Imaging of blood vessels in finger joints using dual wavelength lasers and transmission techniques

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A dissertation submitted for the partial fulfillment of BS-MS dual degree in Science

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Certificate of Examination

This is to certify that the dissertation titled "**Imaging of blood vessels in finger joints using dual wavelength lasers and transmission techniques**" submitted by Asif Mohammed L (Reg. No. MS15081) for the partial fulfillment of BS-MS dual degree programme of the institute, has been examined by the thesis committee duly appointed by the institute. The committee finds the work done by the candidate satisfactory and recommends that the report be accepted.

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(Supervisor)

Dated: June 15, 2020

Declaration

The work presented in this dissertation has been carried out by me under guidance of Dr. Samir K. Biswas at the Indian Institute of Science Education and Research Mohali.

This work has not been submitted in part or in full for a degree, a diploma, or a fellowship to any other university or institute. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due acknowledgement of collaborative research and discussions. This thesis is a bonafide record of original work done by me and all sources listed within have detailed in the bibliography.

Asif Mohammed L
(Candidate)

Dated: June 15, 2020

In my capacity as the supervisor of the candidate's project work, I certify that the above statements by the candidate are true to the best of my knowledge.

Dr. Samir K. Biswas
(Supervisor)

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Abstract

The imaging of blood vessels in finger joints proves to be a crucial part in medical field. Commonly used techniques in this subject belongs to the optics and acoustic field. In this project the imaging of blood vessels is done using noninvasive technique of transmitting light through finger joints. Lights of specific wavelengths (630 nm and 930 nm) are used in this respect and the image is then captured with the help of a Raspberry Pi Noir v2 camera. The captured image is hence analyzed with the help of Matlab for further enhancements.

Chapter 1

Designing the experimental setup for finger joint blood vessels imaging

1.1 Introduction

Current experimental techniques related to imaging of blood vessels lies predominantly in close link with the speckle technique. In speckle imaging light of specific wavelength is allowed to shine and reflect from the finger joints, and the pattern obtained after reflection is studied. Another method of imaging blood vessels using light is through transmission techniques. Here lights of specific wavelengths are passed through the finger joints, and the illuminated joint is the captured using camera. This method also aims to be more cost efficient when further developed into a medical tool.

1.2 Preliminary experimental setup and modelling

At first the blood flow is stimulated externally to study and understand the fine points [Hesko 17]. This is done with the help of PDMS membrane and syringe motor.A PDMS solution is poured into a petri dish and wires of different cross sections are placed in this petri dish. The petri dish is then left in heat chamber for the PDMS

to solidify. Once it is solidified, the wires are removed and channels of different cross sections are obtained. With the help of syringe motor the flow rate is controlled and the liquid is allowed to pass through these channels. Distilled water is used in this step of modelling. This setup was done as a basic step towards fulfilling the transmission technique and to get a feel of the experiment initially.

1.3 Initial Experiment Design

The schematic diagram of the initial setup is shown here. The components used here includes

a) White LED

b) Raspberry PI Camera

c) Raspberry PI Processor

d) Power Source

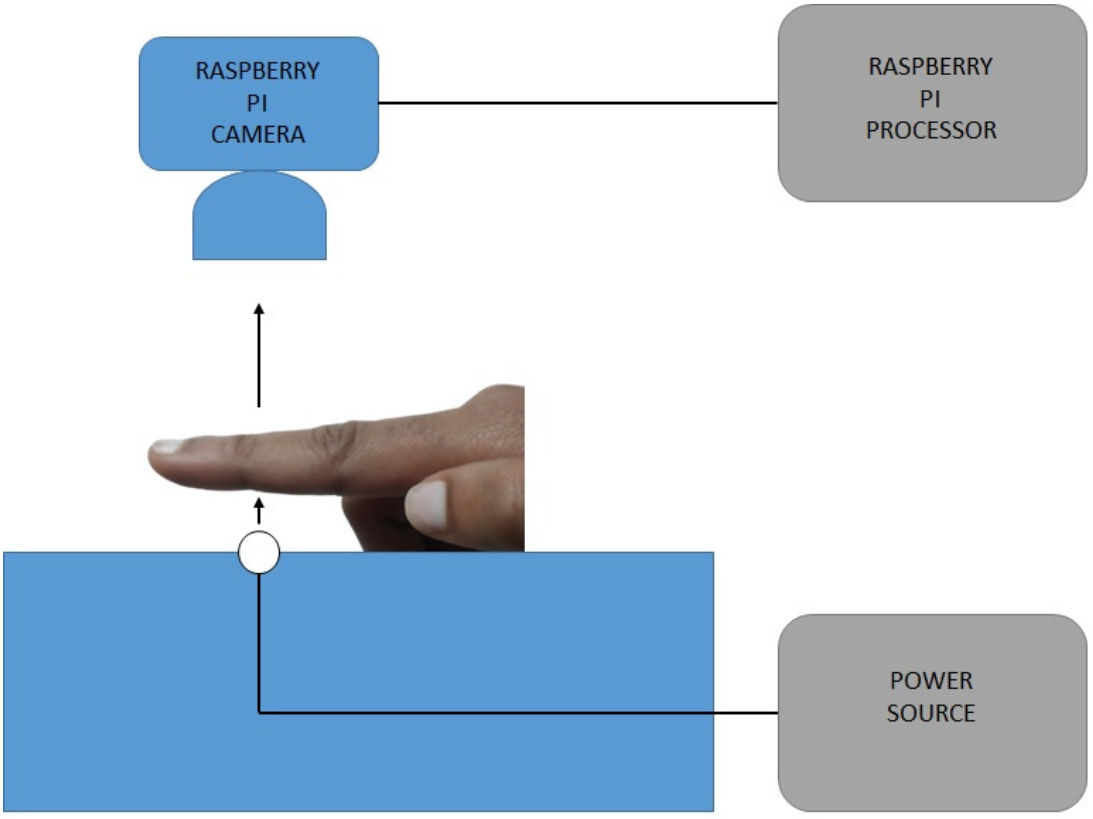
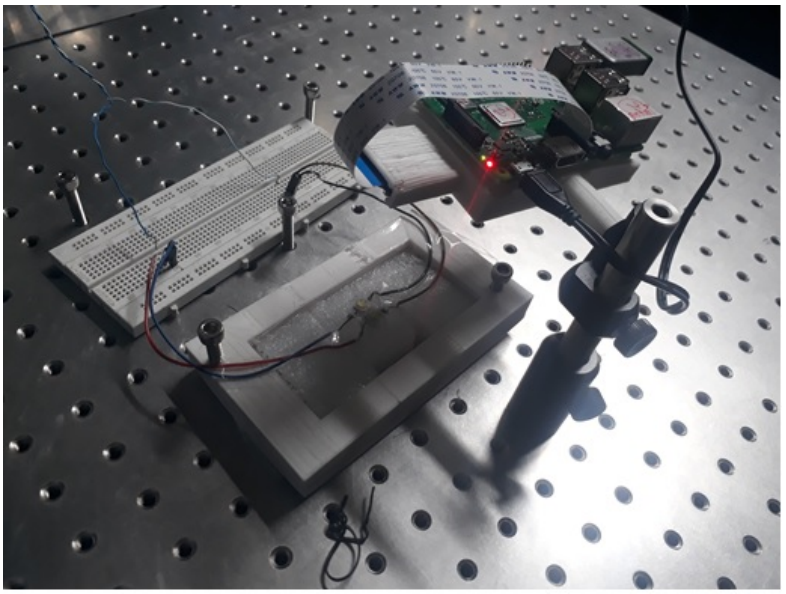


