0-100°C
- Measure temperatures ranging from -40°C - 300°C, ±1.5°C from 0-100°C --> need to expand on the exact resolution
- Uses I2C communication protocol --> research more on how this works
- 3.3-5V supply voltage
- Current consumption less than 23mA

12.4. Field of view (FOV)

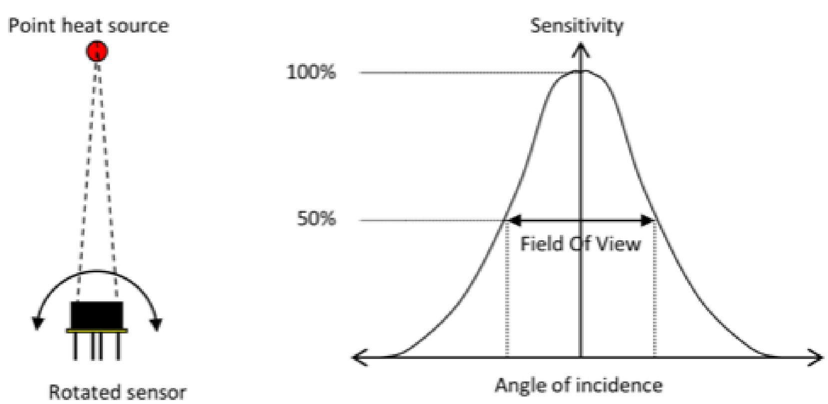


Figure 24 Field Of View measurement

The specified FOV is calculated for the wider direction, in this case for the 32 pixels.

FOV	X direction	Y direction	Central pointing from normal (X & Y direction)
	Typ	Typ	Max
MLX90640-ESF-BAA	110°	75°	5°
MLX90640-ESF-BAB	55°	35°	3°

Table 15 Available FOV options

- Two models: 110°x70° field of view, narrower 55°x35° field of view --> should research which is the better model for visualization

- Able to be interfaced with Raspberry Pi with Python libraries

Conclusions:

This camera seems to be the most ideal and the best in terms of resolution vs cost as it is significantly less expensive than the thermal camera but the resolution and accuracy is much better than other thermal cameras on a price scale. This is currently my proposed thermal camera module but it should be evaluated in a design matrix with other options.

Action items:

- Research other thermal camera modules
- Research I2C communication protocol and how this would work with a Raspberry Pi
- Research more with the different FOV models to determine which is the best for visualization purposes

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THOR LARSON - Feb 26, 2020, 9:03 AM CST

MLX90640 32x24 IR array

Datasheet

1. Features and Benefits

- Small size, low cost 32x24 pixels IR array
- Easy to integrate
- Industry standard four lead TO39 package
- Factory calibrated
- Noise Equivalent Temperature Difference (NETD) 0.1K RMS @1Hz refresh rate
- I²C compatible digital interface
- Programmable refresh rate 0.5Hz…64Hz
- 3.3V supply voltage
- Current consumption less than 23mA
- 2 FOV options – 55°x35° and 110°x75°
- Operating temperature -40°C ÷ 85°C
- Target temperature -40°C ÷ 300°C
- Complies with RoHS regulations

2. Application Examples

- High precision non-contact temperature measurements
- Intrusion / Movement detection
- Presence detection / Person localization
- Temperature sensing element for intelligent building air conditioning
- Thermal Comfort sensor in automotive Air Conditioning control system
- Microwave ovens
- Industrial temperature control of moving parts
- Visual IR thermometers
- Driver software for MCU available at:

3. Description

The MLX90640 is a fully calibrated 32x24 pixels thermal IR array in an industry standard 4-lead TO39 package with digital interface.

The MLX90640 contains 768 FIR pixels. An ambient sensor is integrated to measure the ambient temperature of the chip and supply sensor to measure the VDD. The outputs of all sensors IR, Ta and VDD are stored in internal RAM and are accessible through I²C.

Figure 1 Block diagram

MLX90640-Datasheet-Melexis.pdf(2.3 MB) - download

2/26/20 - Sensor data to Firebase

THOR LARSON - Feb 26, 2020, 9:32 AM CST

Title: Sensor data to Firebase

Date: 2/26/20

Content by: Thor Larson

Present: Individual

Goals: Compile research on sending thermal imaging data to our Firebase Database created last semester

Content:

Link: https://www.hackster.io/varuldcube100/send-sensor-data-to-firebase-real-time-database-4d6b83

Summary

- Tutorial shows how to send temperature and humidity sensor data to a Firebase Database using a Raspberry Pi
- Sensor communication is using the I2C protocol which is similar to the MLX90640 that our team will be using
- Setup uses python which was also our proposed software language for the pre-processing on Raspberry Pi
- Sensor data is stored in JSON format on the Firebase Database

Conclusions:

This tutorial will be extremely helpful when connection the MLX90640 and Raspberry Pi to our database and shows that it is possible to do so and means that we can keep the same database that we used last semester which is extremely useful.

Action items:

- Research how the Raspberry Pi can read data from the database to perform programmatic actions that control electronic components
- Research how to integrate the mobile application into the workflow

2/26/20 - Read mobile app data on Raspberry Pi

THOR LARSON - Feb 26, 2020, 9:59 AM CST

Title: Read mobile app data on Raspberry Pi

Date: 2/26/20

Content by: Thor Larson

Present: Individual

Goals: Compile research on backwards connection between Mobile Application and Raspberry Pi where Raspberry Pi reads data

Content:

Link: https://www.hackster.io/ahmedibrrahim/iot-using-raspberry-pi-and-firebase-and-android-dbe61d

Summary:

- This tutorial describes how to control a RGB LED Strip light wirelessly over wifi using an Android application, Raspberry Pi, and Firebase
- The Raspberry Pi is running a python script that read incoming data from the database and based off this data performs different actions
- Describes the best way to handle power management on the electronic side
- Mobile app and Raspberry Pi board are connected to the same database which saves data that can be synced to both entities simultaneously
- Tutorial describes how to turn on LED lights and control the light intensity with GPIO PWM
    - Our project would simply record the image from the camera when the user presses a button on the mobile application
- Describes the Pyrebase Module --> python wrapper for using Firebase on a Raspberry Pi
- Fully explains retrieving data from Firebase and performing an action on the content of that data

Conclusions:

This tutorial will be an extremely useful reference for retrieving data from Firebase on the Raspberry Pi. This tutorial, combined with a a previous tutorial describing sending sensor data to firebase should provide most of the instruction to achieving the bidirectional flow of information that is needed for this project.

Action items:

- Start implementing these tutorials in an actual design when all electronic components arrive
- Start designing Firebase database structure to read and write data
- Write authentication rules for Firebase so the mobile application and the Raspberry Pi can both be used without any security problems

2/26/20 - Previous Semester Analysis

THOR LARSON - Feb 26, 2020, 8:26 AM CST

Title: Previous Semester Analysis

Date: 2/26/20

Content by: Thor Larson

Present: Individual

Goals: Compile thoughts on evaluation of previous semester

Content:

Previous Semester

- FLIR-One camera was used with a Samsung phone that took high quality thermal images
- An imaging studio was developed that provided a near consistent thermal background with the exception of the bottom of the foot
- IOS Application was developed that allowed for image upload and subsequent selection of points on the foot to analyze
- **Pros**
    - The FLIR-One camera provided high quality thermal images that were trusted in accurately giving us the required data needed
- **Cons**
    - The major flaw of the system was with getting the images from the FLIR-One into the phone application
    - The above process included:
        - attaching the FLIR + phone to the imaging studio
        - manually taking the image
        - physically remove FLIR + phone from imaging studio
        - recording the min and max temp of the photo
        - uploading photo to google drive or some cloud based storage
        - retrieving image and min and max data from google drive or cloud storage and saving to mobile application
        - finally upload that image and start analyzing
    - This is not only cumbersome but also doesn't allow an easy way to keep the patient information with the corresponding thermal image
    - FLIR-One native app was difficult to work with and develop
    - Battery charge for FLIR-One + phone system was very short, required separation of components to charge them
    - FLIR-One was expensive ~$399

Conclusions:

It is obvious from listing out the Pros and Cons from the last semester that a new direction is needed that steers away from using the FLIR-One camera. My initial proposal would be to make a custom built thermal camera that removes a lot of the difficulty with transferring the thermal image from the camera to the mobile application. The new system would also have the ability to not be removed from the imaging studio to transfer images. A custom built camera could also be a lot less expensive. A possible drawback would be the decreased resolution/accuracy that would be achieved with a less expensive thermal camera so comparing the new system and the FLIR-One would be ideal for proving efficacy.

Action items:

- Brainstorm possible ideas for a custom thermal camera system
- What else besides a thermal camera would be needed? Micro-controller? Other electronic components?
- How would a custom thermal camera send images to mobile application?

2/26/20 - Custom Thermal Camera

THOR LARSON - Feb 26, 2020, 8:47 AM CST

Title: Prelim Custom Thermal Camera

Date: 2/26/20

Content by: Thor Larson

Present: Individual

Goals: Compile preliminary ideas on how a custom thermal imaging system would work

Content:

Possible Components

- Thermal Camera
  - Imaging system would consist of a thermal camera preferably less expensive then the FLIR-One model (significantly less than $399)
  - Would need to be accurate to at least less than 2 degree Celsius as 2.2 degrees is the measurable difference parameter that indicates a foot ulcer
  - Would not need to use the same technology as the FLIR-One camera in regards to collecting thermal data --> research different thermal imaging processes to compare
  - Ideally interface nicely with a micro-controller
- Micro-Controller
  - Would need to handle complex processes of the thermal camera and preliminary processes
  - Capacity to handle multiple sensors and possible store images as local storage for backup
  - Connect via wifi or bluetooth to the mobile application or an intermediate database --> would we need a wifi chip?
- Battery + Battery Charger
  - Battery within the imaging system that would connect to the micro-controller to power without any plugins
  - Battery should ideally last a full day of continuous use, possibly consider an exchangeable battery
  - Battery charger should charge relatively quickly, extra charger if using the exchangeable battery method
- Color Image camera
  - If resolution is low on thermal camera it could be beneficial to include a low cost camera that overlays onto the thermal images for segmentation purposes
  - Would ideally record real time video that could output to either the mobile application or display on imaging studio for alignment purposes
  - Would need to send this data via bluetooth or wifi connection from the micro-controller
  - Would need to adjust for distance differences with two cameras --> possibly research how this would be accomplish with shifting image based on location of cameras
- LCD display
  - Used for displaying real time video of RGB camera that was describes above
  - Would not need to be high quality as just for alignment purposes
  - Would not be needed if the video could be outputted to the mobile application instead of a display on the imaging studio
- SD card for local storage?
- Button --> taking the image, would not be used if image could be triggered remotely
- Switch --> turning entire system on

Conclusions:

I think compiling my thoughts on what electronic components would be needed to accomplish a custom thermal camera will be helpful in research for these specific components. I brought up a few things that are going to be important to consider when buying specific components and which ones will be needed/not needed depending on how the system is built.

