Visvesvaraya Technological University,
Belgaum, Karnataka

Project Report
on

DESIGN AND DEVELOPMENT OF A SOFTWARE TO DETECT HEART RATE USING IMAGE PROCESSING

Submitted in partial fulfillment of the requirement for the award of the degree of

Bachelor of Engineering in
in
Computer Science and Engineering

Submittted by

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CERTIFICATE

This is to certify that the project titled **DESIGN AND DEVELOPMENT OF A SOFTWARE TO DETECT HEART RATE USING IMAGE PROCESSING** is a bona fide work carried out by **Apoorva R Upadhya (2SD16CS020), Shravya K (2SD16CS087), and Sushma G Kulkarni(2SD16CS110)** submitted in partial fulfillment of the requirements for the award of the degree of **BACHELOR OF ENGINEERING** in **COMPUTER SCIENCE AND ENGINEERING** of **S.D.M. COLLEGE OF ENGINEERING AND TECHNOLOGY, DHARWAD, KARNATAKA** (An autonomous institution affiliated to Visvesvaraya Technological University, Belgaum, Karnataka), during the year 2019–2020. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report deposited in the department library. The project has been approved, as it satisfies the academic requirements in respect of project report prescribed for the said degree.

DR. J. C. KARUR	**DR. U. P. KULKARNI**
Project Guide	**Head of Department**

External Viva

Name of Examiners	Signature with Date

1)

2)

DECLARATION

We hereby declare that the dissertation work titled **DESIGN AND DEVELOPMENT OF A SOFTWARE TO DETECT HEART RATE USING IMAGE PROCESSING**, has been carried out under the guidance of **Dr. J. C. Karur, Professor, Department of Computer Science and Engineering, S.D.M. College of Engineering and Technology, Dharwad**, in partial fulfillment of the degree of **Bachelor of Engineering in Computer Science and Engineering** from **Visvesvaraya Technological University, Belgaum, Karnataka**, during the academic year 2019–2020.

I also declare that I have not submitted this dissertation to any other university for the award of any other degree.

Place: Dharwad
Date:

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Abstract

Heart Rate is one of the most important physiological parameter and a vital indicator of people's physiological state. Our Heart pumps blood through the blood vessels of cardiovascular system and for each heartbeat, blood circulation creates colour variation in facial skin. This is true for all humans irrespective of gender, race, etc. It is possible to extract heart rate from the colour variation of the facial skin, since blood absorbs light more than surrounding tissues. So, variations in blood volume can be captured by camera by the reflecting and transmitting property of light. After capturing the motion of blood in the face we select the region of interest i.e. cheeks, then find out the pixel value for each bit of the region of interest. This pixel value for a given period of time is the digital signal which should be converted to analog signal. To convert the digital signal to analog signal we need to normalize and filter the signal to remove unnecessary noise and apply Fast Fourier Transformation, Principle Component Analysis algorithms, and Independent Component Analysis, and plot the graph of the analog signal obtained. The highest value obtained from the plotted graph for that second is the heart rate of that person for the second. This would also be beneficial for certified psychological tests, as the subjects would not know they are being monitored, plausibly yielding a higher accuracy reading.

Problem Statement

Design and development of a software to detect heart rate using image processing.

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Chapter 1

Introduction

The cardiovascular system permits blood to circulate in the body due to continuous blood pumping by heart. Our Heart pumps blood through the blood vessels of this system and for each heart beat blood circulation creates colour variation in the Facial skin. This is true for all humans irrespective of gender, race etc. Therefore, it is possible to extract Heart Rate (HR) from the colour variation of the facial skin. We have also verified this from cardiologists and physicians and the details of the conversation with them is given in the Chapter 2 Literature Survey of this report.