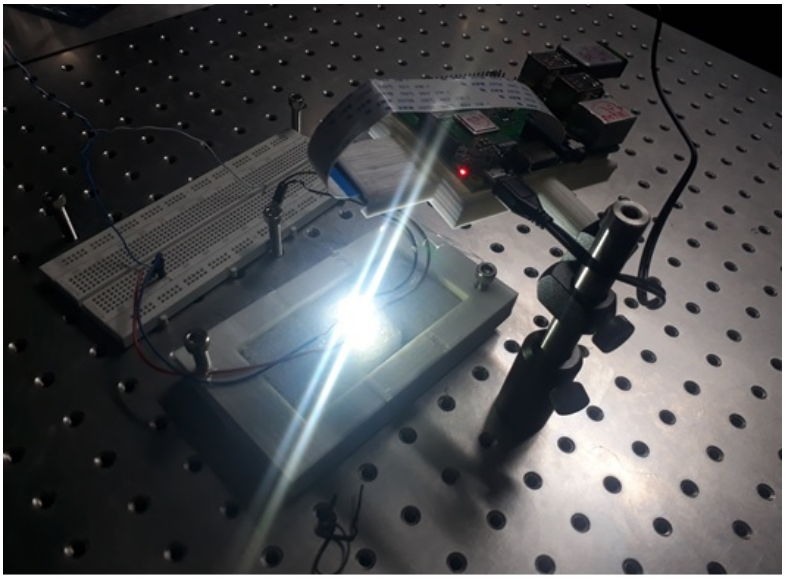
FIGURE 1.1: Schematic Diagram of the initial setup

From the start of experiment one of the aim was to keep the setup as simple as possible.

The idea here is that the LEDs are connected to a constant power source of 5V. The fingers are placed above the LEDs and the light is thus transmitted through the finger joints. The image is then captured with the help of raspberry PI camera, which is connected to a raspberry PI processor. This is the simplest experimental setup in the whole thesis work.



(A) Toggle off case



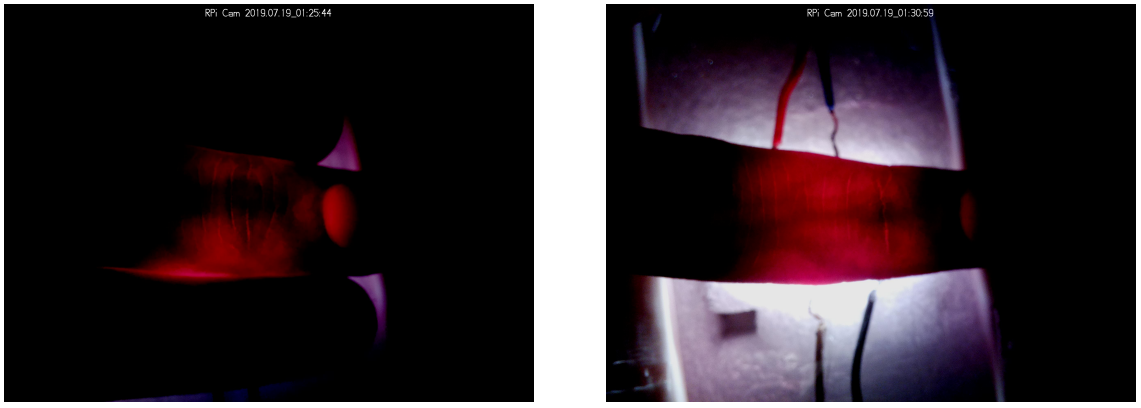
(B) Toggle on case

FIGURE 1.2: Initial experimental setup

The figure shows the experimental setup in the optical bench. Custom case and holder were printed for the Raspberry pi processor and camera using the 3d printer.

1.4 Observations at the initial stage

The initial images obtained were satisfactory and showed a stark contrast between skin and the major blood vessels.



(A) Finger 1 (B) Finger 2

FIGURE 1.3: Initial Observations

Here the image shows fingers of two different individuals.

1.5 Extending the experimental idea and choosing wavelengths for LEDs

The initial stages of experiment showed good results and the next step was to add different wavelength LEDs to the experiment for better results. The wavelengths 630 *nm* (red) and 930 *nm* (IR) are used here in this respect. The reason for choosing these two wavelengths were to incorporate pulse oximetry data into the experiment if possible. This will be discussed in detail in Chapter 2.

1.6 Modified Experimental Setup

As mentioned in the last section the white LED in the initial setup was replaced with IR and red LEDs. The schematic diagram of the modified setup is shown here. The components used here includes

a) IR (930 nm) and Red (630 nm)

b) Raspberry PI Camera

c) Raspberry PI Processor

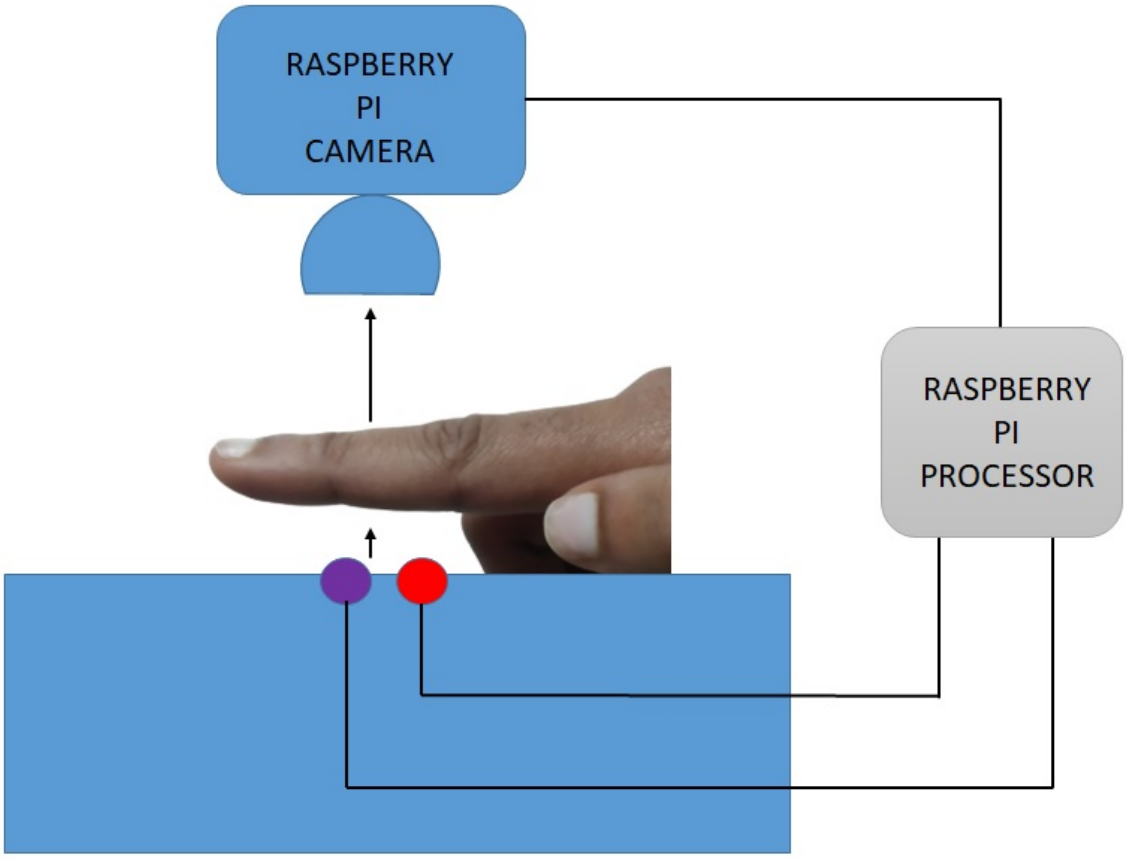


FIGURE 1.4: Schematic Diagram of the modified setup

Another important aspect which can be noticed here is the elimination of power source. In the initial setup the white LEDs were powered by an external power supply which is maintained at a constant potential difference of 5V. Here as show in figure, the LEDs are connected to the raspberry pi processor itself. The advantages are two in this case