Action items:

- Research possible thermal camera modules that are low cost and high quality, compare and contrast different cameras
- Research different thermal imaging processes to compare FLIR process to others
- Is it possible to achieve higher resolution with a lower resolution thermal camera using software to analyze the images
- Research possible micro-controllers that could handle the processes required.
- Should the system use bluetooth or wifi for data transfer? Would we need a separate component to add these capabilities? Integrated into micro-controller?

- Explore different battery options, how would exchangeable batteries work?
- Research possible color image cameras.
- Is shifting image based on small distance between thermal and color camera be possible/effective for image overlay?
- Research different image displays.
- Can live video be streamed via bluetooth or wifi?
- How will data be transferred/stored? Will a local storage backup be necessary?

2/26/20 - Bidirectional Flow, Raspberry Pi + Database + Mobile App

THOR LARSON - Feb 26, 2020, 10:17 AM CST

Title: Bidirectional Flow, Raspberry Pi + Database + Mobile App

Date: 2/26/20

Content by: Thor Larson

Present: Individual

Goals: Compile design thoughts on bidirectional communication between micro-controller and mobile application via online database

Content:

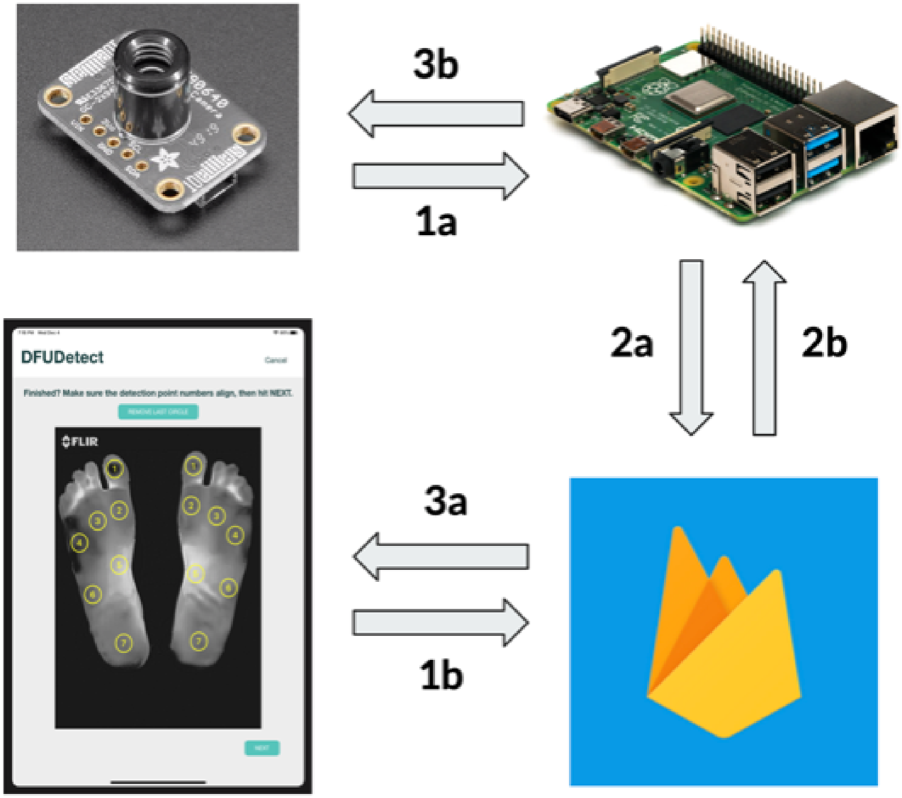
*** See research document tutorial describing how to read sensor data over I2C and send it to Firebase through a Raspberry Pi, and tutorial for reading database data form mobile app on Raspberry Pi

Summary:

- Most of the research performed has led to using the Raspberry Pi as our micro-controller for its ability to interface with the Firebase Database
- We have already created the database last semester and it was used to store information from our mobile application

Bidirectional Data Flow:

- *Forward Flow (A)*
    - (1) MLX90640 will send data that will be read and interpreted by the Raspberry Pi via the I2C communication protocol
    - (2) Raspberry Pi will send thermal data to Firebase via Pyrebase software
    - (3) Mobile IOS application will retrieve the thermal data from Firebase, display it, and perform any image processing algorithms
- *Backward Flow (B)*
    - (1) Mobile application will contain interface to select when to take a picture, upon press, command will be sent to Firebase, a functional data value will change
    - (2) Raspberry will constantly monitor database changes, detect when functional data value has changed
    - (3) Upon data detection, Raspberry Pi will programmatically instruct MLX90640 to take an image
- Other uses
    - This software flow method could be used will multiple different electronic components and sensors
    - All sensors could be controlled from the mobile application using functional data values stored in Firebase



Conclusions:

This method completely alleviates the difficulty of modifying electronics to turn on and off and other tedious functions. This method moves all control to the centralized mobile application making the process smooth and easy to use.

Action items:

- Implement this software flow once electronics arrive
- Can begin programming the functional data values and structuring the database

4/28/20 Camera Linear Actuator

THOR LARSON - Apr 29, 2020, 2:31 PM CDT

Title: Camera Linear Actuator

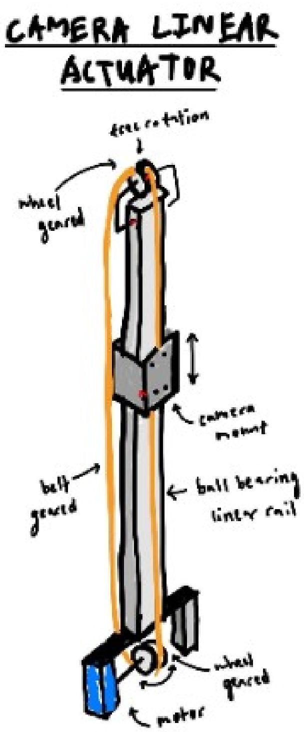
Date: 4/28/20

Content by: Thor Larson

Present: Individual

Goals: Compile thoughts on the panning the camera across the feet

Content:



- The MLX camera would be panned vertically along both feet with images taken at multiple points via a linear actuator system
- Camera movement would be controlled via a stepper motor attached to a GT2 belt with camera position ultimately controlled through the Raspberry Pi (RP) by moving the camera along a vertical linear rail
- Images would be stitched together post processing either on the raspberry pi or the mobile application
- Would need some sort of feature extraction from the foot or exact position calibration to stitch the image perfectly

- **Benefit to the project**
  - Taking multiple images with the thermal camera would increase the resolution of the camera
  - Previous entries show that the camera is more sensitive in the center of the FOV so this would maximize the amount of the foot that is within this thermally sensitive region
  - Increased resolution would also help to identify smaller localized changes in temperature which is important in ulcer detection

Conclusions/action items:

- Further discuss this design with the team and possibly pursue it if we have time
- Figure out mechanisms for feature extraction

- Look more into image stitching post processing

4/28/20 Setting up the Raspberry Pi

THOR LARSON - Apr 29, 2020, 2:38 PM CDT

Title: Setting up the Raspberry Pi

Date: 4/28/20

Content by: Thor

Present: Individual

Goals: Document fabrication process

Content:

- This was my first time using the Raspberry Pi so the entire ecosystem was something new to me
- I mainly followed the Raspberry Pi setup online found below
    - https://projects.raspberrypi.org/en/projects/raspberry-pi-getting-started
- Once I purchased the SD Card and the USB-C power supply for the raspberry pi I installed Raspbian OS

- Additionally did not have a mini HDMI cord to hook up the RP to its own monitor so I had to connect the RP headless
- This meant I was either using a remote desktop to access and control the RP over local wifi
- Or I was using SSH to control the RP through a local terminal using PUTTY on windows
- Below was one of the tutorials I used to get started with this
    - https://www.raspberrypi.org/documentation/configuration/wireless/headless.md

Conclusions/action items:

- Get started with hooking up the MLX90640 once that arrives

4/28/20 MLX vs Pimoroni Libraries

THOR LARSON - Apr 29, 2020, 3:06 PM CDT

Title: MLX vs Pimoroni Libraries

Date: 4/28/20

Content by: Thor

Present: Individual

Goals: Document fabrication process

Content:

- The documentation for connecting the MLX90640 on the Raspberry Pi was not very extensive and much of it was trial and error using the python wrappers provided in the Melexis and Pimoroni documentation pages

- Pimoroni --> https://github.com/pimoroni/mlx90640-library
- Melexis --> https://github.com/melexis/mlx90640-library

- The Pimoroni library was much more helpful in initial testing the the MLX once it was hooked up but a lot of the code was not accessible to be modified in any way however I believe this library would have been the best in the long run
- The Pimoroni library is just an extension of the Melexis library so the Melexis library is really provided the inherent functions used to read data
- This made the Melexis library more helpful in getting a smaller understanding of how the MLX worked but it was difficult to follow as the documentation was quite limiting

