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Thermopile Sensor Imaging System

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ABSTRACT

With vastly growing technologies various sensing devices have emerged, which can be used with a microcontroller to provide mobility and ease for various sensing applications. This paper is focused to interface a thermopile sensor (HTPA8x8dL2.1/0.8) with a Raspberry Pi 3.

The thermopile array acquires thermal image data and communicates with a Raspberry Pi 3 via an I2C (Inter Integrated Circuit) interface. On the Raspberry Pi 3 side the data stream is logged and then transferred to a personal computer (PC). Finally, the thermal image data are visualized in the PC with MATLAB, a scientific computing software. In summary, the Raspberry Pi based thermal imaging system is portable and of low-cost, and is capable to be used in many applications especially in health care area in near future.

CHAPTER 1: INTRODUCTION

BACKGROUND

Thermal Image Sensing is an already existing technology that has its various advantages in several sectors. Heiman Sensors added some new features in this existing technology and provided a more competitive wide range solution with accuracy and sensitivity. Raspberry Pi is a single on chip board computer capable of running various programs to provide a cutting edge solution. Raspberry Pi can be interfaced to various sensors and it supports various programming languages that are helpful in developing different applications.

We will be using the HTPA8x8dL2.1/0.8 temperature and humidity sensor that is a thermopile array with lens optics technology. It comes in a small size, has high sensitivity, low power consumption and is cost effective. This monolithic thermopile sensor array allows the measurement of temperature distribution of the environment such as person detection, fire detection, industrial process control, air condition control and other security applications.

The thermopile array processes the data and communicates to a Raspberry Pi 3 via I2C protocol. The digital data stream transferred from the sensor to the Raspberry Pi contains the signal voltages of the elements, the offset of the amplifiers and the ambient temperature information. On PC side the data stream is logged and visualized with a signal processing software MATLAB. The software development on Raspberry Pi 3 is done using python programming language.

I2C is typically used for attaching lower-speed peripheral ICs to processors and other similar devices in short-distance, intra-board communication. For I2C communication, the chip uses the 7-bit address 0X1A for configuration and sensor data and the address 0X1B to access the internal EEPROM followed by 1 bit of read/write command. Then the address byte is followed by an 8-bit command.

Our objective is to interface thermal imaging sensor to Raspberry Pi using I2C protocol for thermal image processing.

STATEMENT OF PROBLEM

The problem of this research study is to interface the infrared based thermal imaging sensor with Raspberry Pi device, which can be used to develop thermal imaging applications. There are various devices available in the market that uses temperature sensors interfaced with Arduino or Raspberry Pi to detect temperature. Such devices, need contact with the target to obtain temperature of a specific point on the target. However, the thermal imaging sensor converts the infrared radiation emitted from the target into digital data and thus, visualizes the whole temperature map instead of giving the temperature of a specific point. This research is designed to develop a thermal image system which is capable of using a low-priced infrared thermopile array sensor. The HTPA 8x8d is the world smallest infrared array sensor with a resolution of 8x8 pixels inside **TO46 housing**. For interfacing it with Raspberry Pi, only 4 pins are required due to digital **I2C** interface.

PURPOSE OF THE STUDY

The purpose of this study is to design a low cost thermal imaging arrangement, which can receive measurement results from thermopile array sensors, and send an image array from a sensor to a programmed Raspberry Pi device. The objectives of this study supporting this purpose are:

1. To design and develop a thermal imaging circuit to transfer the digital data stream from the module using its built-in lens to the Raspberry Pi device via I2C.

2. To establish communication between Raspberry Pi device and external infrared thermal array sensor to obtain thermal images.

RESEARCH QUESTION

The goal of this research is to design a thermal imaging module using Raspberry Pi via I2C and evaluate its performance in sensing. The research questions for this study were:

1. Would the Raspberry Pi device generate an array for the external infrared thermopile array to support the thermal imaging?
2. What is the data communication technology between Raspberry device and infrared thermopile array sensor?
3. Which programming language or combination of programming language other than C support the interface between raspberry pi device and thermopile array module?

DELIMITATIONS OF THE STUDY

This study is delimited to:

1. The Raspberry Pi models: Raspberry Pi 3 model A.
2. The HTPA8x8d thermopile array.

LIMITATIONS OF THE STUDY

The following limitations are applied:

1. The developed prototype supports only 8x8 infrared thermopile arrays sensor with operating voltage of 3.3V.
2. The study is performed and tested with a Raspberry Pi 3 model A only.

DEFINITION OF TERMS

Raspberry Pi: It is made up of a series of small single-board and is developed by Raspberry Pi Foundation with the intention to promote low-cost computers and free software to the users.

Arduino: It is an open source electronics platform based on easy-to-use hardware and software. It is intended for anyone making interactive projects.

Thermopile Array: It is an array that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly, in parallel.

HTPA8x8d: It is the world smallest infrared array sensor with a resolution of 8X8 pixel inside TO46 housing.

EEPROM: A "read only memory" whose contents can be erased and programmed using a pulsed voltage.

UART: It is universally asynchronous receiver/ transmitter, a computer hardware device for asynchronous serial communication in which the format of data and transmission speed are configurable.

I2C: It is a "multi-master bus" which means that multiple chips can be connected from same bus and each one acts as "master" by processing data transfers.

SDA: It is a mass-storage disk. It is a utility program used by midrange IBM computer systems.

SCL: It is the data signal and clock line. It is used to synchronize all data transfers over I2C bus.

SPI: It is a synchronous serial communication interface used for short distance communication, and is primarily embedded in the systems.

GPIO: It is a generic pin-on integrated circuit whose output and input is controlled by user at run time.

MATLAB: It is fourth generation programming language and a multi-paradigm numerical computing environment.

Bread Board: It is a solder-less device for temporary prototype with electronics and test circuit's designs.

Putty: It is a free and open-source terminal emulator; serial console and network file transfer application. It supports several network protocols.