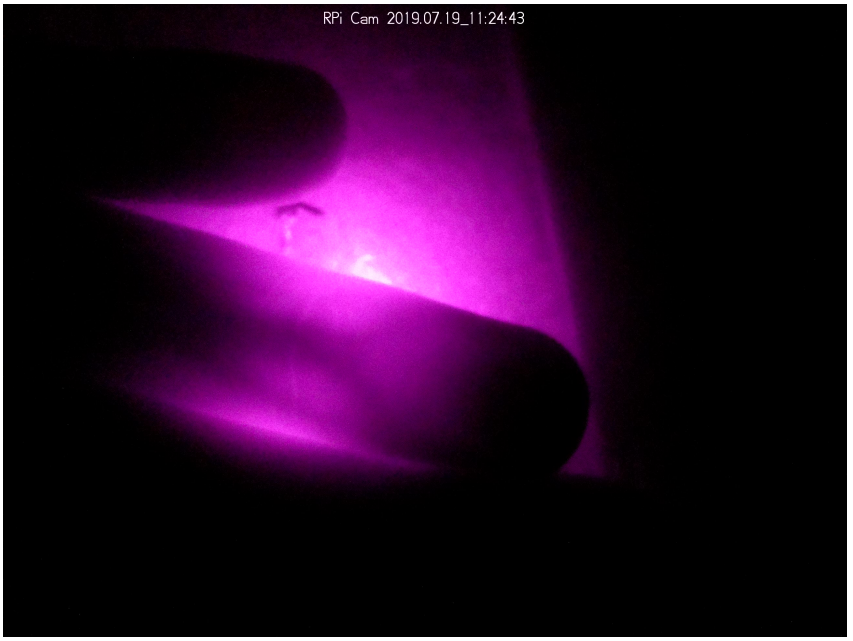
1) By eliminating the need of an external power supply exclusively for the LEDs, the setup is simplified further.
2) By connecting the LEDs to the Raspberry Pi processor, we can program the toggle situation of the lights.

And the latter point is really useful now. The modus operandi of image capture should be mentioned before discussing the usefulness. With the help of Raspberry Pi camera, a video is shot and screenshots are taken from it. In this way more data can be captured (as taking snapshots in a defined interval can lead to loss of information). By connecting the LEDs to the raspberry pi, we are able to synchronise the LEDs with the frame rate of camera. But then the question is why are we synchronising the LEDs with the fps of camera. The working of LEDs should be discussed first. Here we have dual wavelengths, and making them work simultaneously is not fruitful. The method here is to alternatively on and off the two LEDs. Because we need information with both the lights, and if it is working at the same time, separating the images will be a tedious task.
With the help of python code we are able to program the LEDs. The code is included in the appendix section. Initially the LEDs are programmed to toggle on and off alternatively within a time period of 1 second. The time gap was then made as small as possible without interfering the video quality. But still a complete synchronisation between the camera and LED was not made possible at this stage.

1.7 Improved results with the modified setup

The modified experimental setup worked well and the results obtained were satisfactory at this stage [Li 18] . Another aspect which is to be worth mentioning is the clarity and depth of IR images. Images obtained under the IR lighting found out to be of superior clarity compared to that of Red light. Following images shows the finger under IR lighting. Fingers of four different people are imaged to check the productivity of the experimental setup

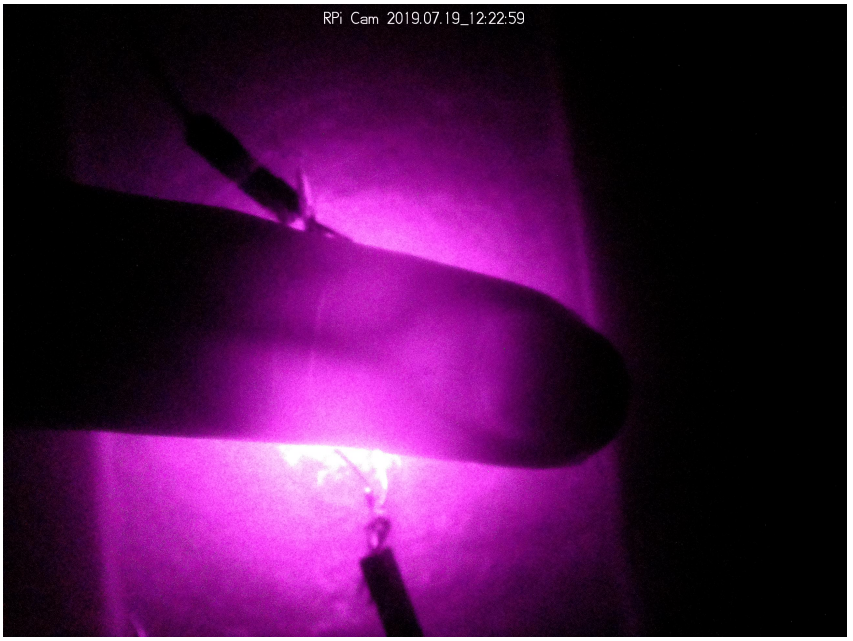
(A) Finger 1



(B) Finger 2

FIGURE 1.5: Fingers under IR Lighting

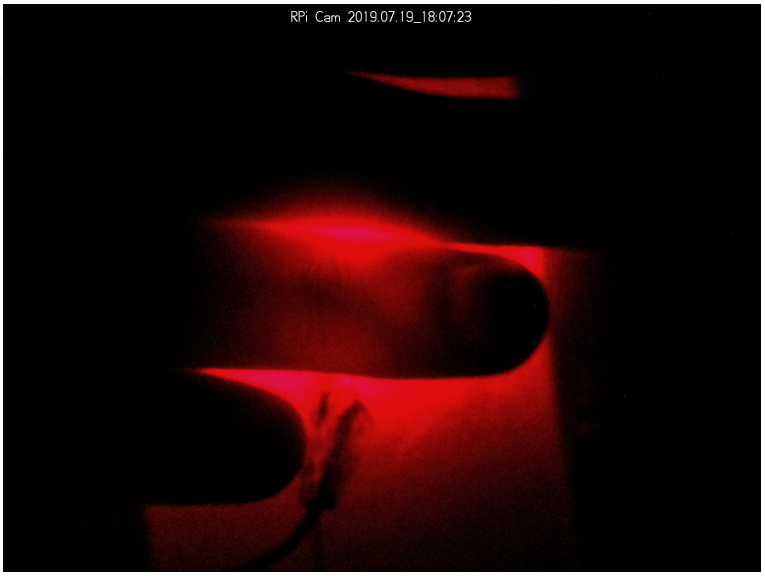
(C) Finger 3



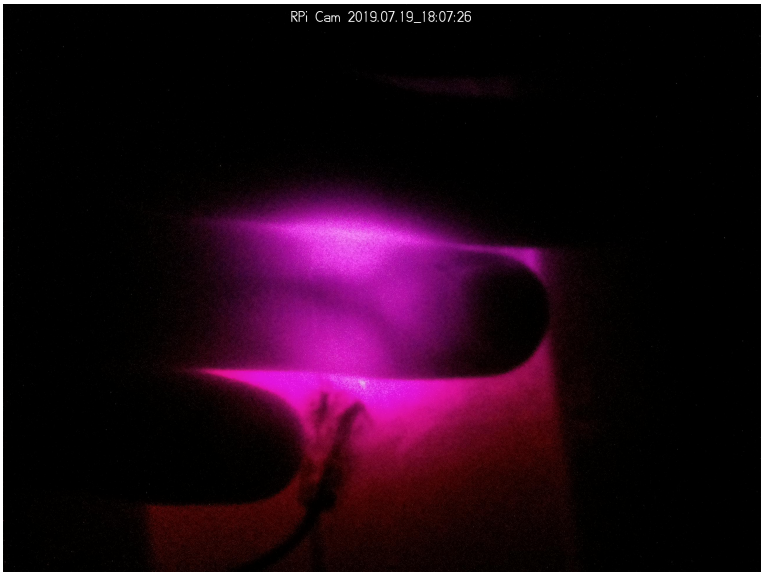
(D) Finger 4

FIGURE 1.5: Fingers under IR Lighting

Now below showcase a finger under Red and IR ligthing.