- Ended up getting thermal readout and color representation in the SSH terminal of the raspberry pi
- The below code was able to read in thermal data and display color pixels in a 32 x 24 array in the terminal corresponding the temperature
- I was not able to read out the actual temperature of each picture or take a snapshot and store it on the raspberry pi but I believe this is a good starting point

```
#include <stdint.h>
#include <iostream>
#include <cstring>
#include <fstream>
#include <chrono>
#include <thread>
#include "headers/MLX90640_API.h"

#define ANSI_COLOR_RED "\x1b[31m"
#define ANSI_COLOR_GREEN "\x1b[32m"
#define ANSI_COLOR_YELLOW "\x1b[33m"
#define ANSI_COLOR_BLUE "\x1b[34m"
#define ANSI_COLOR_MAGENTA "\x1b[35m"
#define ANSI_COLOR_CYAN "\x1b[36m"
#define ANSI_COLOR_NONE "\x1b[30m"
#define ANSI_COLOR_RESET "\x1b[0m"

//#define FMT_STRING "%+06.2f "
#define FMT_STRING "\u2588\u2588"
```

```
#define MLX_I2C_ADDR 0x33

int main(){
int state = 0;
printf("Starting...\n");
static uint16_t eeMLX90640[832];
float emissivity = 1;
uint16_t frame[834];
static float image[768];
float eTa;
static uint16_t data[768*sizeof(float)];

std::fstream fs;

MLX90640_SetDeviceMode(MLX_I2C_ADDR, 0);
MLX90640_SetSubPageRepeat(MLX_I2C_ADDR, 0);
MLX90640_SetRefreshRate(MLX_I2C_ADDR, 0b010);
MLX90640_SetChessMode(MLX_I2C_ADDR);
//MLX90640_SetSubPage(MLX_I2C_ADDR, 0);
printf("Configured...\n");

paramsMLX90640 mlx90640;
MLX90640_DumpEE(MLX_I2C_ADDR, eeMLX90640);
MLX90640_ExtractParameters(eeMLX90640, &mlx90640);

int refresh = MLX90640_GetRefreshRate(MLX_I2C_ADDR);
printf("EE Dumped...\n");

int frames = 30;
int subpage;
static float mlx90640To[768];
while (1){
state = !state;
//printf("State: %d \n", state);
MLX90640_GetFrameData(MLX_I2C_ADDR, frame);
// MLX90640_InterpolateOutliers(frame, eeMLX90640);
eTa = MLX90640_GetTa(frame, &mlx90640);
subpage = MLX90640_GetSubPageNumber(frame);
MLX90640_CalculateTo(frame, &mlx90640, emissivity, eTa, mlx90640To);

MLX90640_BadPixelsCorrection((&mlx90640)->brokenPixels, mlx90640To, 1, &mlx90640);
MLX90640_BadPixelsCorrection((&mlx90640)->outlierPixels, mlx90640To, 1, &mlx90640);

printf("Subpage: %d\n", subpage);
//MLX90640_SetSubPage(MLX_I2C_ADDR,!subpage);

for(int x = 0; x < 32; x++){
for(int y = 0; y < 24; y++){
//std::cout << image[32 * y + x] << ",";
float val = mlx90640To[32 * (23-y) + x];
if(val > 99.99) val = 99.99;
if(val > 32.0){
```

```
printf(ANSI_COLOR_MAGENTA FMT_STRING ANSI_COLOR_RESET, val);
}
else if(val > 29.0){
printf(ANSI_COLOR_RED FMT_STRING ANSI_COLOR_RESET, val);
}
else if (val > 26.0){
printf(ANSI_COLOR_YELLOW FMT_STRING ANSI_COLOR_YELLOW, val);
}
else if ( val > 20.0 ){
printf(ANSI_COLOR_NONE FMT_STRING ANSI_COLOR_RESET, val);
}
else if (val > 17.0) {
printf(ANSI_COLOR_GREEN FMT_STRING ANSI_COLOR_RESET, val);
}
else if (val > 10.0) {
printf(ANSI_COLOR_CYAN FMT_STRING ANSI_COLOR_RESET, val);
}
else {
printf(ANSI_COLOR_BLUE FMT_STRING ANSI_COLOR_RESET, val);
}
}
std::cout << std::endl;
}
//std::this_thread::sleep_for(std::chrono::milliseconds(20));
printf("\x1b[33A");
}
return 0;
}
```

Conclusions/action items:

- Continue to play with the MLX and try to write personal program to extract temperature data

4/28/20 Problems with the MLX

THOR LARSON - Apr 29, 2020, 3:00 PM CDT

Title: Problems with the MLX

Date: 4/28/20

Content by: Thor

Present: Individual

Goals: Document fabrication process

Content:

- The MLX worked previously with the Pimironi library as discussed in prior entries
- After continued development the board stopped outputting data
- Found that the I2C communication protocol was impaired
    - Using the i2cdetect command usually is used to verify that the sensor is connected to the write slave address
    - When calling i2detect after the board stopped working the output said that all addresses had devices which was impossible
    - i2detect works by letting the SDA pin on the RP float high and any sensor will pull the pin low at the corresponding address
    - When all addresses are shown that means that the SDA pin was constantly connected to ground and could either be a wiring issue or a short on the breakout board
    - After checking all the wiring it was determined the there was indeed a short on the board making the MLX unusable

Conclusions/action items:

- Because this happened so late in the process it is not possible to buy another board in time
- Was able to determine that the MLX worked so I believe getting a breakout board from a different retailer in the future should solve this problem

01/31/2020 - Background Diabetic Foot Ulcer Information

JARETT JONES - Apr 09, 2020, 11:08 PM CDT

Title: Background Diabetic Foot Ulcer Information

Date: 01/31/2020

Content by: Jarett Jones

Present: N/A

Goals: Organize notes regarding general information about diabetic foot ulcers, causes, and effects of the impairment.

Content:

https://www.ncbi.nlm.nih.gov/pubmed/26072202

The Diabetic Foot.

Peripheral Neuropathy

Around 60% of diabetes patients are impacted by peripheral neuropathy. This disease becomes more prevalent as age increases. For diabetic patients, peripheral neuropathy encompasses large and small fibers; disrupting temperature discrimination and automatic functions. As a result of failing to accurately discriminate between temperatures or pain often early signs of foot deformity or lesions go unnoticed and subsequently uncorrected. Callus is commonly present in neuropathic ulcers and they reduce the potential for a healthy ulcer leading to infection. In addition to ulcers, neuropathy of the foot also diminishes the function of intrinsic muscles of the foot leading to a subsequent imbalance between flexor and exterior mechanisms (clawing to the toes, increased prominence of metatarsal heads, loss of sweat gland function, increase of distal arterial flow leading to edema and osteopenia).

Infections

Neuropathy of the foot in diabetic patients can often lead to severe damage resulting from infection. Infection can be bacterial (often the case for irritated and poorly managed ulcers) or can result from fungal growth between toes or under toe nails. Foot ulcers have either an active or passive infections. Active infections of ulcers includes ascending erythema, edema, purulence, increased drainage and malodour. These symptoms usually are associated with temperature increase but are these changes are not felt by diabetes patients. However, infection is already onset when symptoms such as loss of blood glucose control or flu like symptoms are present. Biofilms of ulcers consist of bacterial colonies that form on the surface of wounds.

Common foot deformity locations

Most diabetic neuropathy damage occurs at the forefoot with equal distribution on the plantar and dorsal surfaces (these should be areas of interest when imaging with the IR camera).

https://www.ncbi.nlm.nih.gov/books/NBK537328/

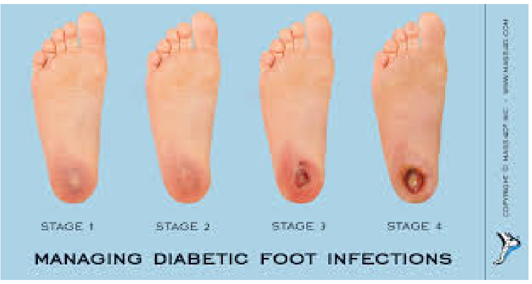
Diabetic Foot Ulcer

Pathophysiology of Ulcers

Diabetic foot ulcers usually form in a three stage process. The first stage results in callus formation due to neuropathy inhibiting the recognition of repeated stress on a given area. Continually this area will undergo drying and cracking of the skin as a result of autonomic neuropathy which inhibits the proper functioning of glands in the foot. Eventually, the combination of the traumatized callus and the drying of the skin in that region, a hemorrhage of the skin will occur and erosion leads to ulcerification.

Following the diagnosis of an ulcer, the wound is categorized into different grade stages. Grading occurs 1-5 (5 being most severe): Superficial ulcer; deep ulcer involving tendon, bone, or joint; deep ulcer with abscess or osteomyelitis; Gangrene involving the forefoot; Gangrene involving the entire foot.

https://www.southwestwoundcare.com/diabetic-foot-ulcer-causes-symptoms-diagnosis-treatment-in-lubbock-tx/



I wanted to include this diagram of the different stages of ulceration on a foot to show the changes in physical appearance as the impairment increases in severity. Similar stages are occurring at a subdermal level, these are what we are attempting to quantify.

Conclusions/action items:

These are necessary notes and resource articles for team members to refer back to throughout design planning, testing, and data analysis. Team should continue compiling articles regarding the biology and physiology of diabetic foot ulcers for use in background information sections of both our preliminary and final deliverables.

02/04/2020 - Background Information - Temperature Difference Importance

JARETT JONES - Apr 09, 2020, 11:16 PM CDT

Title: Background Information - Temperature Difference Importance

Date: 02/04/2020

Content by: Jarett Jones

Present: N/A

Goals: Organize and compile background information regarding the importance of the 2.2 degree difference between feet and its relevance to early detection of diabetic foot ulcers.

Content:

https://www.ncbi.nlm.nih.gov/pubmed/17192326

Preventing diabetic foot ulcer recurrence in high-risk patients: Use of temperature monitoring as a self-assessment tool

A physician-blinded study with 173 diabetic patients with a history of diabetic foot ulcerations were analyzed. Subjects in the enhanced therapy group used an infrared skin thermometer to measure temperatures on six different foot locations each day. Temperature differences greater than 4 degrees F between left and right corresponding foot locations were determined to be of importance. Patients in this study who were not able to use the infrared monitoring system were almost 5 times more likely to develop full blown ulceration than those patients who had access to home monitoring.

Inflammation is one of the earliest signs of tissue injury and ulceration; clinical signs of inflammation are too subtle for the naked eye of even a medical professional. However, inflammation can be seen by infrared temperature readings taken of the tissue in question to visualize subepidermal changes.

https://www.ncbi.nlm.nih.gov/pubmed/18060924

Skin temperature monitoring reduces the risk for diabetic foot ulceration in high-risk patients.

A physician-blinded study with 225 diabetic patients at high risk for ulceration were analyzed. Dermal Thermometry Group was assigned an infrared skin thermometer to measure foot temperatures on 6 different spots on the foot, twice daily. The group was instructed to see their medical professional for temperature differences greater than 4 degrees F between left and right foot corresponding sites. In addition to contacting a medical professional, the patients with large temperature differences were instructed to drastically reduce activity time until temperatures normalized. Subjects in the study group without the thermal monitoring were 66% more likely to ulcerate within this study population. The patients that did experience ulceration experienced temperature differences that were 4.8 times greater at the site of ulceration in the week before ulceration than patients who did not ulcerate.

Conclusions/action items:

These resource articles regarding the importance of the specific temperature difference between feet that is indicative of the formation of diabetic foot ulcers is important for use in background information/testing/accuracy sections of our preliminary and final deliverables. The temperature differences that are important for identifying diabetic foot ulcers must be able to be captured in good resolution by our device, this is something we can discuss in our deliverables and should consider when drafting our testing protocol for our device.

02/08/2020 Pathogenesis/Pathophysiology of Diabetic Foot Ulcers

JARETT JONES - Apr 29, 2020, 11:49 AM CDT

Title: Pathogenesis/Pathophysiology of Diabetic Foot Ulcers

Date: 02 - 08 - 20

Content by: Jarett Jones

Present: N/A

Goals: Define the components of the pathophysiology of diabetic foot ulcers.

Content:

https://journals.lww.com/jaapa/fulltext/2015/05000/pathogenesis_and_management_of_diabetic_foot.6.aspx

Pathogenesis and management of diabetic foot ulcers

Diabetic foot ulcers in terms of pathophysiology have three major components from three major body groups: Neuropathic, Vascular, and immune systems.

Neuropathic Pathophysiology -

Hyperglycemia associated with diabetes produces increased stress on nerve cells which can lead to neuropathy, most commonly found in the peripheries. A combination of damage to the autonomic nerves in the feet as well as loss of peripheral sensation can often lead to inability to properly moisturize the skin leading to epidermal cracks and overall epidermal breakdown.