CHAPTER 2: LITERATURE REVIEW

THERMOPILE SENSOR IMAGING SYSTEM

Thermopile Sensors: Thermopile sensors are responsible for generating a thermoelectric voltage that is proportionate to noticed radiation. Use of these sensors varies from application to application. According to the non-dispersive infrared spectroscopy principle, these sensors can be used to measure the gas concentrations, for example CO, CO2, or hydrocarbons. The operated temperature for these sensors varies from -20 to 120 degree centigrade. These sensors are armed with thermistor that is beneficial in determining the housing temperature of the sensor which is, equal to ambient temperature. They are available with different housing in standard packages, like TO-39 packages, TO-46 packages and micro TO packages. Heimann Sensor is a German manufacturing company that has developed the first monolithic thermopile array and the worlds' smallest thermopile sensor in TO housing [1}. These sensors are available in the market in reasonable amount and much cheaper than other existing technologies, where high resolution is never a matter of worry. Some examples are: person detection, surveillance of temperature critical surfaces, security cameras and hotspot detection where the primary objective is to capture a thermal image rather than focusing on its resolution. There are several other applications that can be found in industrial process control and air condition control [2]. Its low cost, high sensitivity of the system with very small power consumption makes it prime [3]. Heimann Sensor has launched the improved version by increasing the quality of the sensors and changing the shape of the pixel and reducing the chip size.

Improved sensitivity: For the HTPA8x8 thermopile array the sensitivity was increased to a significant level to improve the housing by a factor of 3.8 from 65 V/W to 246 V/W. Changing the shape of the pixel, improved its quality. In addition to this, the housing is filled with inert gas to reduce the thermal conductivity. Fig. 1 depicts a thermal picture with a person showing his hands. The picture is taken and then hence processed with the Heimann Array Software.

Figure 1. Thermal picture with a person showing his hands

Improved distance dependency: An experiment to measure the distance dependency for HTPA8x8 thermopile array sensors with or without an aperture. It was noticed that there is a significant improvement of the distance dependency with the aperture.

HTPA8x8 small chip size: A small chip for HTPA8x8 thermopile array sensor that is designed by Heimann Sensor to fit into the TO39 package with a radius of only 4.55 mm. A 9-pin special TO39 header was selected to accomplish the desired needs. The TO39 housing with the HTPA8x8 on it can be seen in Fig. 2. The pixels of the HTPA8x8 are shown in Fig. 3.

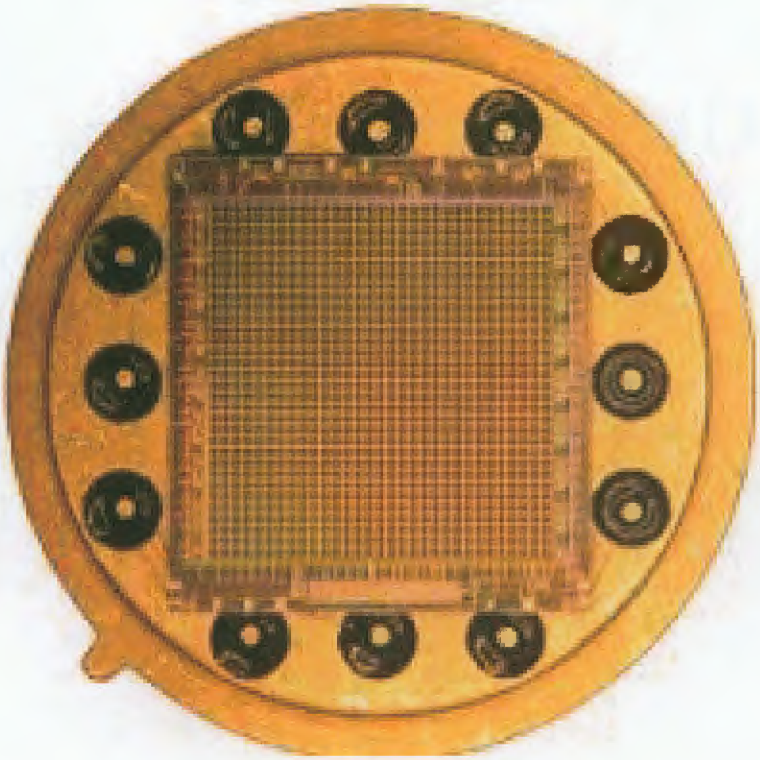

Figure 2. Picture of the HTPA8x8 chip pasted onto the TO39 header

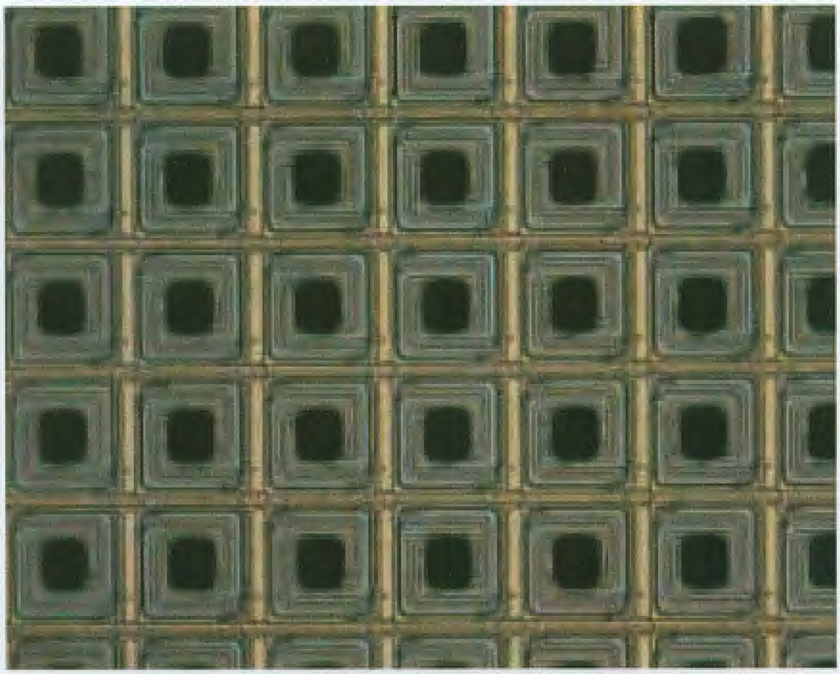

Figure 3. Picture of the pixels of the HTPA8x8.