(A) Finger under Red Light



(B) Finger under IR Light

FIGURE 1.6: Same finger under both Red (630 nm) and IR (930 nm) Lights

From the images one of the main problem observed is the leakage of light laterally. The next step was to eliminate this leakage and making the finger brighter.

1.8 Avoiding light leakage and revising the experimental setup

The main aim at this stage, as mentioned in the previous section was to eliminate leakage of light through the sides of finger. A simple 3D printed sliding apparatus helped with this. The revised setup is shown below.

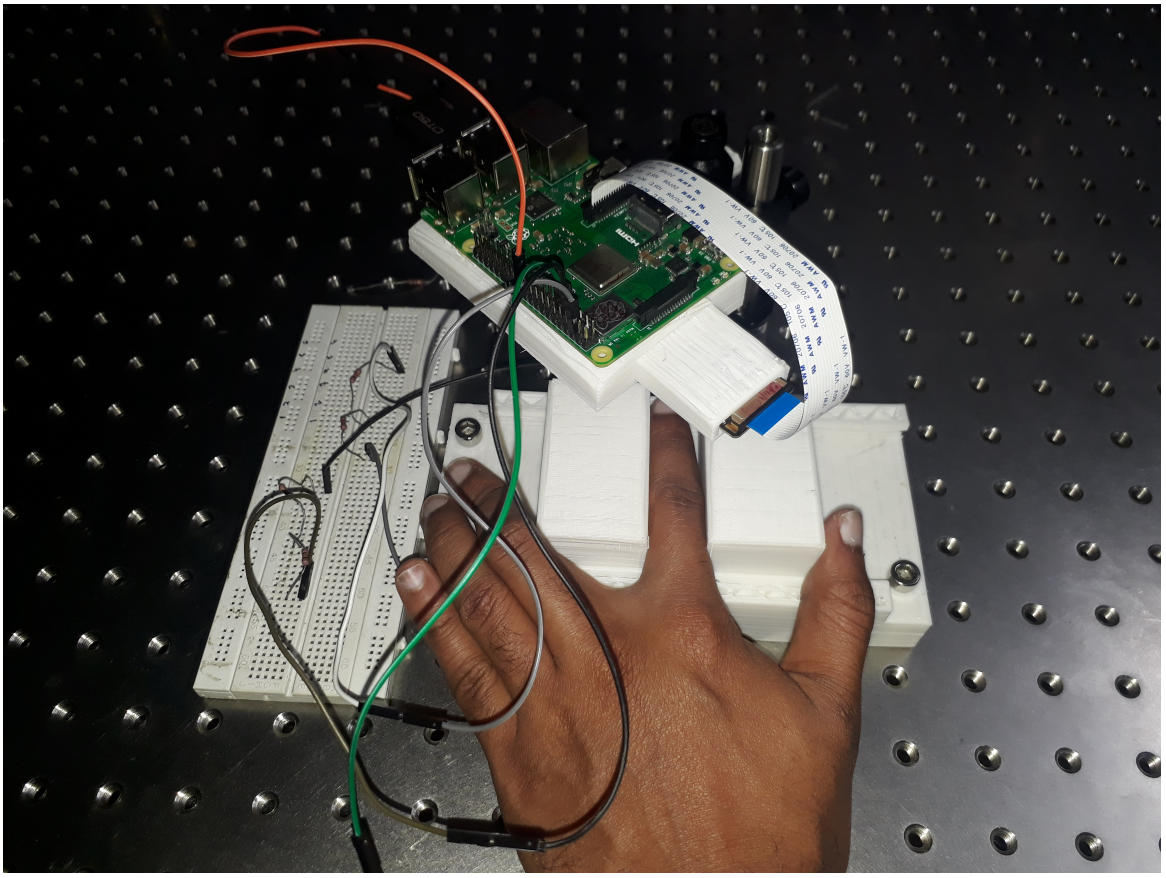


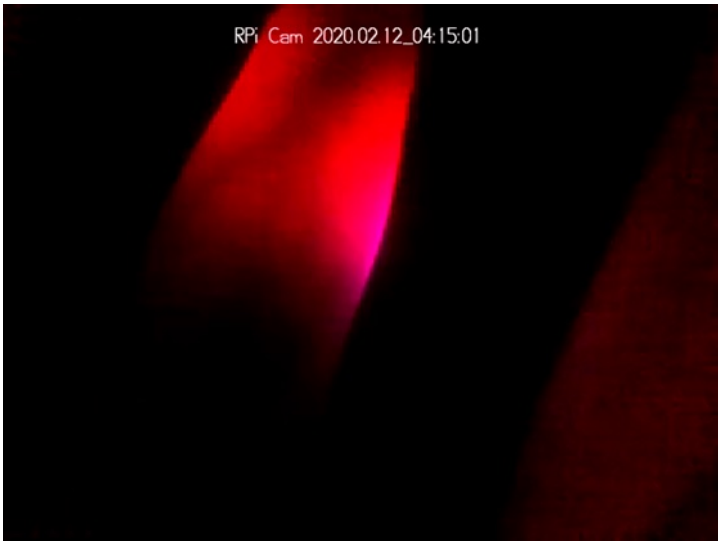
FIGURE 1.7: The revised setup to stop leakage of light

Along with this a further addition was made by adding rectangular piece of sponge on both sides of the finger. This ensured in maximum leakage proof of light.

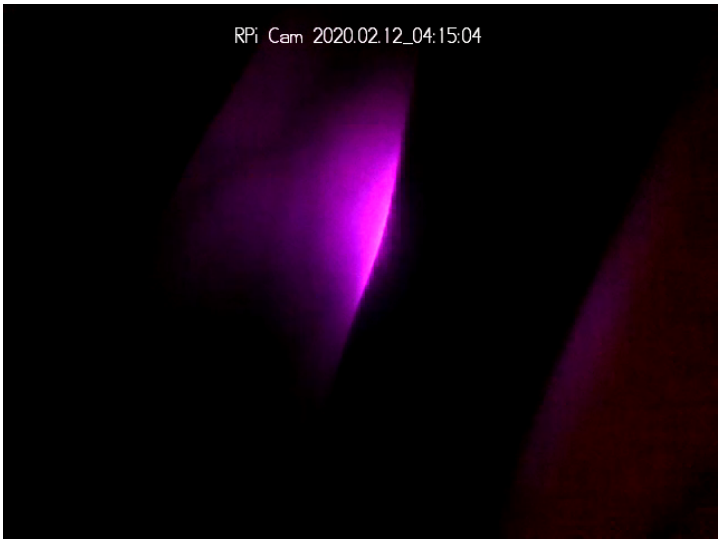
1.9 Changing fps of camera and image capturing

The camera used through out the experiment session was Raspberry Pi Camera Noir V2. Initially videos were recorded on a quality of 1080p at 30fps. Although the images

were of superior quality, a problem encountered was the loss of frames/information in between. As blood flow is a dynamic process, the more the frames we had for analysis, the better the result will be. Since more frames give even the minute details in blood flow. But increase in the frames leads to reduce in quality of the video. A balance needs to be thus find out and hence a video quality of 480p at 90fps was fixed. The image captured in this setting is shown below.