Vascular Pathophysiology -

Vascular pathophysiology of diabetic foot ulcers can also be tied back to the hyperglycemia induced changes in the peripheral blood flow to hands and feet. The result of vasoconstriction to these regions is ischemia and subsequent heightened risk for ulceration.

Immune System pathophysiology -

When someone is suffering from diabetic foot ulcers they often have increased T-lymphocyte apoptosis which inhibits the healing response in foot sores such as ulcers.

Conclusions/action items:

Better understanding of the physiological effects of diabetic foot ulcers on many different body systems is important to better understanding the importance of this project and will help in the motivation section of both preliminary and final deliverables.

04/28/2020Treatment for Patients

JARETT JONES - Apr 28, 2020, 4:50 PM CDT

Title: Treatment for Patients with Diabetic Foot Ulcers

Date: 04 - 28 - 20

Content by: Jarett Jones

Present: N/A

Goals: Determine some of the most common treatment options for patients after they have been diagnosed with a potential ulcer or already have an ulcer on their foot.

Content:

https://clinical.diabetesjournals.org/content/24/2/91

Treatment of diabetic foot ulcers that have already broken the surface of the skin first involve removal of all necrotic tissue as well as callus tissue. Removal of such tissues will increase the chances that the patient's wound does not become infected. After the wound site has been properly tended to and cleaned out the next major phase of patient treatment is simple offloading. The treatment and healing that can be provided through reducing walking is effective in ulcer patients who's ulcer has not yet broken the surface of the skin as well.

https://www.apma.org/diabeticwoundcare

This source recommends that for those who are able, extensive offloading measures should be taken such as specialized braces, casts, or even wheelchair use have yielded the best recovery results for diabetic patients suffering with foot ulcers.

Conclusions/action items:

This is a question we as a team have received on numerous occasions throughout the preliminary deliverable phase as well as the final poster presentation phase of design. Although most of the work we would have been doing in the VA clinic or in India would have been triaging patients to determine which ones would need to return to see a medical professional it is essential to be able to answer some basic treatment questions. This page provides team members with a brief overview of how these patients are commonly treated.

04/28/2020 Pressure Sensing Sock for Ulcer Detection

JARETT JONES - Apr 28, 2020, 5:37 PM CDT

Title: Pressure Sensing Sock for Ulcer Detection

Date: 04 - 28 - 20

Content by: Jarett Jones

Present: N/A

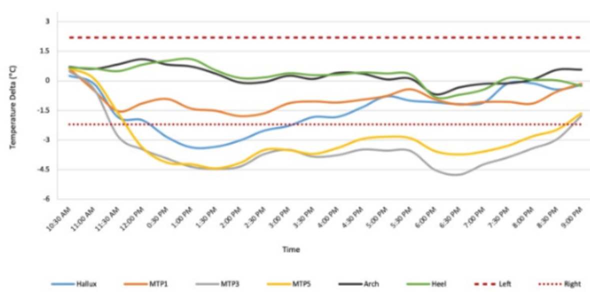
Goals: Determine other existing designs that exist on the market for early detection of diabetic foot ulcers, additionally determine if there exist a patent for these designs.

Content:

*Patent Number (*US20170188841A1)

This idea seems like a good fit for certain patient demographics. Our goal is to provide a low cost method for early detection of ulcers in low resource settings. Additionally, many individuals in rural India do not typically wear socks so this does not apply to our expected patient demographic very well. However, it provides an interesting concept of looking at pressure instead of temperature for diagnosis of early stage ulcers.

This method for early detection of diabetic foot ulcers involves wearable socks containing stand-alone censors that monitor temperature at different pressure points on the feet throughout the day. This is an interesting idea but no clinical testing of the accuracy and feasibility of this device's ability to actual distinguish healthy and patients developing ulcers. The only methods of product testing involved surveys administered to determine if the socks were noticeably different than regular socks in terms of comfort/style. Continually, the temperature data was able to show all data point's temperatures throughout the course of the day but this is a lot of data to compile daily. For this reason, they did not have a scoring system or risk detecting threshold defined as to what segments of data would be useful in determining a patients actual risk of developing ulcers. (Sample data



seen below).

The concept of having continuous wireless monitoring does seem appealing in terms of a method for patients to stay up to the min knowledgeable of their foot health. However, it would be interesting to see the amount of false positives this test would identify as foot temperature fluctuations could behave irregularly depending upon particular activities being completed.

Conclusions/action items:

It is crucial to understand other designs competing to fill the same need in the patient market. In this case, the developers have already patented a solution to the same problem we are trying to solve. However, this method of solving the problem uses pressure sensors instead of thermal data making our design still viable and potentially a better solution to the problem than using pressure data.

04/28/2020 Mobile Application using Thermal Data for Ulcer Detection

JARETT JONES - Apr 28, 2020, 6:03 PM CDT

Title: Mobile Application Using Thermal Data for Ulcer Detection

Date: 04 - 28 - 20

Content by: Jarett Jones

Present: N/A

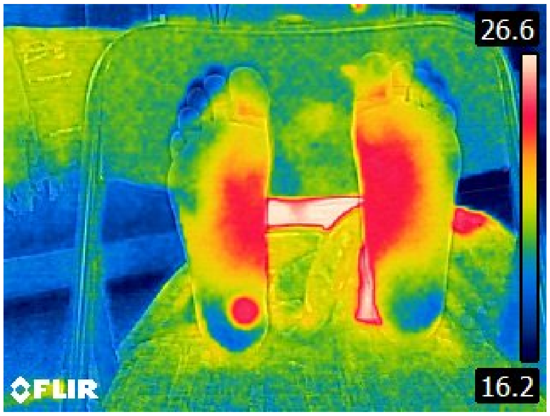
Goals: Determine what existing competing designs exist to solve the same problem we are addressing with our design.

Content:

Diabetic foot ulcer mobile detection system using smart phone thermal camera: a feasibility study

ncbi.nlm.nih.gov/pmc/articles/PMC5627424/

The thermal imaging process for this design occurs using a FLIR camera that is adaptable to a standard Samsung smartphone (important to note that the use of Samsung over Apple is crucial when considering the patient populations ability to access this brand). This particular study implemented a crucial temperature threshold of +2.2 degrees celsius as indicative of early stage ulceration. This design does not outline a method to control the image capturing process, leaving the door open to inacurate patient data due to poor image quality. Additionally, in this design, temperature thresholding was done using Otsu and Point-to-Point mean difference technique in MATLAB. This process was indeed successful in quantifying the regions of interest for ulceration. A major shortcoming of the design idea proposed by this group is that all data that they have based their algorithms off of has come from simulated ulcers on the foot. The temperature hot spots on the foot could be far more profound when simulated than in an actual ulcer patients foot. Below is a thermal image we captured while simulating ulcers, it should be noted how obvious the hot spot is in the image, this would not be the case in the field. Additionally, no patent exists for this design.



This study is lacking actual clinical testing on a patient population. Additionally, methods to standardize the image collection process could make our project more novel and successful.

Conclusions/action items:

This study provides a similar solution to our design. However, this study/design lacks testing on a patient population and additionally lacks standardizing of images as well as a low cost low resource component.

04/28/2020 Thermochromic Crystals for Early Ulcer Detection

JARETT JONES - Apr 28, 2020, 6:38 PM CDT

Title: Thermochromic Crystals for Early Ulcer Detection

Date: 04 - 28 - 20

Content by: Jarett Jones

Present: N/A

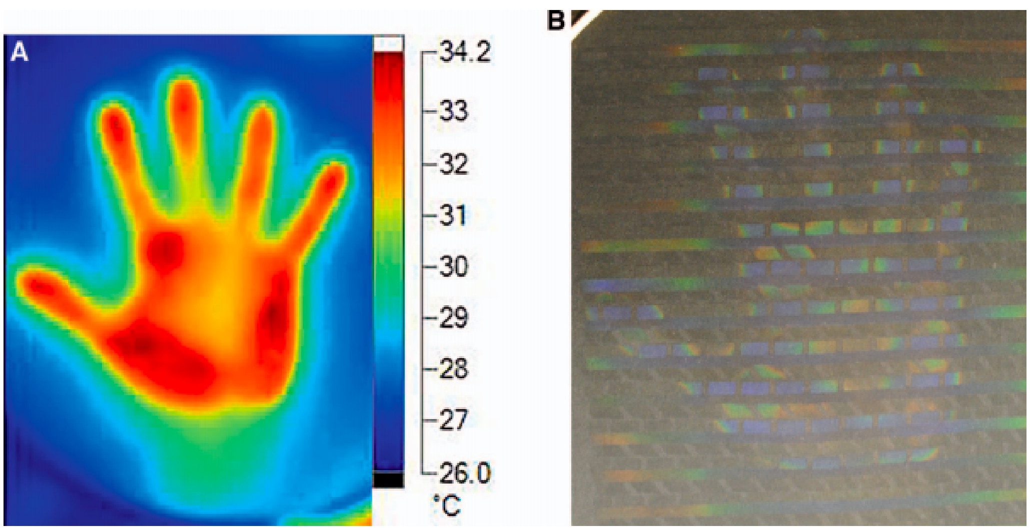
Goals: Document other existing designs that serve to detect early stage diabetic foot ulcers.

Content:

A Novel Thermochromic Liquid Crystal Fabric Design for the Early Detection of High-Risk Foot Complications

https://www.researchgate.net/publication/318018259_A_Novel_Thermochromic_Liquid_Crystal_Fabric_Design_for_the_Early_Detection_of_High-Risk_Foot_Complications

This study found that thermochromic liquid crystal mats were capable of accurately mapping temperatures across different regions of a hand imprint. Thermochromic liquid crystals are the same material that are used in the color changing cups or pencils many of us had when we were kids. The color of the liquid crystals changes color with different temperatures. This study achieving accurate temperature mapping across a hand imprint validated the concept of utilizing this material for foot applications in ulcer patients. It will be interesting to see if subsequent studies in this technology yield enough accuracy and precision of temperature mapping to locate small regions of increased heat such as an ulcer. The image below shows the ability of the liquid crystals to map the temperatures on a hand imprint.



Conclusions/action items:

This provides a rather unique solution to solving our problem of early detection of diabetic foot ulcers. It is essential to understand other competing designs currently being researched in order to better our own design as well as not to infringe upon any existing patents.

03/26/2020 Gold Standard FLIR Thermal Imaging Technology

JARETT JONES - Apr 28, 2020, 3:16 PM CDT

Title: Gold Standard FLIR Thermal Imaging Technology

Date: 03 - 26 - 20

Content by: Jarett Jones

Present: N/A

Goals: Determine the thermal imaging technology behind the expensive BME department FLIR camera. What technology is present that offers such accurate thermal imaging data.