According to the research "Scanning Thermal Imaging Systems with Thermopile Array Modules," the main idea is to demonstrate the outcome of developing the blueprint of thermal imaging scanning systems based on optical-electronic modules HMLX90620 (HTPA 4x16) and HTPA 32X31L17/0.8 thermocouple FPA with a 4x16 and 32x31format offered on the market by Heimann Sensor Gmb [4].

The main features of IR FPA are:

- Quick response to thermal radiation due to high thermal insulation and low weight of MEMS elements.
- Linearity
- Low power consumption
- High sensitivity

The primary cause of evolution of Uncooled IR Imagers was their ability to identify long-wave infrared radiation in the range from 7.5 to 14 μm.

The main benefits of the thermocouple sensors are:

- Compatible technological processes of sensitive elements manufacturing with standard CMOS technology,
- Possibility of realization IR FPA without cooling,
- Low cost of the IR thermal imaging modules and IR systems based on them,
- Sensing elements consume no power,
- Voltage output provides the ability of the electrical signal readout,
- High operating speed (response time ~0.05 s),
- High sensitivity (NETD ~0.15K).

In the apparatus with cooled photodetector, scanning of objects is done by moving mirrors or prisms positioned in the path of heat flow. This is how the image of scan field is moved corresponding to stationary detector in systems with optomechanical [4].

In conclusion, author says, Thermocouple IR FPA are appropriate for thermovision scanning systems with wide fields of view. Rather than using optical scanners here, the suggested solution use integration in a miniature module of all hardware control and signal processing of the image, while providing a low moment of inertia of the module.

The source is reliable because the invention of uncooled thermal sensors based on MEMS thermocouples for infrared optical-electronic thermovision systems seems very hopeful.

These systems can be implemented for:

- Energy saving,
- Environmental management
- Safety
- Special equipment

Another research presented by Fu-Feng Lee on Infrared Thermal Imaging System on a Mobile Phone dated 30 April 2015. According to this research, the main Idea is to launch a low-cost infrared thermal imaging system on the mobile phone which is embedded with an exclusive software. According to this, a measurement console and temperature measurement is developed which provides the essential function of thermal imaging.

The measurement console includes several Thermal Sensing Module (Thermal Infrared Module, TIM) which are coordinated in hubs for locating different positions.

The while architecture includes:

- A Wi-Fi Router
- A mobile phone (that plays the role of console)
- 64x62 thermopile IRFPA sensor
- A Microcontroller
- Ethernet controller circuits

The sensor consists of a single germanium lens so that the optical mechanism is made more comprehensible. In order to reduce spherical aberration, the surface of lens is made aspheric. On the lens, anti-reflective coasting (ARC) is embedded in a wavelength of 8-12 μm so that transmittance can be drastically improved without any obstruction [5].

In conclusion, the MTIS project present achievement are satisfactory and it attempts to deliver a new solution for low-cost thermal image that offers reliability along with accessibility and cost-efficiency.

Source is reliable, as it will not only offer promising solution for thermal imager but it will also reduce the price of low cost thermal imager based on thermopile detector below $1000 US dollars.

Moreover, integrating mobile phone with thermal imager will further reduce the cost if the mobile plays a role in computing as well as, a display unit. This will reduce the hardware cost of the thermal imager.

Another research work published on February 28, 2011 used thermal imaging for fever screening. The purpose of this research work is to describe the features of modern infrared imaging technology and the standardization protocols for thermal imaging in medicine. The main idea of this research, is how the features of modern infrared imaging technology and standardization protocols for thermal imaging helps assist in the field of medicine. The study of temperature also holds critical importance which, has widespread application across science and other industries.

For us as humans, 'comfort' plays an important role. To increase our comfort, we use clothing which are good as insulation in winters and we reduce clothing layers in summer gradually. The shell of the body (surface tissue mainly the skin), which forms the part of the regulatory process, are less likely to be stable than the body internal systems in terms of temperature. The human skin acts as a black body which has an emissivity of 0.96-0.98 [6].

For the last 50 years, thermal imaging has been used for conducting many researches. Thermal imaging has been used to study a number of diseases where temperature can effectively reflect the inflammation that still persists under the skin tissues or where due to clinical abnormality, the blood flow keeps on showing considerable variation [6].

In conclusion, thermal imaging can be effectively and efficiently applied in medicines either in the form of a diagnostic test or as an outcome for clinical trial.

Moreover, using thermal infrared for fever screening has its shortcoming too. ISO recommendation are often ignored when some of the equipment are currently used at airports and the way in which they are employed can increase the uncertainty of the accuracy.

Source is reliable as due to multiple industrial application, technology has become:

- More viable
- Technically more reliable

- Considerably much portable

THERMOPILE SENSOR IMAGING SYSTEM APPLICATIONS

There is a wide acceptability and growth of thermopiles and infrared sensors and its application. There are many applications where the thermopiles can be effectively used. The major benefits of using a sensor is that measurement system becomes easier and cost reduction can be successfully implemented [7].

Moreover, the sensor fitted in is so robust. It can be easily fitted, mounted or it can be glued to the surface.