(A) Red Light



(B) IR Light

FIGURE 1.8: Fingers at 90fps

Chapter 2

Analysing the results obtained and applications

2.1 Introduction

The experimental setups in the previous chapter provided with data for analysis. Further image analysis is done using Matlab to form more clearer images and to establish results. But before that it is important to discuss why the IR(930 nm) and red(630 nm) is used in the experiment.

2.2 Reason for choosing specific wavelengths and Pulse Oximetry

In the last chapter it was said that the reason for choosing 930nm and 630nm will be discussed in this chapter. For that first it is necessary to understand the principle of Pulse Oximetry. Pulse Oximeters are certain medical devices which calculates the amount of oxygenated Haemoglobin in the blood (or the oxygen saturation in blood). When we inhale, oxygen enters our lungs and from the lungs, it is distributed to different parts of the body through blood. The blood contains haemoglobin molecules, and when the oxygen molecules get linked with haemoglobin molecules, it is called

oxygenated haemoglobin. And the haemoglobin molecules which do not carry oxygen are called deoxygenated haemoglobin. Now as we breathe in and breathe out, the concentration of oxygen in our body varies and hence the concentration of oxygenated haemoglobin, and thus the concentration of deoxygenated haemoglobin. Oxygen saturation refers to the percentage of oxygenated haemoglobin in the blood.
In Pulse Oximetry, optics is used to find out the oxygen saturation in blood. The schematic diagram is shown below

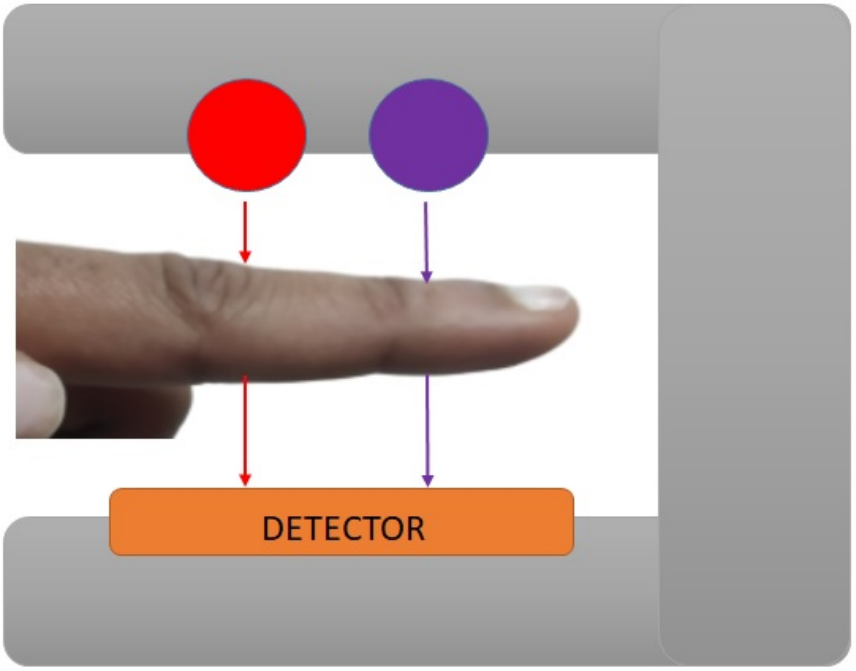


FIGURE 2.1: Schematic Diagram of the Pulse Oximetry Setup

The oxygen saturation is calculated using the percentage of light that reaches the detector. Explaining this in detail now. When light passes through the finger, fraction of light gets absorbed by the finger and the other fraction reaches the detector.
The percentage of light that is absorbed by the finger depends on many physical properties and these properties are used by the pulse oximeter to calculate the oxygen saturation.

The amount of light absorbed by the finger depends on:

1. concentration of the light absorbing substance(oxy and deoxy haemoglobin)
2. length of the light path (in this case thickness of finger)
3. oxyhaemoglobin and deoxyhaemoglobin has different absorption rates for different wavelengths of light

Here the last point is important for our study and research. That is oxyhaemoglobin and deoxyhaemoglobin absorbs different lights in specific ways. In this case red and IR are the lights we have used.

Deoxyhaemoglobin absorbs the wavelength around 650 nm more than the oxyhaemoglobin. And oxyhaemoglobin absorbs wavelength after 900nm more than deoxyhaemoglobin. The absorption spectra is shown below.

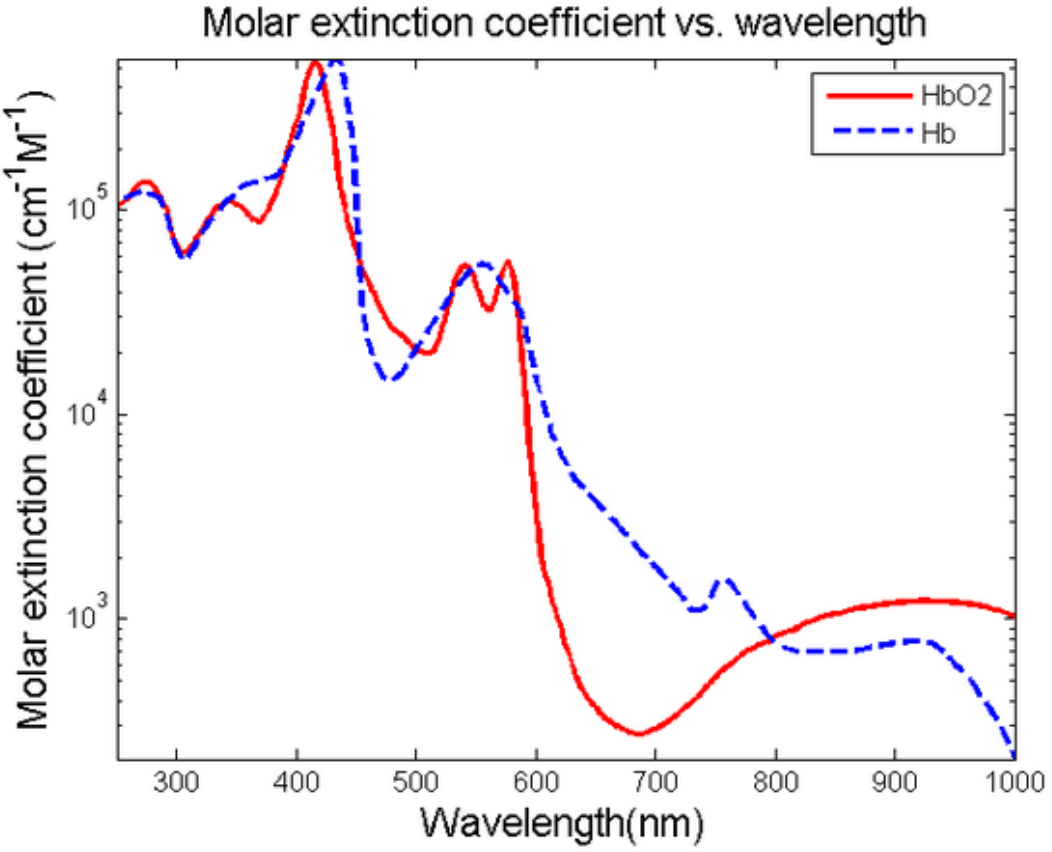


FIGURE 2.2: Absorption Spectra of Haemoglobin ; *Source* : *https* : *//www.wikiwand.com/en/Photoacoustic*$_i$*maging*

To summarise in a nutshell,
Oxy Haemoglobin absorbs more infrared light than red light
Deoxy Haemoglobin absorbs more red light than infrared light

So how the detector works is that, with the help of this spectra, and calculating how much IR and red light is absorbed by the blood. If the oxygen in blood is more, more IR light will be absorbed and vice versa. As the wavelengths used in this experiment are 631 and 931 nm, here is the exact Molar extinction coefficient.