Content:

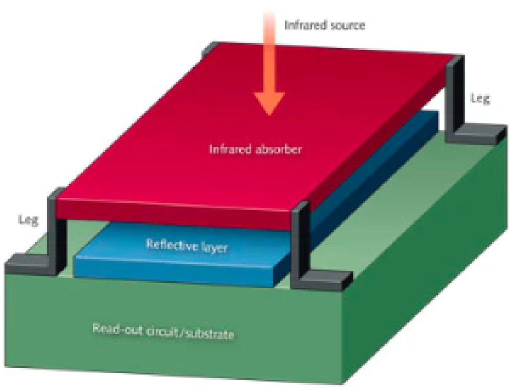
https://www.laserfocusworld.com/detectors-imaging/article/16549566/photonic-frontiers-roomtemperature-ir-imaging-microbolometer-arrays-enable-uncooled-infrared-camera

Photon Detectors

Photon detectors provide the ultimate thermal imaging device in terms of speed and sensitivity. However, the image quality of these devices is poor unless coupled with a rigorous cooling mechanism for the thermal detectors. This makes photon detector thermal imaging very expensive and difficult to use for our applications in use on diabetic feet.

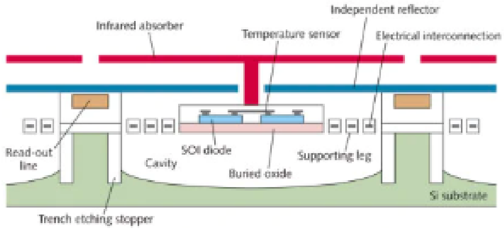
Microbolometer Technology

Uncooled Infrared cameras are built around an array of small thermal detectors in order to avoid the high cost of cooling requirements present in photon detectors. These advances are making handheld thermal imaging devices more accurate and cost effective for regular people to use. Microbolometers measure the temperature changes caused by infrared absorption in each individual pixel. This provides an accurate measurement mechanism as the pixels are arranged in focal-plane arrays (FPAs) which are thermally isolated from one another.



IR Absorbing Materials

Pyroelectric or ferroelectric crystals generate electrical signals that represent a value directly proportional to the increase in temperature caused by the infrared absorption. Various materials are currently used and they are then compatible with common semiconductor processing technology used to create the read-out that generates the thermal image we observe. This is seen in more detail in the diagram below.



This microbolometer technology is present within the FLIR E5 thermal imaging device which we define as a gold-standard in thermal imaging devices. Additionally, this technology undergoes frequent and rapid recalibration of the image to adjust temperature scaling as well as account for thermal radiation emitted from objects being imaged.

Conclusions/action items:

This information is essential to understand prior to being able to compare two thermal imaging devices. The team should familiarize themselves with this technology and then the technology of cheaper thermal imaging options such as the MLX. Understanding these technologies will be useful to explain shortcomings or potential benefits of utilizing the MLX in a low resource setting.

03/25/2020 MLX Thermal Imaging Technology

JARETT JONES - Apr 28, 2020, 3:45 PM CDT

Title: MLX Thermal Imaging Technology

Date: 03 - 25 - 20

Content by: Jarett Jones

Present: N/A

Goals: Determine the thermal imaging technology that is utilized in our low resource setting MLX thermal imaging camera. What technology is used in the capturing of thermal images with this camera?

Content:

https://www.sciencedirect.com/topics/engineering/pyroelectric-sensor

Pyroelectric sensors are aligned in a imaging array. The MLX does not require frequent re-calibration, unlike microbolometer alternatives. This may allow for continual temperature monitoring without accounting for stoppage due to calibration. Additionally, the resolution of the IR array makes this system much lower cost and more applicable to our utilization of it in low resource settings.

https://www.edgefx.in/thermal-imager-circuit-working/

This article does a great job explaining how low cost thermal imagers work in collaboration with microcontrollers to collect thermal data.

"A special lens is employed to focus the infrared emission emitted by objects. The focused light is scanned by a phased array of infrared-detector elements. The detector elements produces a much elaborated temperature pattern referred to as a thermogram. It solely takes concerning one-thirtieth of a second for the detector array to get the temperature data to form the thermogram. This data is obtained from many thousand points within the field of view of the detector array. The thermogram created by the detector elements is translated into electrical impulses. The impulses are sent to a signal-processing unit, a circuit card with a passionate chip that interprets the information} from the elements into data for the display. The signal-processing unit sends the information to the display wherever it seems as numerous colors depending on the intensity of the infrared radiation. The mixture of all the impulses from all of the elements creates the image. It is quite straightforward to examine everything throughout the day, but at nighttime you'll be able to see little or no. Thermal imaging permits you to see once more."

Conclusions/action items:

This is important to understand prior to being able to compare two thermal imaging devices. The team should familiarize themselves with how this technology differs from the technology utilized in more expensive thermal imaging devices such as the FLIR E5. Understanding these technologies will be useful to explain shortcomings or potential benefits of utilizing the MLX in a low resource setting.

MLX90621 Open Source Thermal Imager

JARETT JONES - Feb 13, 2020, 11:56 PM CST

Title: MLX90621 Open Source Thermal Imager

Date: 2/13/20

Content by: Jarett Jones

Present: N/A

Goals:

Conduct research on current affordable thermal technologies.

Content:

This thermal imaging option is slightly more expensive than what we would be hoping to spend but may be worth it in terms of quality of thermal imaging (It is currently priced in a few different places at around 130$). The product is factory calibrated and has a sensor temperature of -40 to 85 degrees celsius and an object temperature range of -20 to 300 degrees celsius. Obviously this range is impressive but may be paying for a range beyond what we would ever reasonably need. A large concern is I am having a hard time finding a consistent answer for the +/- temperature sensitivity. It does have a digital display on the device but can also be integrated with raspberry pi, thermal sensor is MLX90621. Link Below.

https://www.ebay.com/itm/MLX90621-Open-Source-Thermal-Imager-with-ATmega328p-MCU-/122130933690?_trksid=p2349526.m4383.l4275.c10#viTabs_0

Conclusions/action items:

Take into consideration the advice given to us by professor Nimunkar. Additionally we should be reading over the options gathered as a team and make some selections on devices/priorities in device using a design matrix. Hope to get some design components ordered.

FLIR E5 Thermal Imaging Camera (Gold-Standard)

JARETT JONES - Apr 28, 2020, 4:34 PM CDT

Title: FLIR E5 Thermal Imaging Camera (Gold-Standard)

Date: 04 - 15 - 20

Content by: Jarett Jones

Present: N/A

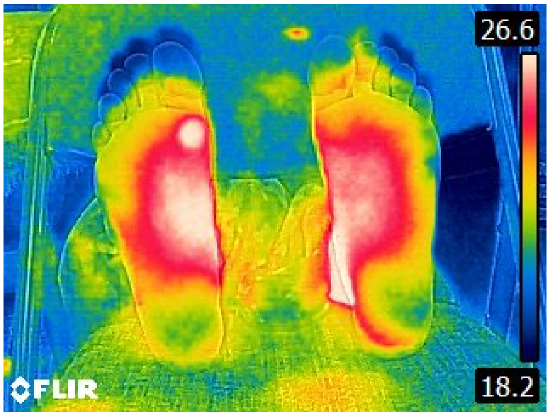
Goals: Define the capabilities in terms of resolution and accuracy of a gold standard thermal imaging device.

Content:

https://www.flir.com/products/e5/

The FLIR E5 thermal imaging camera provides an accuracy of +/- 2 degrees C or +/- 2% of the reading for ambient temperatures between 10 - 35 degrees C. This imaging range is perfect for our application to test the camera's ability to locate hot spots on a foot as the accuracy will allow for detection of 2.2 degrees C which we know to be a warning metric for ulcer formation as well as the temperature range maps well to physiological temperatures. The detector type present in this camera is an uncooled microbolometer. The microbolometer represents the industry standard in high precision thermal imaging. Additionally, the camera will output a good picture resolution of 120x90 pixels. Lastly, the thermal sensitivity of the camera is outstanding. The camera has a thermal sensitivity of <.1 degrees C, this means that the camera can detect differences between points of as low as .1 degrees C.

Below is a sample image of a foot taken with this style of camera.



Conclusions/action items:

In order to compare the ability of our low resource MLX thermal imaging device to capture thermal images that provide accurate temperature data as well as sufficient resolution and ability to detect hot spots on the feet it is necessary to compare these data to a gold standard thermal imaging device. Doing such comparisons will ensure that we are not losing too much accuracy, resolution, and ability to detect hot spots with what we gain in cost-effectiveness as even if it is very cheap it still must be able to give patients accurate diagnosis. These comparisons will be important metrics to include in our testing procedure and the results section of our final deliverables.

03/26/2020 - Project Impact/Importance Statement and Literature Review

JARETT JONES - Apr 09, 2020, 11:31 PM CDT

Title: Project Impact/Importance Statement and Literature Review

Date: 03/26/2020

Content by: Jarett Jones

Present: N/A

Goals: Compile literature resources that quantify/describe the severity of diabetic foot impairments in India and other low-income settings. This is important to reflect upon when discussing our "why" for participating in design to combat this issue.

Content:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6020220/

Community based study to assess the prevalence of diabetic foot syndrome and associated risk factors among people with diabetes mellitus

This article does a nice job laying out not only the prevalence of diabetes in India but also quantifying the amount of those patients that then go on to experience foot impairments as well as amputations. Additionally, the article discusses the growth of this patient population over recent history with no real cure/plan of action to combat the growing number of foot amputees coming as a result of foot ulcers.

https://pdfs.semanticscholar.org/46ae/5c6caeb57df0001fd844d530f3cbffe51004.pdf

Prevalence of Diabetic Foot Ulcer and Associated Risk Factors in Diabetic Patients From North India.

This article highlights the prevalence and severity of the diabetic outbreak in India. India is currently known as the diabetic capital of the world as nearly 60 million people suffer from the disease and lack the treatment/guidance to make informed decisions to negate the complications that arise from this disease. A large percentage of the population that is subjected to this disease experience neuropathy in their feet. In developing regions, shoes are not commonly worn; therefore, the neuropathic feet experience many severe complications such as ulceration, infection of ulcer, and ultimately the need for amputation as a whole which results in life altering consequences. For all of these reasons it is our duty to not only develop a device for early-stage ulcer detection but to develop one at a low enough cost that it can become common place in India and hopefully stop these horrific complications of diabetes before they begin.

https://www.sciencedirect.com/science/article/pii/S2214109X18303875

The increasing burden of diabetes and variations among the states of India: the Global Burden of Disease Study 1990–2016

This graphic coming from an article in science direct nicely depicts the growing severity in diabetic foot complications in India throughout recent history.

Conclusions/action items:

It is important to accurately understand not only the biological/physiological components of the problem you are solving but also the severity/importance of the problem. It is important to understand the demographic and quantity of people suffering from the disease. Some of these figures from the resource articles will be crucial to convey the severity of our problem and our design solution during the poster presentation.