MAJOR AREAS	APPLICATIONS
1. **Preventive and Predictive Maintenance**	• Overheat control units for bearings, transmission and gearboxes • Overheat control units for motors • Overheat protection for compressor units • Temperature control units for industrial rollers

2. <u>Housing control Systems</u>	• Small and smart control units for HVAC technology to monitor indoor climate • Contactless light switch units • Indoor air quality control
3. <u>Home Appliances</u>	• Control units for microwave ovens • Control units for tumble dryers • Control unit in toasters and stoves
4. <u>Medical and Wellbeing</u>	• Body temperature monitor units • Respiration monitor units • Non- contact fever Thermometers
5. <u>Industrial Process Control</u>	• Process liquid /gas flow detection in pipes • Heat flow detectors
6. <u>Security and surveillance</u>	• Sensors for entrance detection • Detection systems for monitoring presence • Motion detectors • Wake-up circuits for electronic door locks

7. **<u>Consumer Electronics</u>**	• Input devices • IR Thermometers • Fever Thermometers • Wake-up circuits for stand by operations

Table 1. Thermal Image Sensing Applications

CHAPTER 3: METHODS

LOW COST THERMAL IMAGING TECHNOLOGY

The low cost Thermal Imaging Technology enables the widespread use of Infrared imaging system that uses lens optics. The infrared imaging has the ability to see through obscurant, providing valuable information even in environment with degraded visibility. For data acquisition a single on-chip board is used with temperature and humidity. For this purpose, thermopile array HTPA8x8Dl2.1/0.8 needs to be integrated with Raspberry Pi 3 with the help of lens optics using I2C and the result will BE shown on the PC using MATLAB.

Various programming were used in trying to solve the research question. A suit of programming languages such as C, python, C++, Java, MATlab and ruby etc. were extensively studied to successfully develop a combination of programming languages which, would work in the proposed architecture. A combination of MATlab and python were found to be the ideal programming languages which, have worked successfully in the proposed architecture.

The interface and combination of programming language for Raspberry Pi and thermopile architecture were studied and found that "above said" methodology is the best and efficient combination for analyzing the results.

Python is the programming platform that is used to allow the communication between the Raspberry Pi device and infrared thermopile array sensor. The Pi has three types of serial interface on the GPIO header, they are UART, SPI, and I2C. I2C has been preferred over other communication protocols and the reason has been answered in the subsequent sections. The data is processed by thermopile array through I2C to Raspberry Pi 3, data stream is locked on a PC and then further these data streams are visualized by MATLAB. 7- Bit address OX1A is used for I2C communication and configuration to access the internal EEPROM OX1B. The1-bit read and write command is also used for this purpose. Now this address byte is followed by 8-bit command for further deliberations. Thermal imaging has led to dramatic size, cost and power reductions. The rich array of thermal application shows that the future of thermal sensors and imagers is very bright indeed.

COMPARISON WITH OTHER MODULES

FLIR LEPTON: It is long-wave infrared (LWIR) camera module. It can easily interface with consumer electronics and native mobile devices. It has a wavelength band of 8-14 microns and it captures radiation input in this particular wavelength and delivers a uniform thermal image as an output. Its dimensions are:

8.5x11.7x5.6 mm (without socket)

10.6x11.7x5.9 (with socket)

It also has a SPI video interface with thermal sensitivity which is less than 50 mk. It is also made to accommodate low power standby mode. This sensor is effectively used in thermal imaging, gesture recognition and building automation [8].

EXCELITAS COOLEYE SENSOR: This is a thermopile innovation which is, often associated with conserving energy. It is designed for those applications that requires low resolution 3-D thermal images capable of resolving human and small animals without the use of expensive, high resolution infrared imaging cameras.

It includes factory calibration, temperature signals, module (with connector), E2PROM configuration and data storage. It can also be adapted to specific requirements. All the modules are PCB with communication interface and a 4-pin connector. For line arrays, it offers 8 elements and 16 elements in two different configurations, one with 3.9 mm focus and another with 5.5 mm focus [9].

The thermopile array module consists of a 1x8, 1x16, 4x4 element thermopile chip connected to the integrated multiplexing and signal condition circuit. It can be effectively used on household appliances such as hair dryers, microwave oven, toaster etc.

ULIS MICRO80 GEN SENSOR: It provides 80x80 format thermal imager sensor which also includes a digital system, high quality imaging and lower power consumption features. It is filled with an integral lens holder that provides new standards for M10 mount optics. It uses standard implementation protocol (i.e. I2C) with full access to sensor features.

It consumes very low energy which is less than 55 Mw of all 80x80 sensors in the market. Micro80 Gen sensor also provided vision up to 150 m with accurate measurement of (+/-) 2%. It is more compact and light weight. Its overall dimensions are 14x14x9 mm with weight which accounts for less than 2 gram. It is based on micro bolometer detection technology. It is one of the best thermal image sensors of all times, with its outstanding battery life, advance performance, proven reliability, and easy implementation [10].

INTERFACING RASPBERRY PI WITH THERMOPILE ARRAY

There are various methods by which one could connect the Raspberry Pi device to other peripheral devices. Raspberry Pi GPIO pins and components identification are shown in Fig. 4. There are following essential things required to make a connection with other devices and make the pi device functional.

1. **SD Card:** It serves a purpose of saving memory that must be pre-installed with operating system called Raspbian.

2. **Display and Connectivity Cable:** HDMI cable is required to display the screen or see the graphical user interface. HDMI cable is connected from the Pi's HDMI port to monitors input port to display the Pi screen.

3. **Keyboard and Mouse:** These devices are connected to Pi's USB port for navigation and writing a code or browsing.

4. **Power Supply:** The Pi is powered by a USB micro power supply that can supply at least 5V of DC power.

5. **Bread Board:** This is required to avoid soldering and flexible use of wiring to connect the sensor with Pi device.

6. **Connecting Wires:** Minimum four male to female wires are required to make the connection between Pi device and peripherals via I2C.