Wavelength (nm)	Molar Extinction Coefficient ($cm^{-1}M^{-1}$)	
	Hb	HbO
631	5.04×10^4	5.90×10^3
931	7.81×10^3	1.27×10^4

FIGURE 2.3: Molar Extinction Coefficient

The amount of oxy or deoxy haemoglobin in the blood is in relation to how much IR or red light is absorbed. Once the ratio of the light absorbed is known, the oxy or deoxay content in haemoglobin can be calculated using a program.
And this is how the pulse oximeter works in summary. Here it is realised that the use of IR and red light can give information about the oxygen content in blood. By using the same wavelengths in the experiment I am working on, in addition to image the blood vessels, it is also tried to calculate the oxygen percentage in blood. An application of knowing the oxygen percentage in finger joints is to detect Rheumatoid Artheritis at an early stage. This will be discussed in detail, later in this chapter.

2.3 Primary Image Analysis

Matlab is used predominantly in the analysis part of the experiment. An initial analysis consisted of converting the images into matrices and making them greyscale. This was also done in order to familiarise with the tools in Matlab.

FIGURE 2.4: Greyscale Image

From the image we can observe that the primary analysis yield better quality images. Here especially in the first image there is a nice contrast between the nerve and skin.

2.4 Decomposing IR and Red images into RGB components

In the second part of analysis, it was aimed to use more matrix calculations in the image analysing. Therefore another idea that struck at this time was to decompose the images obtained with IR and Red lighting into its individual RGB channels and then do matrix manipulation with the decomposed images.