2/25/20 Pathophysiology

CARSON GEHL - Feb 25, 2020, 3:01 PM CST

Title: Pathophysiology

Date: 2/25/2020

Content by: Carson Gehl

Present: N/A

Goals: Resesarch into the processes behind diabetic foot ulcer formation

Content:

https://en.wikipedia.org/wiki/Diabetic_foot_ulcer#Pathophysiology

-Damaged extracellular matrix triggers response from immune system which recruits fibroblasts to build collagen. This influx of fibroblasts is the cause of inflammation.

-Perclean, which is found in the epidermal and endothelial basement membrane, is an important part of wound healing that is responsible for binding growth factors. It is known that high levels of glucose can decrease the expression of perclean in some cells through transcriptional and post-transcriptional modification. For this reason, poor wound healing abilities in diabetic patients could possibly be attributed to low perclean expression.

-Skin suffers from reduced hydration making the tissue less elastic and more vulnerable to mechanical stress. Compression and shear stresses experienced are greater in the average diabetic foot compared to that of a regular foot.

Conclusions/action items:

Finish preliminary report

2/25/20 Mobile detection system

CARSON GEHL - Feb 25, 2020, 3:04 PM CST

Title: Diabetic foot ulcer mobile detection system using smart phone thermal camera: a feasibility study

Date: 2/25/2020

Content by: Carson Gehl

Present: N/A

Goals: Competing design research

Content:

There were a lot of good takeaways from this publication that I will explain below. More in depth information on them can be found in the publication itself

- a temperature difference of 2.2 degrees C can indicate a possible development of ulcers (this is before the ulcer has formed however, so that it is not too late to act). Kayla had mentioned that we may want to be more on the safe-side (i.e. identifying false positives would be better than under-diagnosing). We could consider this value or possibly a smaller value depending on the accuracy.
- They performed two image segmentations in their program - the first to remove the feet from the background and the second to detect ulcers
    - They used a technique called Histogram shape thresholding which results in a bi-modal histogram with two peaks. This requires finding the optimal temperature to act as the threshold to separate the feet from the background. Quite a bit of statistics included in this that I will not list in here.
    - Image smoothing was performed to further clean up the images before final analysis. Most of the smoothing needed to be done around the edges of the feet.
    - To analyze for ulcers, the same method was used as before, except that now the feet act as the background, and any region in which the mean pixel value was 2.2 degrees Celsius above the mean pixel value of the feet themselves, it was considered the start of a possible ulcer.
- It seemed that they had issues with background noise which could be relatively easily improved by prototyping something in which the patient can place their feet and the background will be significantly cooler to assure for a cleaner image. Kayla utilized a wet towel behind the feet to achieve this.
- No actual clinical trials were done to test the prototype. It was tested by heating up various areas of an individuals foot and testing if the program was able to detect the change in temperature. This is a good idea that we talked about using to help train the program since we do not have an adequate amount of images to create an efficient AI algorithm yet.

A shareable link to the paper being discussed: https://drive.google.com/open?id=1ZFcxfG0QB2VoTKxC-JnVwfruBgy1uvA5

Conclusions/action items:

Explore low cost design

2/25/20 Asymmetric analysis

CARSON GEHL - Feb 25, 2020, 3:08 PM CST

Title: Automatic detection of diabetic foot complications with infrared thermography by asymmetric analysis

Date: 2/25/2020

Content by: Carson Gehl

Present: N/A

Goals: Research into competing designs

Content:

Takeaways:

- Improved foot segmentation from background by utilizing color images to guide segmentation
    - Method for segmentation described in citation [20]
- Improved comparison between left and right foot regardless of foot shape, size, position, etc. using nonrigid landmark-based registration B-splines
- Machine learning split into two main groups
    - Supervised - parameters learned during design stage based on data provided by the programmer
    - Unsupervised - program adapts itself to statistics of the data being presented and learns on the go. This is what we are looking for so that we can get a start here and then take more images in India to further train the program.
        - They used K-means clustering and expectation-maximization clustering. Could look further into these methods
        - There is a lot of statistical analysis for each general step of their program in the publication which could be of use (but I do not understand as of now)
        - Used MATLAB with additional toolbox PRtools V5
- IR camera was 80-90 cm from object
- Final thoughts on article: very very good information in this article, although I simply do not have the statistical background to understand large portions of it. This seems to be a very accurate but expensive model, and the imaging device itself was very large (which they noted). They also noted the inability to detect ulcers if a foot has already been amputated as well as the ability to detect ulcers if they are forming in the same area on both feet

Conclusions/action items:

Improve on image processing techniques from last semester.

4/8/20 Research on FLIR camera

CARSON GEHL - Apr 08, 2020, 4:43 PM CDT

Title: Research into FLIR camera being used for testing purposes

Date: 4/8/20

Content by: Carson Gehl

Present: N/A

Goals: Look into specifications for the FLIR camera so that we know what we are working with when we utilize it for testing

Content:

IR Resolution: 160 x 120 (19,200 pixels)

Thermal Sensitivity: < 0.1 degrees C / < 100 mK (I looked into this and am still a bit confused by why it uses C and K, but essentially this determines amount of noise. This rating looks good).

Accuracy: +/- 2 degrees C or +/- 2% of reading for ambient temperature 10-35 degrees C and object temperature above 0 degrees C; as we would not expect to be using it outside of 10-35 degrees C ambient temperature and object temperature is above 0 degrees C, I think the +/- 2% should be correct for our scenario. If we assume a human foot is ~35 degrees C, comes out to +/- 0.7 degrees C which is not too bad.

Conclusions/action items:

I think this camera should serve well for doing testing; especially as it has high resolution and low noise. Should move on to testing ASAP

4/18/30 IR Technology Search

CARSON GEHL - Apr 18, 2020, 12:26 PM CDT

Title: IR Technology Search

Date: 4/18/20

Content by: Carson Gehl

Present: N/A

Goals: Gain better understanding of the technology behind IR sensors i.e. how they work, differences, what makes some better than others, etc.

Content:

Reference: https://www.dhs.gov/sites/default/files/publications/ThermalImagingTech_TN_0305-508.pdf

- Two types of IR detectors:
  - Photon detectors - very good sensitivity, but cooled by liquid nitrogen and therefore very large and expensive
  - Thermal detectors - more applicable for most scenarios... two different types
    - Resistive bolometer - No moving parts, but must periodically recalibrate themselves as they respond to respond to radiation being produced by object
    - Pyroelectric sensor - Respond to changes in radiation, must use a rotating wheel to detect changes in radiation, therefore creating more noise and less reliability
- Determining Performance:
  - Responsivity - defines range of performance
  - Noise Equivalent Temperature Difference (NETD) - determines sensitivity, should be less than 100 mK
  - Dynamic range - ability to produce an image over a wide range of IR emissions, should be 60 dB
  - Wavelength sensitivity - ability to distinguish between different wavelengths
  - Array size - Number of pixels i.e. 160x120
  - Detector pitch - pixel spacing i.e. pixel spacing should be less than 60 microns

Conclusions/action items:

2/9/20 Adafruit AMG8833 IR Camera

CARSON GEHL - Feb 09, 2020, 9:00 PM CST

Title: Adafruit AMG8833 IR Camera

Date: 2/9/20

Content by: Carson Gehl

Present: N/A

Goals: Do some research into available thermal technologies

Content:

The Adafruit AMG8833 IR Thermal camera is a very cost effective camera at only $40, however, there may be concerns as to the resolution and accuracy of the camera. The temperature picked up by this camera range from 0 to 80 degrees Celsius which is certainly adequate for our needs. The largest initial concern is that the camera has an accuracy of +/- 2.5 degrees Celsius, which could be problematic. 8x8 array can be interpolated using Rasberry Pi to produce MUCH greater resolution. This could make for some fun coding and instrumentation to work on. Link for product below.

https://www.adafruit.com/product/3538?gclid=CjwKCAiA-P7xBRAvEiwAow-Vad_jI5w4U44sDnttDuvp61NY1HzkzGe-PqzzeF-Td2W-mTU2KTq49BoCVoAQAvD_BwE

Conclusions/action items:

This camera could be good. Should get some input from others. Do some research into some other cameras to make comparisons.

2/11/20 MEMS Thermal Sensors D6T

CARSON GEHL - Feb 13, 2020, 2:44 PM CST

Title: MEMS Thermal Sensors D6T

Date: 2/11/20

Content by: Carson Gehl

Present: N/A

Goals: Continue research into various thermal sensors

Content:

Looking into MEMS D6T thermal camera. Temperature range is 5-50 degrees Celsius which is adequate for our uses. Very cost-effective at just $40. In terms of accuracy I'm seeing +/- 1.5 degrees Celsius and +/- 3 degrees Celsius (it says to see notes but I am a a bit confused by the notes). It's only a 4x4 display but I am wondering if we could increase the resolution as with the adafruit camera. Resolution: 0.14 degrees Celsius.

https://www.digikey.com/en/product-highlight/o/omron/d6t-thermal-sensor

After taking a second look at this camera, I don't think it will come anywhere close to what we need. Use is for more general temperature detection, not picking apart pixel by pixel.

Conclusions/action items:

Continue researching thermal cameras.

2/13/20 FLIR ONE Pro

CARSON GEHL - Feb 13, 2020, 2:41 PM CST

Title: FLIR ONE Pro

Date: 2/13/20

Content by: Carson Gehl

Present: N/A

Goals: Use our existing camera as a "control" for other cameras

Content:

19,200 pixel resolution (wow). Can sense between -20 and 40 degrees Celsius (this is overkill, probably paying for capabilities we don't need when it comes to this). Frame rate of 8.7 Hz (this is relatively unimportant as we are not planning on taking videos).Thermal resolution of 160 x 120 and visual resolution of 1440 x 1080 (I am not exactly sure what this means/what the differences are).

Major disadvantage: Only ~1 hour battery life, and costs $400, interfaces with FLIR application (not as compatible when trying to transfer images onto computer).

https://www.flir.com/products/flir-one-pro/

Conclusions/action items:

Pick a camera (sooner rather than later) and order it along with a rasberry pi so we can get started.

02/25/20: Summary of last year's accomplishment

TAMARIN TANDRA - Feb 25, 2020, 11:54 PM CST

Title: Summary of last year's accomplishment

Date: 25 Feb 2020

Content by: Tamarin Tandra

Present: N/A

Goals: to summarize the project foundings from last semester

Content:

Diabetic patients suffer from ulceration in their feet which, in an extreme, can result in amputation of the foot. The team has been tasked with designing an imaging device along with image processing software and an algorithm for early-stage detection of ulceration. Last semester's team was able to fabricate an insulated folding studio with retractable and folding components to aid in its portability (Figure 1). They used particle boards, polystyrene foam, and PVC pipes as materials. They have also developed a software using MATLAB in which a user was able to grayscale an image, select points on this image to estimate foot height, then select multiple detection points and calculate the average pixel value within the circle. It was then implemented in Swift 5 to make an IOS application which had all of these features and additionally allowed the user to enter patient information, score the data, and save the results to a database. Scores were calculated based on multiple different parameters including a 2.2 ºC difference between corresponding points and other measurements identified by the client upon prior research and data she has collected previously.