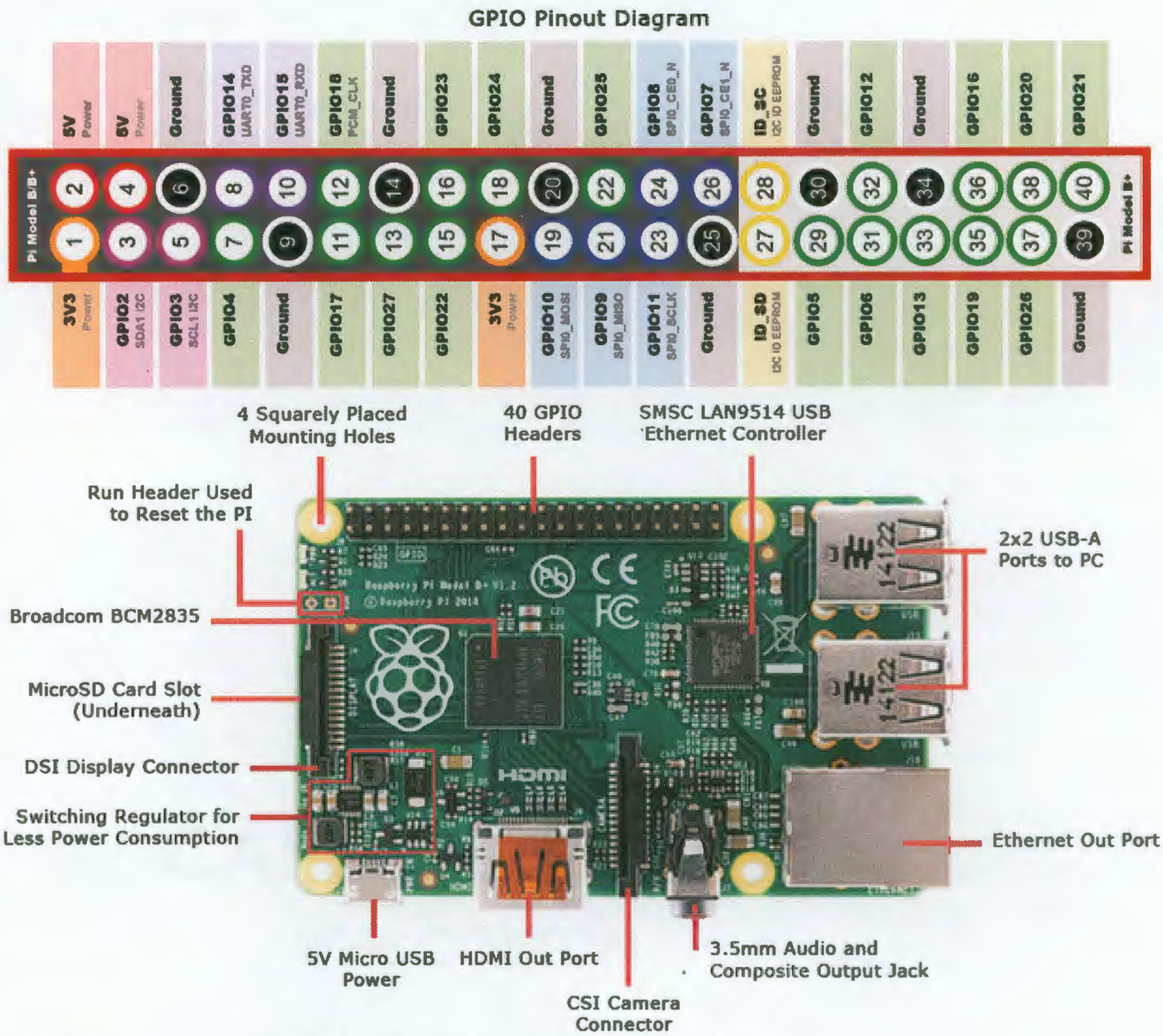

Figure 4. Raspberry Pi GPIO pins and components identification

Once the power is provided to the Pi device the SDA and SCL port of Raspberry pi 3 is connected with the respective SDA and SCL pin of HTPA8x8d infrared thermopile array sensor using the bread board. The Pi device has a row of GPIO pins along the edge of the board. There are total 40 extended GPIO pins that area physical interface between the Pi and the outer world. The Pi has three types of serial interface on the GPIO header that are UART, SPI, and I2C.

UART serial port allows opening a login session from a serial terminal application, such as putty. However, SPI allows for up to two devices, while I2C potentially allows many devices with a condition that their addresses should not conflict. The diagram below is the bottom view of HTPA8x8dL2.1/0.8 thermopile array and GPIO pins layout of Raspberry Pi device. Raspberry Pi and Thermopile Imaging System Architecture is shown in Fig. 5. Pin layout of HTPA8x8 thermopile array is shown in Figure 6. and Figure 7.