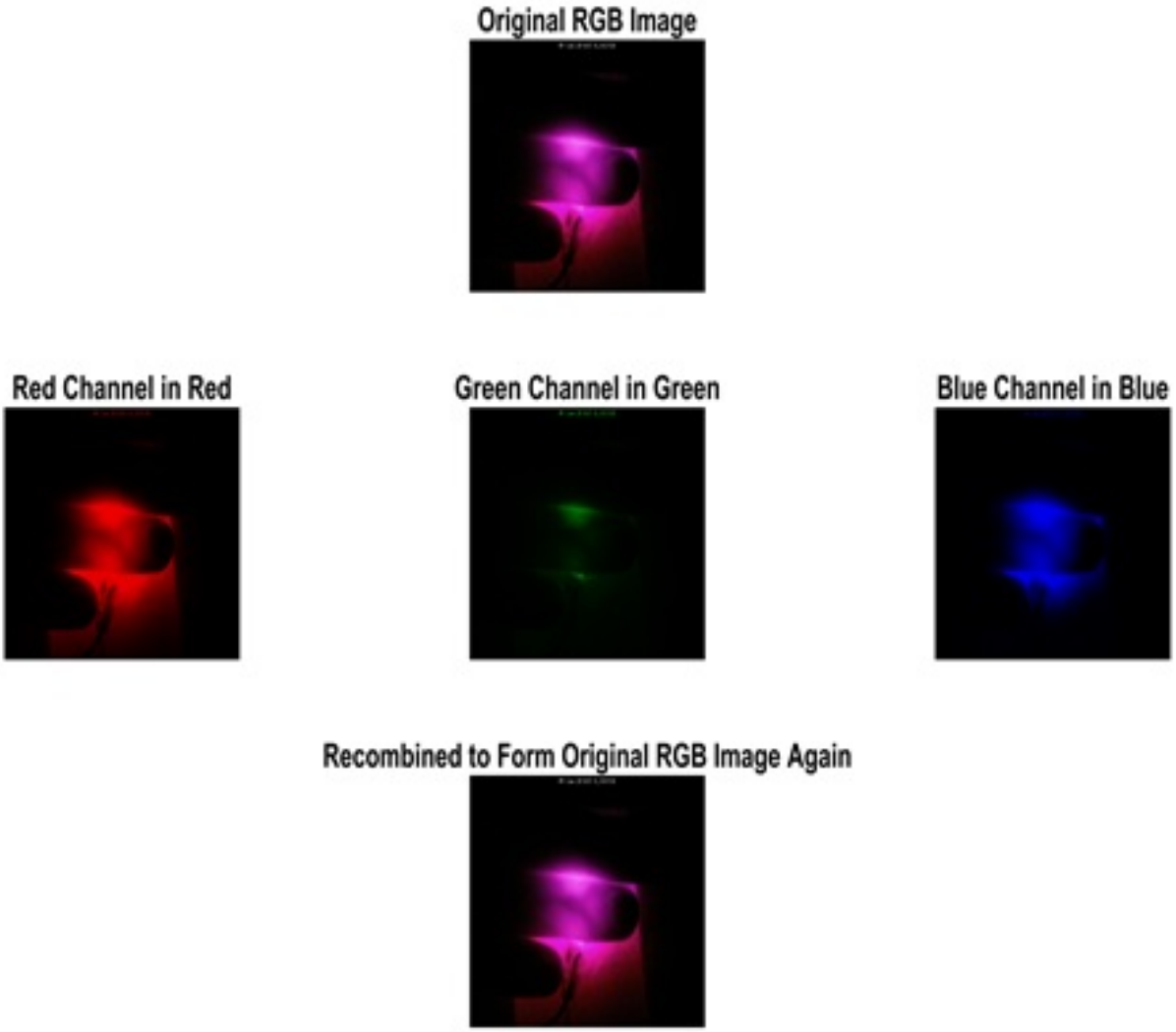


FIGURE 2.5: Decomposed IR Image

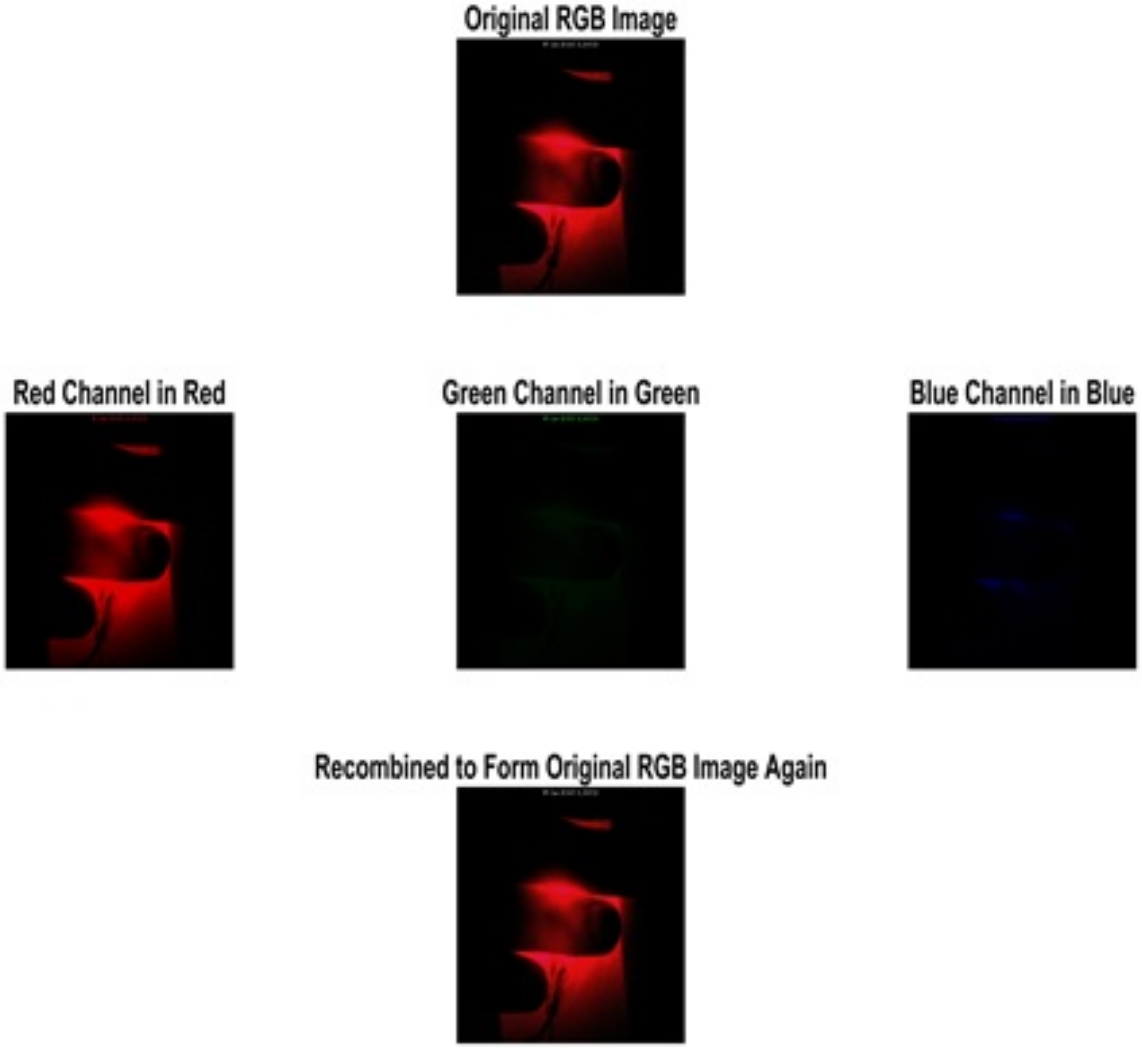


FIGURE 2.6: Decomposed Red Image

After decomposing the images into RGB channels, a Gaussian filtration function is applied in Matlab to smoothen the image. Then the red image is taken and pixelated (converted into matrix). With the individual matrices of IR image (RGB channles of IR image), the Red image is divided. That is an element wise division of red matrix is done with each RGB channel matrix of IR. Similarly for IR image also it was done. Then the images are concatenated to see if it gives any better analysis.

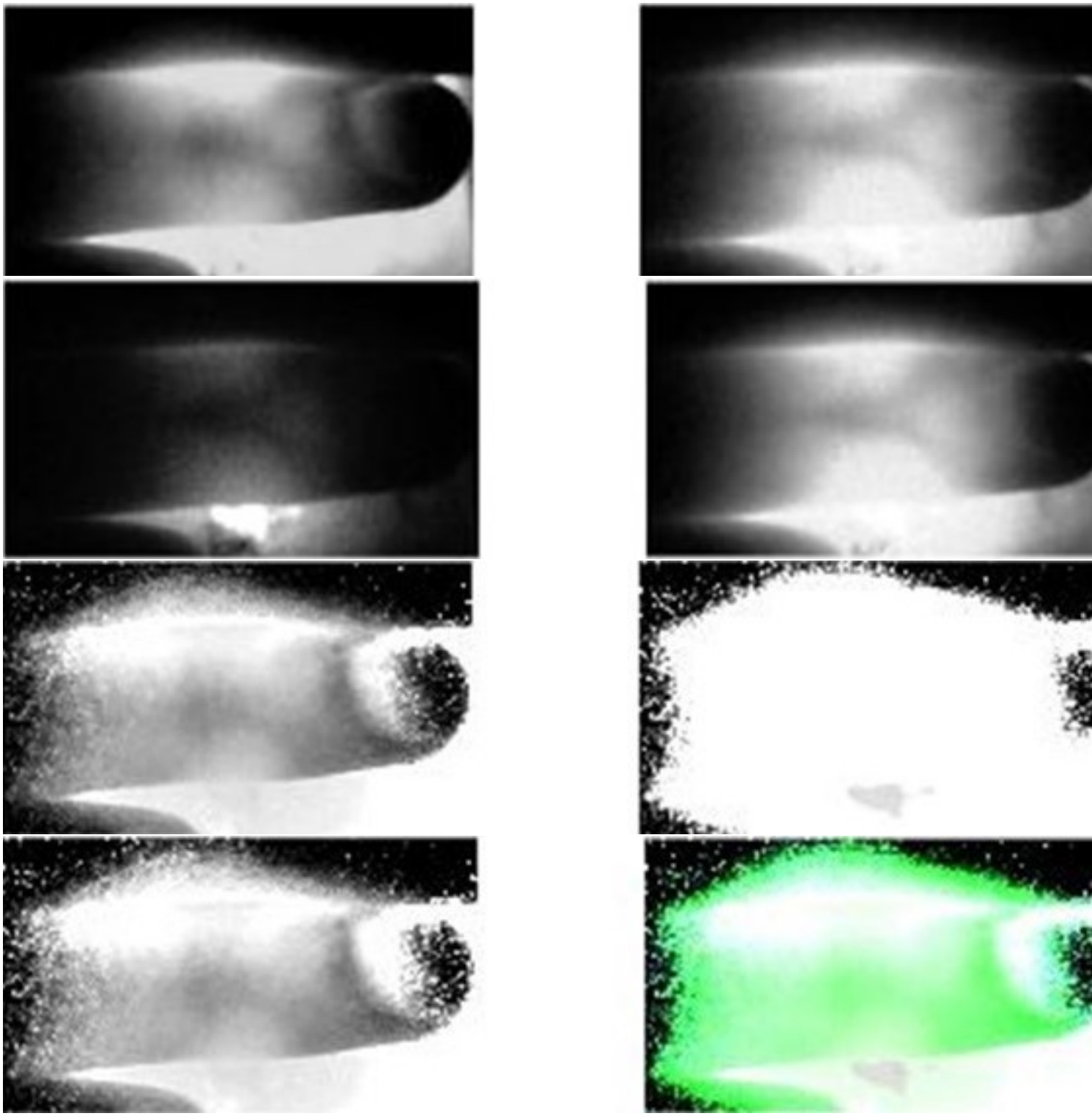


FIGURE 2.7: Matrix Analysis of the Image

2.5 Applications and future work

With this experiment we can image the blood vessels and also find out that it is possible to calculate the oxy and deoxy haemoglobin concentration using pulse oximetry data. And lately it is found that joint hypoxia plays a pivotal role in the progression and may even lead to the formation of Rheumatoid Arthritis (RA) [Lighter 19]. In a patient having RA, extra growth of stromal cells and invasion of these inflammotory cells into synovium causes many changes including, joint hypoxia (inadequate oxygen supply), increased blood vessel formation and increase in protein and leukocytes. These factors leads to a change in optical properties (when the light is made to pass through the finger) of the finger joint. We can compare the obtained data with that of a healthy finger joint to analyse and come to a conclusion. The advantage of this method lies in its feasibility and is inexpensive. It can also be used to calculate the followings:

- Hb/HbO saturation
- Pulse repetition rate
- Veins and Capillaries imaging [Deegan 19]
- Blood flow rate [Nadort 16]

Further work is needed to collect data and optimise the results. Also due to the COVID pandemic issue, the whole work was affected and cthe work could not be completed.

Appendix A

Matlab Code to decompose images into RGB channels and perform matrix operations

This is the Matlab code `matcode.m` used to decompose Red and IR images into its RGB components and perform matrix operations.