Figure 1: Imaging box used as background and thermal insulation

The software identified 80% of patients who had already experienced ulceration as “high risk” and 94% of patients who were non-diabetic as “low risk”. There were about 20% of patients who had ulcers and were not identified as high risk.

Conclusions/action items:

Throughout the course last semester, the team was able to create an imaging apparatus and analysis software capable of distinguishing known ulcerated and known healthy patients. Future work for the project will entail working on more sophisticated software. They would also like a way to improve the box in regards to keeping the patient's feet from flaring to the sides of the box.

02/25/20: Diabetic Foot Ulcer

TAMARIN TANDRA - Feb 26, 2020, 12:07 AM CST

Title: Diabetic Foot Ulcer

Date: 25 Feb 2020

Content by: Tamarin Tandra

Present: N/A

Goals: To learn more how diabetic patients can develop ulcer on their feet

Content:

Diabetic foot ulcer is an open sore or wound that occurs in approximately 15 percent of patients with diabetes and is commonly located on the bottom of the foot. Approximately, 14-24 percent of patients with diabetes who develop a foot ulcer will require an amputation. However, research has shown that the development of a foot ulcer is preventable.

Ulcers form due to a combination of factors, such as lack of feeling in the foot, **poor circulation, foot deformities, irritation** (such as friction or pressure), and trauma, as well as duration of diabetes. Patients who have diabetes for many years can develop **neuropathy**, a reduced or complete lack of ability to feel pain in the feet due to **nerve damage** caused by **elevated blood glucose levels** over time. The nerve damage often can occur without pain, and one may not even be aware of the problem. Vascular disease can complicate a foot ulcer, reducing the body's ability to heal and increasing the risk for an infection. Elevations in blood glucose can reduce the body's ability to fight off a potential infection and also slow healing.

Reference: https://www.apma.org/diabeticwoundcare

Conclusions/action items:

Ulcers are likely to develop in diabetic patients because of damaged nerves and blood vessels caused by high blood sugar level. This will result in **lessen blood flow**, which makes it harder for sores and cuts to heal.

02/25/20: I2C

TAMARIN TANDRA - Feb 26, 2020, 12:24 AM CST

Title: I^{2}C

Date: 25 Feb 2020

Content by: Tamarin Tandra

Present: N/A

Goals: To learn more about the I^{2}C protocol that interfaces our sensor for efficient temperature reading

Content:

The Inter-integrated Circuit (I^{2}C) Protocol is a protocol intended to allow multiple "slave" digital integrated circuits ("chips") to communicate with one or more "master" chips (Figure 1). It is only intended for short distance communications within a single device and requires two signal wires to exchange information.

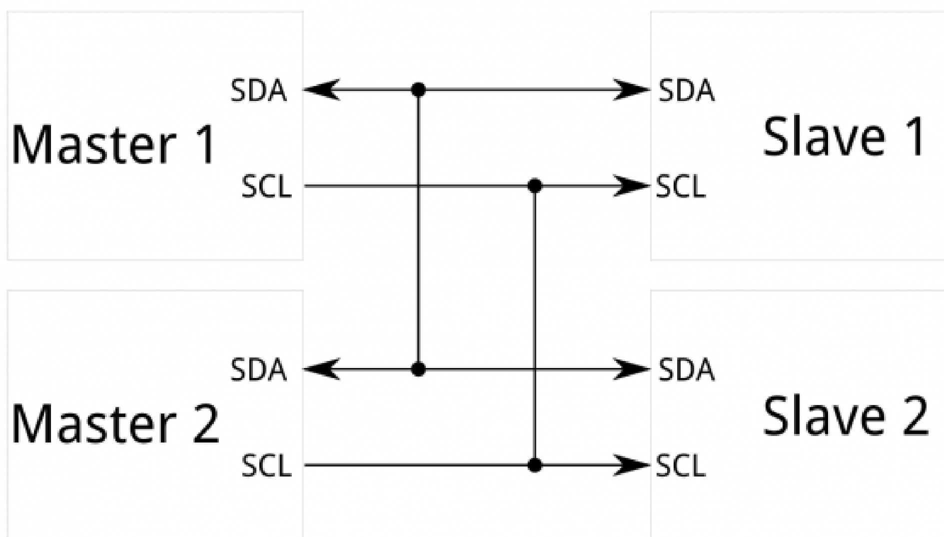


Figure 1: I^{2}C communication protocol

Why use I^{2}C?

I^{2}C's two wires can support up to 1008 slave devices. Also, unlike SPI, I^{2}C can support a multi-master system, allowing more than one master to communicate with all devices on the bus. Most I^{2}C devices can communicate at 100kHz or 400kHz.

Signals

Each I^{2}C bus consists of two signals: SCL and SDA. SCL is the clock signal, and SDA is the data signal. The clock signal is always generated by the current bus master, though some slave devices may force the clock low at times to delay the master sending more data. Since the devices on the bus don't actually drive the signals high, I^{2}C allows for some flexibility in connecting devices with different I/O voltages.

Figure 2: Raspberry Pi connected with I^2C

Conclusions/action items:

I^2C is a useful bus that allows data exchange between microcontrollers and peripherals with a minimum of wiring.

04/26/20: Microbolometer

TAMARIN TANDRA - Apr 26, 2020, 10:34 PM CDT

Title: Microbolometer Technology

Date: 26 April 2020

Content by: Tamarin Tandra

Present: N/A

Goals: To research on microbolometer sensors (not used in our MLX90640 thermal camera)

Content:

Microbolometer is a form of thermal imaging technology that is commonly available today. It is built using vanadium oxide (VOx) or amorphous silicon (a-Si) processes. Typical prices for microbolometer-based cameras range from $8,000 - $20,000 depending on resolution, performance, and feature set. The pixel is shaped like a table with two legs that separate it from a substrate and read out integrated circuit (ROIC). The "table" is made of electrically conductive material such as VOx and forms a complete circuit with the underlying electronics. When incident LWIR energy strikes the "table top", the electrical resistance of its material change. Therefore, changes in temperature can be read out as electronic signals and used to produce an image.

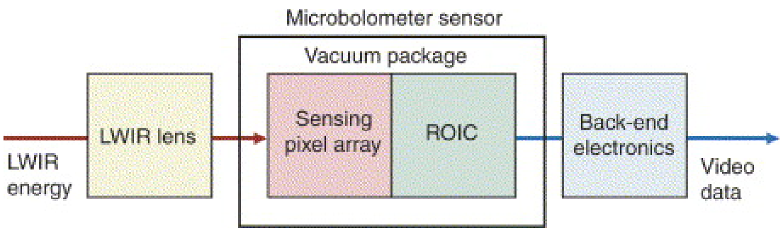


Figure 1: Microbolometer camera engine block diagram

Power consumption: 2W for normal operation

Image quality: 2.5% change per in signal per degree C change in temperature

Due to the complicated manufacturing process, the individual pixels of a microbolometer array have different characteristics. The calibration process eliminates these differences and determines the relationship between the signal voltage of a pixel and the temperature of the object to be measured.

Reference:

https://www.sciencedirect.com/science/article/pii/S0961129006717641

www.ama-science.org - Calibration of Infrared Cameras with Microbolometers

Conclusions/action items:

Sensors based on microbolometer arrays have excellent infrared thermal and spatial resolution. It also operates at room temperature and do not require expensive cooling. However, they need frequent re-calibration which extensively increase the operational expense.

04/29/20: Thermopile Detectors

TAMARIN TANDRA - Apr 29, 2020, 12:15 PM CDT

Title: Thermopile Detectors

Date: 29 April 2020

Content by: Tamarin Tandra

Present: N/A

Goals: To research on thermopile sensors (used in MLX 90640)

Content:

Thermopile detectors have a combination of characteristics that make them well suited for some low power applications. They are highly linear, require no optical chopper, and have D* values comparable to resistive bolometers and pyroelectric detectors. They operate over a broad temperature range with little or no temperature stabilization. They are employed as linear arrays that are mechanically scanned to form an image of stationary or nearly stationary objects.

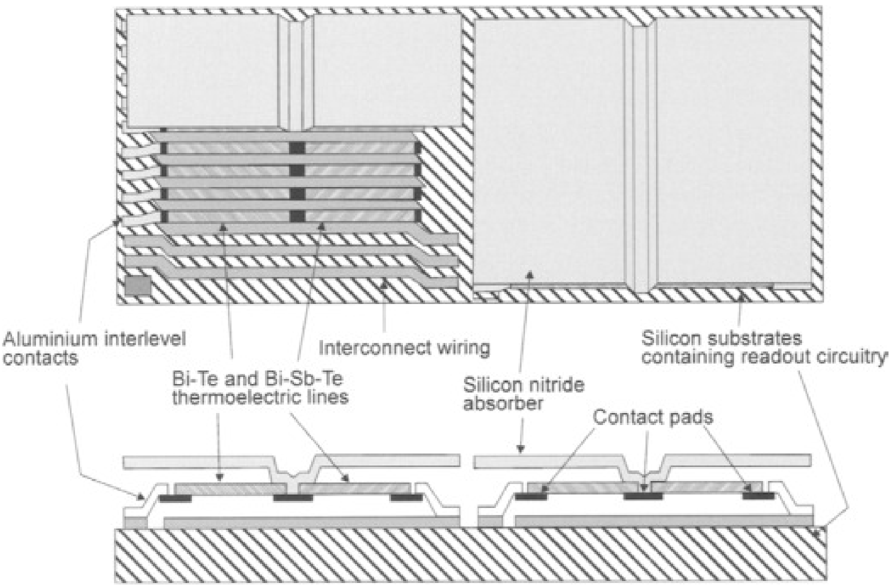


Figure 1: Schematic diagram of thermopile detector structure. The top diagram shows two pixels viewed from the top, with part of the left pixel cut away to show the underlying structure. The lower diagram shows a cross section side view of two pixels.

Reference: https://www.sciencedirect.com/topics/engineering/thermopile

Conclusions/action items:

Thermopile detector doesn't require temperature stabilization hence causing them to be suitable for some low power applications. However, the performance may not be as good as the microbolometer sensors.

02/11/20: Adafruit MLX90640

TAMARIN TANDRA - Feb 11, 2020, 3:33 PM CST

Title: Adafruit MLX90640 Thermal Camera

Date: 11 Feb 2020

Content by: Tamarin Tandra

Present: N/A

Goals: To do some research on IR camera

Content:

Adafruit MLX90640 IR Thermal Camera Breakout:

- Has a narrow **55° x 35° field of view** or a wider **110° x 70°** field of view (can choose).

- Measures temperatures ranging from **-40^o to 300^{o}C** with an accuracy of **+- 2^{o}C** (in the 0-100^{o}C range).

- Maximum frame rate of 16 Hz

- Code on Arduino or Raspberry Pi on Python.