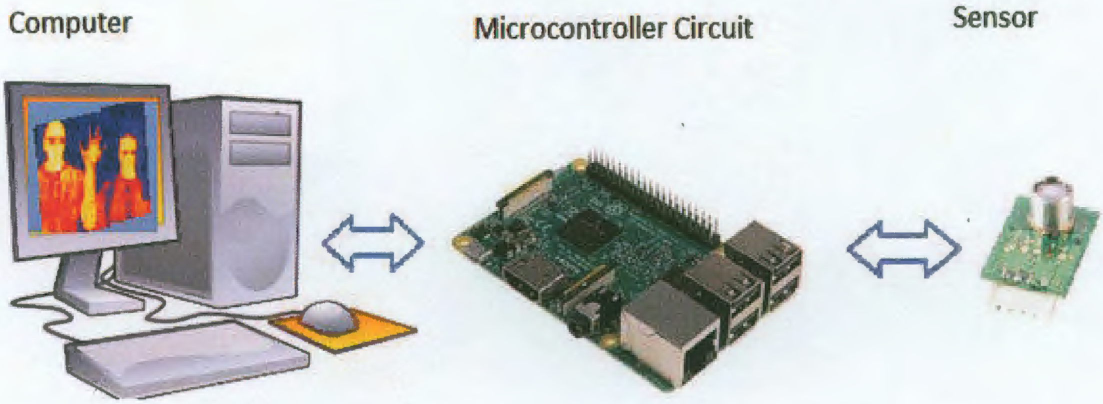

Figure 5. Raspberry Pi and Thermopile Imaging System Architecture

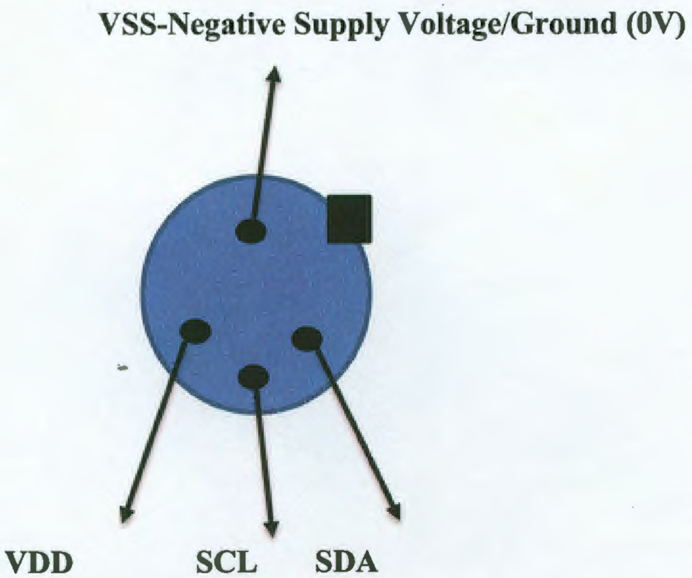

Figure 6. Bottom View (HTPA8x8d thermopile array sensor)

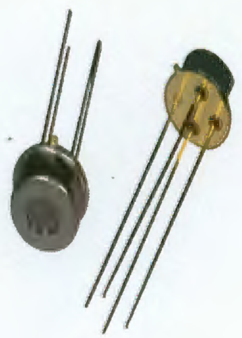

Figure 7. HTPA 8x8dL2.1-0.

INTERFACING PROTOCOL I2C

By default the I2C interface is disabled in the Raspberry Pi device. In order to enable this, it is suggested to open the command terminal and enter the below mentioned commands to enable the I2C interface. The commands mentioned below help to install the software and also upgrade it to latest version.

Step 1: Run the command below command and enable the I2C ARM interface in advanced option:

sudo raspi-config

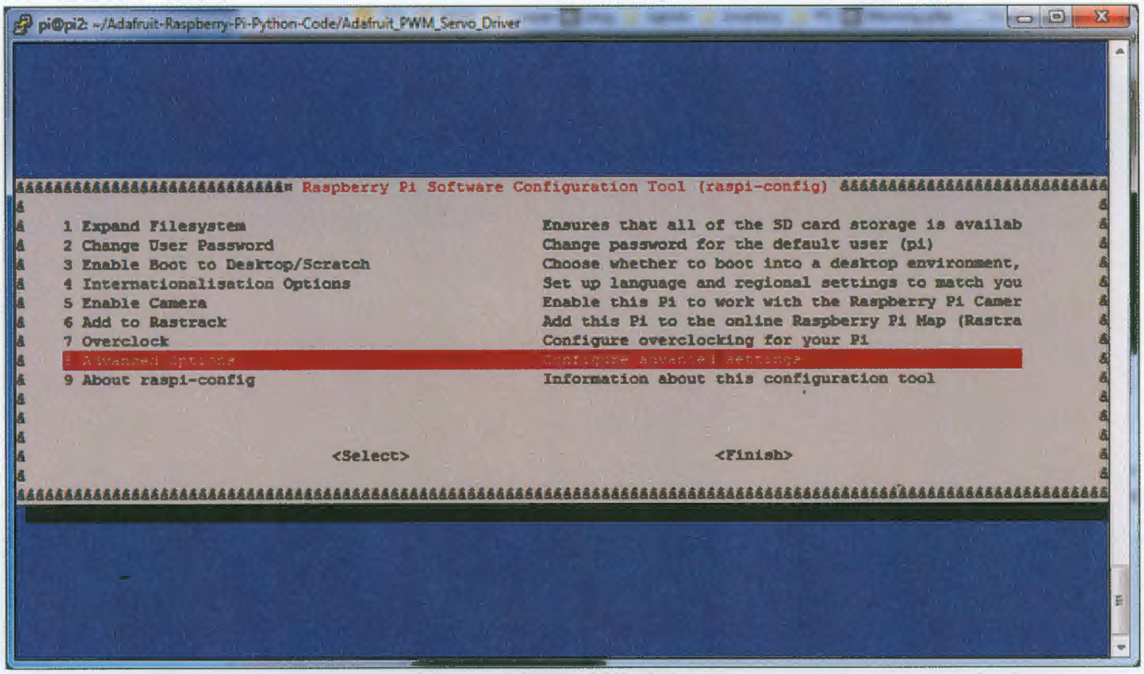

Figure 8. Raspberry Pi software configuration tool

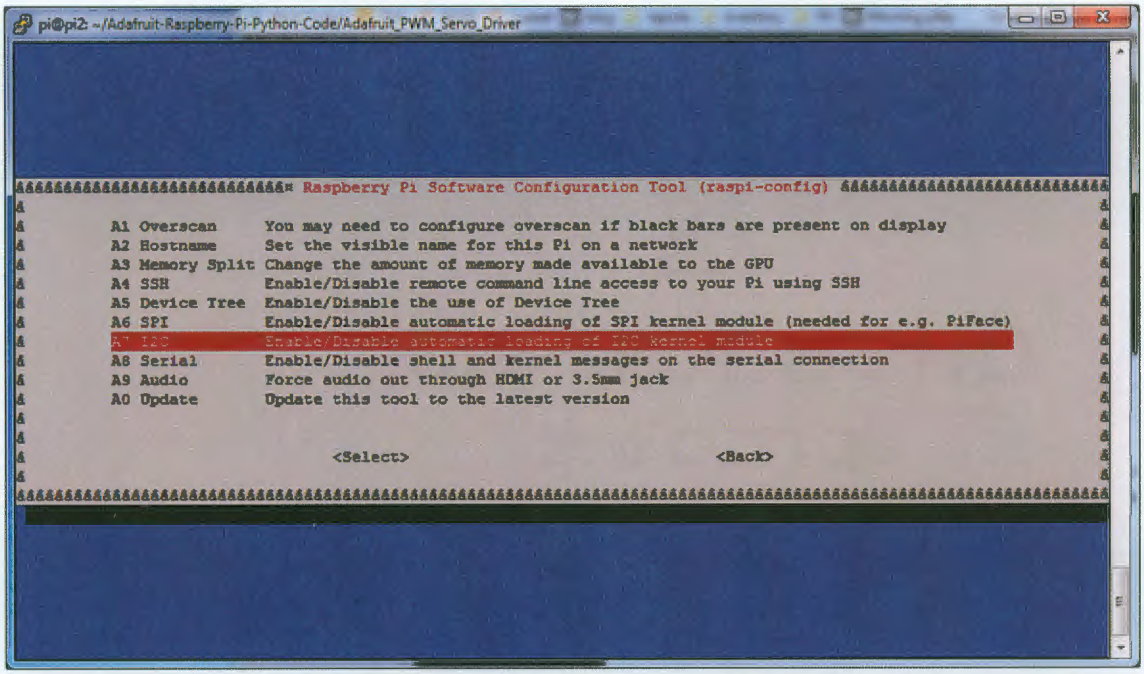

Figure 9. Raspberry Pi software configuration tool for I2C enable/disable

Figure 10. Raspberry Pi software configuration tool confirmation interface

Step 2: ***Then reboot it : sudo reboot***

Step 3: Run the following commands to get the latest updates:

sudo apt-get update

sudo apt-get upgrade

sudo apt-get dist-upgrade

Step 4: Run the following command to install SMBus and Python Dev:

sudo apt-get install python-smbus python3-smbus python-dev python3-dev

Step 5: Run the following command to install i2c: ***sudo apt-get install i2c-tools***

Step 6: Enable I2C and SPI protocol: ***sudo nano /etc/modprobe.d/raspi-blacklist.conf***

Step 7: Disable the blacklisting by adding '#' in the starting of below text:

#blacklist spi-bcm2708

#blacklist i2c-bcm2708

Step 8: update file config.txt: ***sudo nano /boot/config.txt***

Step 9: Add the following text:

dtparam=i2c1=on

dtparam=i2c_arm=on

Step 10: Set the Raspberry Pi to start I2C automatically at boot by editing /etc/modules:

sudo nano /etc/modules

Step 11: Add a new line and then add: ***i2c-dev***

Step 12: To avoid having to run the I2C tools at root add the 'pi' user to the I2C group:

sudo adduser pi i2c

sudo reboot

The above commands help user to enable I2C on their Pi device and the sensors are able to communicate with the Pi device.

CALIBRATION OF THERMOPILE ARRAY MODULE

For the purpose of calibrating a thermal camera, multi-point calibration needs to be performed accurately. Moreover, various steps need to be presented to the camera in succession, including multiple temperature samples and scanning the entire temperature range of the camera. Due to heat dissipation, which occurs during calibration, the camera detector, readout electronics and the lens will experience a temperature drift. Since, the above phenomenon occurred, some errors would be created during the calibration that may exceed the stated specification of the camera. This problem can be solved by using one or two black bodies since their settling time would most likely exceed the time taken for calibration. An array of black bodies is generally used by the manufacturers to mitigate the potential issues, where these black bodies are programmed at different temperatures across desired temperature range of the camera. By doing so, the camera can be quickly moved from one black body to another by a robotic arm thereby, reducing the time for calibrating the next temperature point.

A temperature calibration is always required to obtain the most accurate temperature measurements from the device where, the output of the device is compared to a temperature reference. As far as, an IR camera is concerned, it is calibrated by imaging a target surface over a range of known temperatures. Usually the range of temperature is lesser than the range of the calibration temperature which, are to be measured during the experiment or application. A look-up table or curve fit to data can be derived from the relationship between the camera gray level and the target surface temperature.

Since, the response of the sensor is not linear, therefore calibration is needed. By saying that the response of sensor is not linear, we mean that if you have an infrared light sensor of low intensity, then every pixel will not give exactly the same response. Let us take an example that a pixel gave a response of 100 and it gives another response of 90 to the light of the known infra-red light source. Now each pixel gives a response which, lies within a range of 0-255 i.e. 8-bits unsigned. Then in order to make two pixel responses more linear and then normalize them, we need to find the mean of two responses which, is calculated below:

Mean = (100+90)/2 = 95

And now we need to multiply the above value with a constant factor to get the mean value

Pixel 1= 100*0.95=95

Pixel 2=90*1.055=94.5

The pixels gave the same response which, is the desired behavior. Therefore, in this project, dark image is used every time to carry the calibration process, as by doing this, we get the response of all pixels on same intensity of light and afterwards we can normalize it as explained above. For any analog sensor, linear response is always expected and if, such linear response is not achieved, then somehow we need to fix or calibrate it to get linear response.