A.1 matcode.m

```
I = imread('c.jpg');
I = im2double(I);
%I = I(:,:,2);
% plot(I(:,204,1))
%imshow(I)

R = imread('red_new.jpg');
R = im2double(R);
R = R(:,:,1); % just extracting the red matrix
R = R(565:1387,486:1900);
R = imgaussfilt(R,2);
figure(1);
```

```
13 subplot(1,8,1)
14 axis equal
15 axis tight
16 imshow(R);
17
18
19 IR = imread('ir.jpg');
20 IR = im2double(IR);
21 IR_red = IR(565:1387,486:1900,1);
22 IR_red = imgaussfilt(IR_red,2);
23 IR_green = IR(565:1387,486:1900,2);
24 IR_green = imgaussfilt(IR_green,2);
25 IR_blue = IR(565:1387,486:1900,3);
26 IR_blue = imgaussfilt(IR_blue,2);
27 subplot(1,8,2)
28 axis equal
29 axis tight
30 imshow(IR_red);
31
32 subplot(1,8,3)
33 axis equal
34 axis tight
35 imshow(IR_green);
36
37 subplot(1,8,4)
38 axis equal
39 axis tight
40 imshow(IR_blue);
41
42 D_red = R./IR_red;
43 subplot(1,8,5)
44 axis equal
45 axis tight
46 imshow(D_red)
47
```

```
48 D_green = R./IR_green;
49 subplot(1,8,6)
50 axis equal
51 axis tight
52 imshow(D_green)
53
54 D_blue = R./IR_blue;
55 subplot(1,8,7)
56 axis equal
57 axis tight
58 imshow(D_blue)
59
60
61 %{
62 final = cat(3, D_red, D_green,D_blue);
63 subplot(1,8,8)
64 axis equal
65 axis tight
66 imshow(final)
67 %}
68
69 %{
70 final = cat(3, IR_red,IR_green,IR_blue);
71 subplot(1,8,8)
72 axis equal
73 axis tight
74 imshow(final)
75 %}
76 D_fuf = D_red
77 final = cat(3, D_red,D_green,D_blue);
78 subplot(1,8,8)
79 axis equal
80 axis tight
81 imshow(final)
```

Appendix B

Python program to control LEDs

This is the Python program `LED.py` used to control the LEDs with the help of Raspberry Pi V3 Processor.

B.1 LED.py

```
from gpiozero import LED
import time

red = LED(15)
ir  = LED(27)

for i in range 100:
    ir.toggle()
    time.sleep(0.1)
    ir.toggle()
    red.toggle()
    time.sleep(0.1)
    red.toggle()

```

Appendix C

Spectrum of the lights used in the experiment

Spectrum of the Red and IR light used in the experiment is recorded using a spectrometer and the images are attached below.

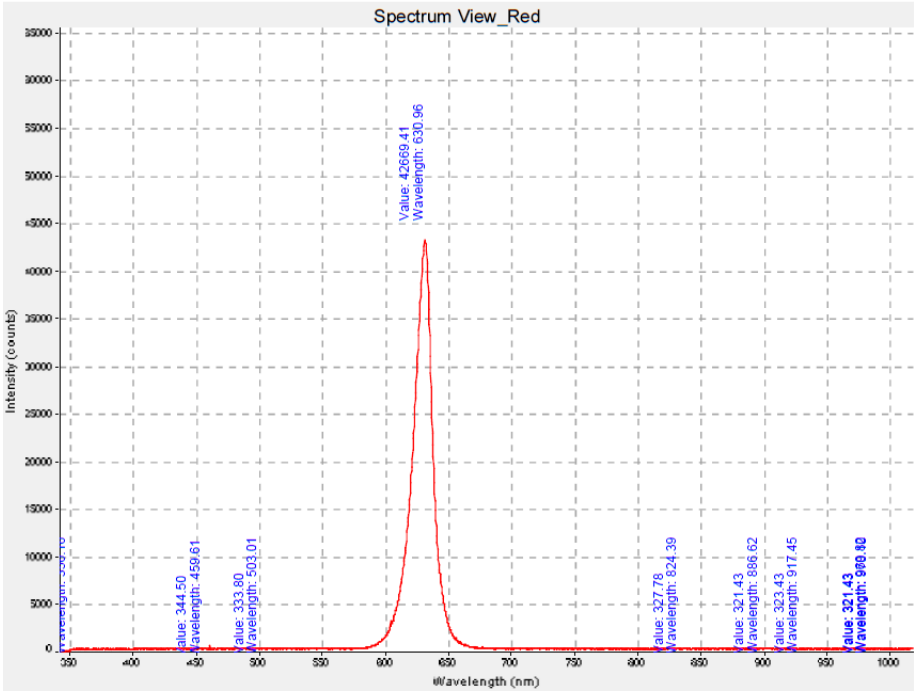


FIGURE C.1: Spectrum of Red light

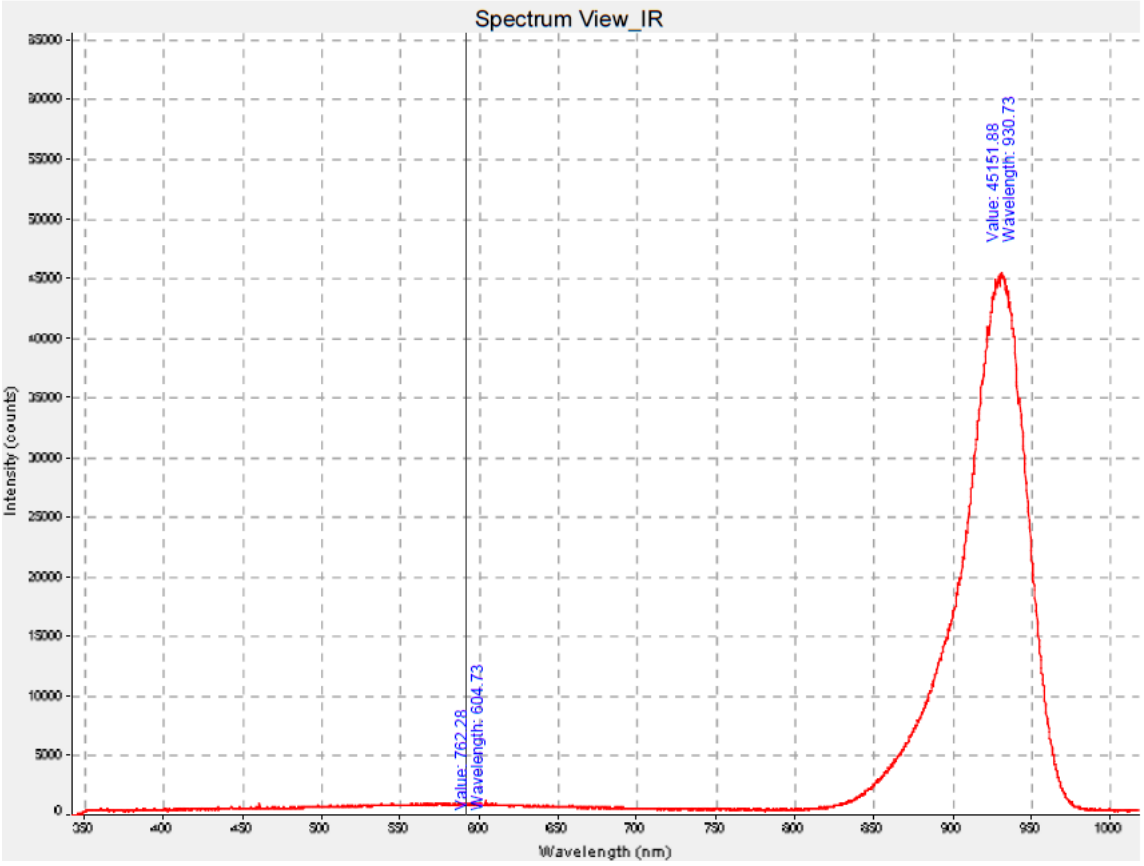


FIGURE C.2: Spectrum of IR light

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