- 3.3 V regulator and level shifting, can use with any 3V-5V microcontroller or computer.

- I2C compatible digital interface.

- Cost: **$59.95**

Reference: https://www.adafruit.com/product/4407?gclid=EAIaIQobChMIjJilwLXK5wIVAtvACh26swO6EAQYAiABEgKlSvD_BwE

Conclusions/action items:

This can be a viable option for our DIY thermal camera. Will have to wait for the team's input.

02/11/20: OpenMV Cam H7 + FLIR Lepton Thermal Sensor

TAMARIN TANDRA - Feb 11, 2020, 3:54 PM CST

Title: OpenMV Cam H7 + FLIR Lepton 3.5 with Radiometry Thermal Sensor

Date: 11 Feb 2020

Content by: Tamarin Tandra

Present: N/A

Goals: Research on IR Camera

Content:

The OpenMV Cam H7 can bring FLIR Lepton 1/2/3 Thermal Sensor to run algorithms on thermal images using FLIR Lepton Adapter.

The FLIR Lepton is a micro thermal imager that is smaller than a dime.

- Scene Dynamic Range: **-10 to 400°C** (Low Gain Mode); **-10 to 140°C** (High Gain Mode)

- Effective Frame Rate: **8.7 Hz**

- Pixel Size: **12 µm**

- Input Supply Voltage: 2.8 V, 1,2 V, 2.5 V to 3.1 V IO

- The FLIR Lepton Adapter Module allows OpenMV Cam to interface with the FLIR Lepton 1/2/3 Thermal Imaging Sensor for Thermal Vision applications.

- Cost:

Camera: $65

FLIR Lepton Thermal Sensor: $199

FLIR Lepton Adapter: $15

Total: $279

Reference:

https://www.kickstarter.com/projects/1798207217/openmv-cam-h7-machine-vision-w-micropython

https://www.flir.com/products/lepton/

https://openmv.io/products/flir-lepton-adapter-module

Conclusions/action items:

The total cost is higher than expected but the specifications are suitable for our project. More input from the team is needed.

04/20/20: FLIR E5

TAMARIN TANDRA - Apr 20, 2020, 11:43 PM CDT

Title: FLIR E5

Date: 20 April 2020

Content by: Tamarin Tandra

Present: N/A

Goals: Background check on department's thermal camera (FLIR E5) that will be tested against our thermal camera.

Content:

- Resolution: **10,800 (120 x 90) pixel**

- Accuracy = **2%**

- Thermal Sensitivity = < 10^{o}C

- Temperature Range = -20^{o}C - 250^{o}C

- Field of View = 45^{o} / 34^{o}

- Weight = 1.2 lbs

- Price: **$1,199.00**

Reference: https://www.flir.com/globalassets/imported-assets/document/ex-series-no-wifi-datasheet.pdf

Conclusions/action items:

This camera will be tested against MLX90640 thermal camera as reference.

04/20/20: FLIR Testing Data

TAMARIN TANDRA - Apr 20, 2020, 11:42 PM CDT

Title: FLIR Testing Data

Date: 20 April 2020

Content by: Tamarin Tandra

Present: N/A

Goals: Data analysis on FLIR testing

Content:

FLIR testing pictures were acquired by Jarett. Water was heated to 48.89^oC / 120^oF temperature and placed in a glass cup. Picture was taken using FLIR E5 every 15 seconds for the first 5 minutes and every minute for another 5 minutes. The pictures were then converted to grayscale and the water temperature is calculated on MATLAB.

The resulting graph of Water Temperature vs. Time is as shown:

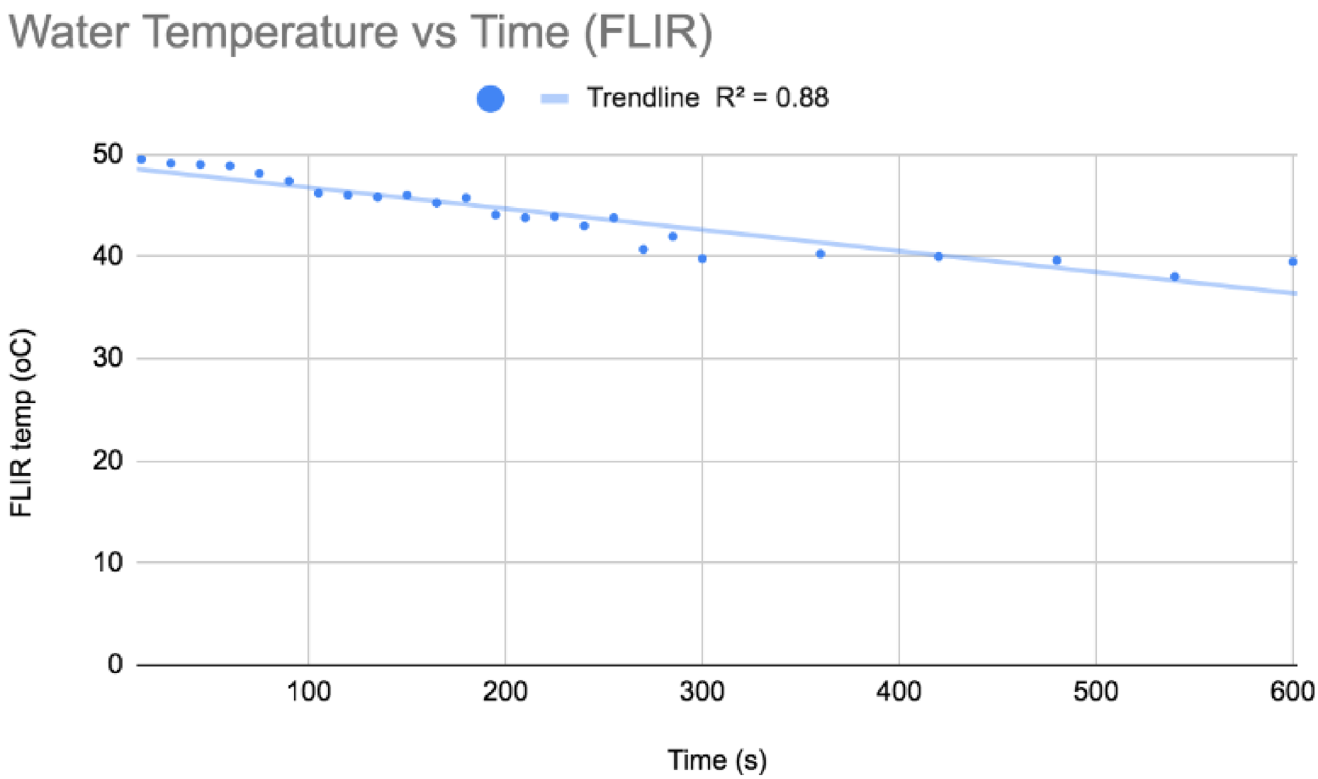


Figure 1: Line graph of Water Temperature (captured by FLIR) vs. Time

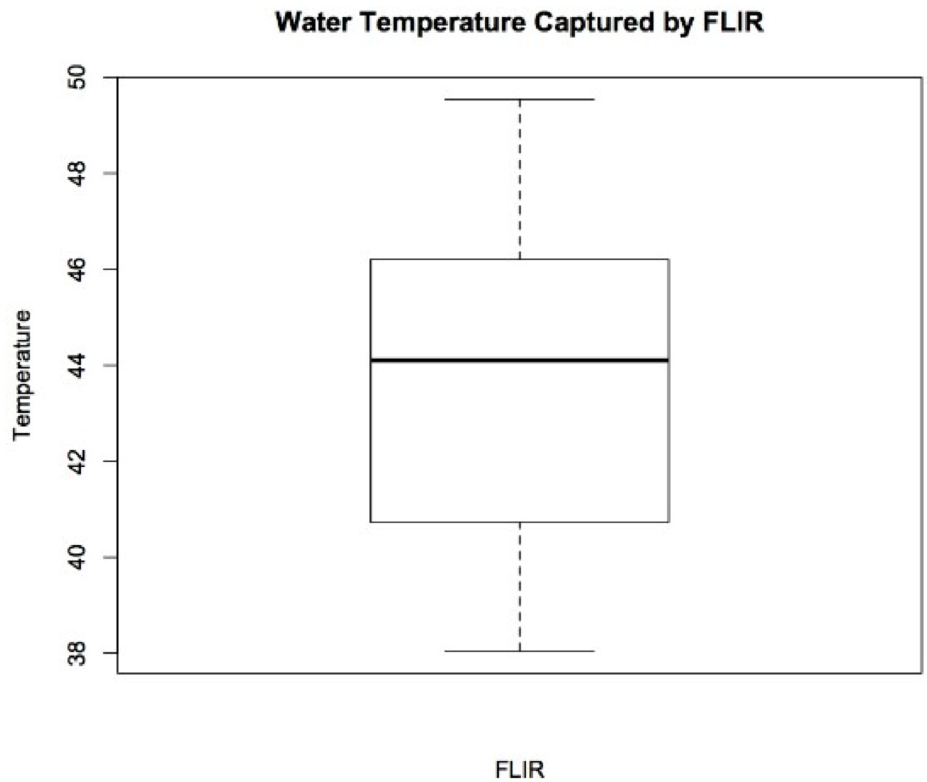


Figure 2: Boxplot of temperature points captured by FLIR

As shown on Figure 1, the data points for the first five minutes are very close together as the pictures were taken every 15 seconds. The temperatures recorded were also differ by a small magnitude which displays good camera resolution. It has mean of 44.23624^{o}C and standard deviation of 3.492498 which shows that the data points are pretty close to one another (Figure 2).

It was also proven to be accurate since the data points at time = 0 was recorded as 49.5422^{o}C while the actual water temperature was 48.89^{o}C (measured using meat thermometer).

Conclusions/action items:

FLIR E5 that was tested shows great accuracy and resolution. It will be compared to MLX.

2014/11/03-Entry guidelines

John Puccinelli - Sep 05, 2016, 1:18 PM CDT

Use this as a guide for every entry

- Every text entry of your notebook should have the **bold titles** below.
- Every page/entry should be **named starting with the date** of the entry's first creation/activity, subsequent material from future dates can be added later.

You can create a copy of the blank template by first opening the desired folder, clicking on "New", selecting "Copy Existing Page...", and then select "2014/11/03-Template")

Title: Descriptive title (i.e. Client Meeting)

Date: 9/5/2016

Content by: The one person who wrote the content

Present: Names of those present if more than just you (not necessary for individual work)

Goals: Establish clear goals for all text entries (meetings, individual work, etc.).

Content:

Contains clear and organized notes (also includes any references used)

Conclusions/action items:

Recap only the most significant findings and/or action items resulting from the entry.

2014/11/03-Template

John Puccinelli - Nov 03, 2014, 3:20 PM CST

Title:

Date:

Content by:

Present:

Goals:

Content:

Conclusions/action items:

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Complete Notebook

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