CODE

```
from periphery import I2C
import time
import numpy as np
import copy
import pickle
#from PIL import Image
i2c = I2C("/dev/i2c-1") # Define I2C bus controller address
device_addess = 0x1A
def generate_command(register, value):
    return [I2C.Message([register, value])] # send message to register


def send_command(cmd):
    i2c.transfer(device_addess, cmd)
    time.sleep(0.005) # sleep for 5 ms
wakeup = self.generate_command(0x01, 0x01) # wake up the device
adc_res = self.generate_command(0x03, 0x0C) # set ADC resolution to 16 bits
bias_top = self.generate_command(0x04, 0x0C) # Generate bias commands
bias_bottom = self.generate_command(0x05, 0x0C) # Generate bias commands
clk_speed = self.generate_command(0x06, 0x14) # Generate clock speed command
cm_top = self.generate_command(0x07, 0x0C) # Generate trimming current for top part of the
sensor to 1.5uA
cm_bottom = self.generate_command(0x08, 0x0C) # Generate trimming current for bottom part
of the sensor to 1.5uA
pull_ups = self.generate_command(0x09, 0x88) # Activate 100kohm pull up resistors on SDA
and SCL I2C pins command
```

```
expose = generate_command(0x01, 0x09) #configure register 1 to start and wakeup
print("Sending commands")
send_command(wakeup)
time.sleep(1)
send_command(adc_res)
time.sleep(1)
send_command(bias_top)
time.sleep(1)
send_command(bias_bottom)
time.sleep(1)
send_command(clk_speed)
time.sleep(1)
send_command(cm_top)
time.sleep(1)
send_command(cm_bottom)
time.sleep(1)
send_command(pull_ups)
time.sleep(1)
send_command(expose)
query = [I2C.Message([0x02]), I2C.Message([0x00], read=True)] # Send I2C commands to read
EEPROM , read 0 for 0X02 and  read 1 for 0X0A
done = False
while not done:
    i2c.transfer(device_addess, query)
    if not(query[1].data[0] == 1):
```

```
        print ("Not ready")
        time.sleep(1)
    else:
        done=True
print("message" % query[1].data)
msg = [I2C.Message([0x0A]), I2C.Message([0x00]*130, read=True)] #read 130 bytes
i2c.transfer(device_addess, msg)
dataLSB=msg[1].data[1::2] # to get the least significant bits
dataMSB=msg[1].data[::2] # to get the most significant bits
data_Temp = np.zeros(len(dataLSB))
Fdata = np.zeros(64)
Ptat= np.zeros(1)
for i in range(len(dataLSB)):
    dataMSB[i]=dataMSB[i]<<8
    dataLSB[i]=dataLSB[i]& 0x00FF
    data_Temp[i]=dataMSB[i]+dataLSB[i]
Ptat=data_Temp[0]
Fdata=data_Temp[1:65]
print(len(data_Temp))
print(Ptat)
print(Fdata)
Arraydata=Fdata.reshape(8,8)
print(Arraydata) #to print the 8x8 array
###############################################################
```

RESULT

```
#Data Received:

Sending commands
Not ready
message
65 #length of the array data
31809.0 #PTAT value

[ 33058. 33058. 32993. 33002. 32941. 33103. 32742. 33169. 32926.
 32848. 33163. 32993. 33041. 33004. 32913. 33017. 33020. 32705.
 32955. 32992. 32958. 33012. 32983. 32778. 33042. 32856. 33040.
 32700. 32932. 32747. 32941. 32971. 33099. 33083. 33123. 33080.
 33055. 33107. 33164. 33038. 32876. 33041. 33284. 32838. 32801.
 33100. 33058. 33245. 33141. 33251. 33070. 32975. 33002. 33127.
 33115. 33223. 33067. 33092. 33177. 33014. 32935. 33115. 33122.
 33025.]

[[ 33058. 33058. 32993. 33002. 32941. 33103. 32742. 33169.]
 [ 32926. 32848. 33163. 32993. 33041. 33004. 32913. 33017.]
 [ 33020. 32705. 32955. 32992. 32958. 33012. 32983. 32778.]
 [ 33042. 32856. 33040. 32700. 32932. 32747. 32941. 32971.]
 [ 33099. 33083. 33123. 33080. 33055. 33107. 33164. 33038.]
 [ 32876. 33041. 33284. 32838. 32801. 33100. 33058. 33245.]
 [ 33141. 33251. 33070. 32975. 33002. 33127. 33115. 33223.]
 [ 33067. 33092. 33177. 33014. 32935. 33115. 33122. 33025.]]
```

*Figure 11.*Generated Array from the thermopile array module.

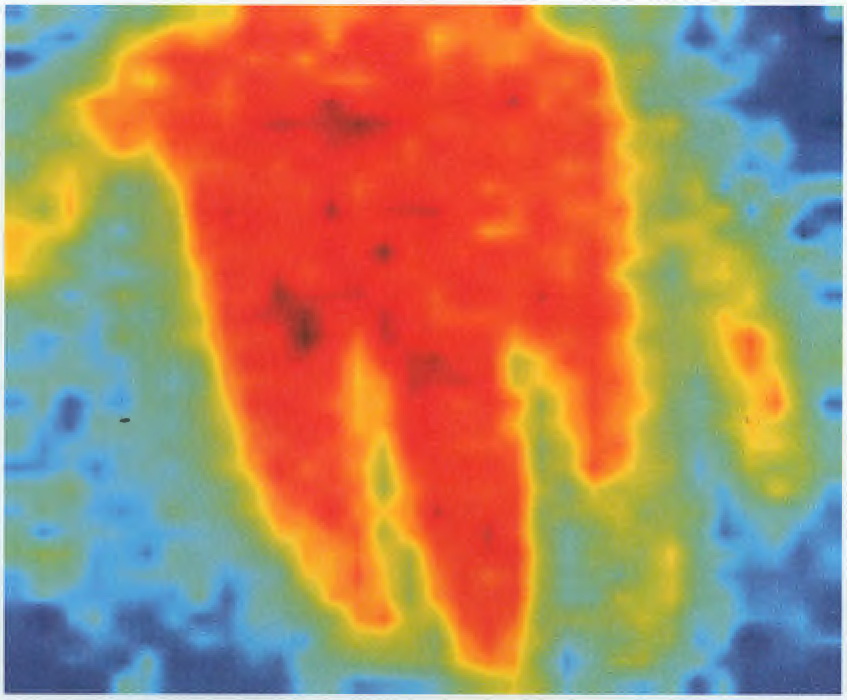

Figure 12. Image of a palm produced for the generated array.

CONCLUSION

Through this methodology and architecture studied, imaging results were successfully retrieved. This image, answers that the proposed methodology generates a successful thermal image which, contributes to the research questions. This methodology also, provides a working combination of programming languages which also, contributes to the research questions. Using I2C communication protocol was an efficient approach to bridge the communication between Raspberry pi and the thermopile array module. The results proved that this combination of programming languages and communication protocol can be used in a wider scale for applications, as mentioned in the literature survey. An improvement can be made using semiconductor micro computer chips and integrating thermopile array modules which, would drastically reduce size, production cost, and can be used as a subsystem component for other applicable devices.

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