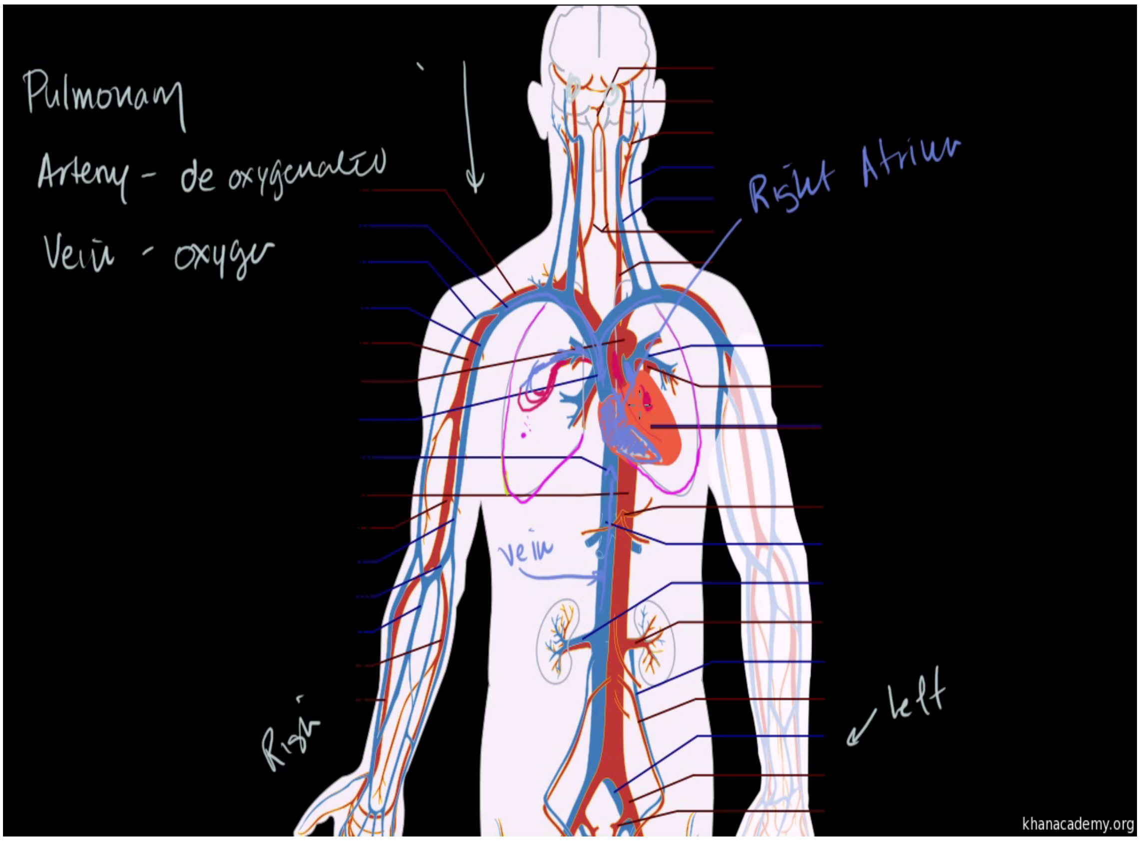


Figure 1: Cardiovascular system pumping blood to face[1]

Detection of the cardio-vascular pulse wave traveling through the body is referred to as Plethysmography, and this detection can be done by means such as variations in air pressure, impedance, or strain. Photo-plethysmography (PPG), introduced in the 1930's uses light reflectance or transmission to detect the HR and is simple to use.It is also least expensive system. PPG is based on the principle that blood absorbs light more than surrounding tissue so variations in blood volume affect transmission or reflectance correspondingly [4].

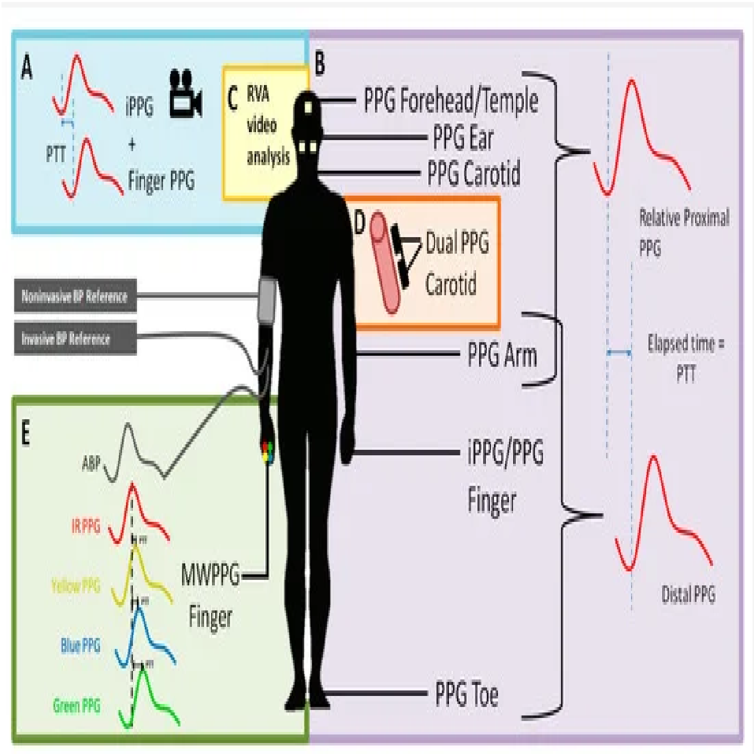


Figure 2: Photo-plethysmography (PPG)[2]

PPG has always been performed with dedicated light sources and typically red and/or infra-red (IR) wavelengths. Due to the historical emphasis of PPG on pulse oxymetry and the associated need to sample relatively deep (e.g., 1 mm) veins and arteries, the visible spectrum (with a shallower penetration depth in skin) has often been ignored as a light source for PPG. PPG signals can be remotely measured on the human face with normal ambient light as the source and a simple digital, consumer level photo camera in movie mode[4]. According to [4] at distances of 1.5m, signal to noise ratio (SNR) was found to be up to four harmonics of the fundamental HR frequency can be measured, thus rendering not only the HR but also the shape of the waveform.

The evolution of non-contact based HR monitoring has been going on since 1995, when people found that colour variations of skin can be captured on camera and by this we can detect HR. Presently, in a time of well-developed graphic cards,high resolution cameras, and processor and also with advancements in AI particularly in image processing field, the research still continues to make the detection of non-contact based HR measurement more accurate and we are making an attempt to achieve the same[5].

Figure 3: Colour variation observed when colour amplified by x100[3]

Chapter 2

Literature Survey

2.1 Summary of our conversation with a cardiologist:

First, he gave us a brief of how our cardiovascular system works. Next he explained how our blood which is a fluid connective tissue helps in the detection of pulse because of its varied speed inside our blood vessels at regions where it is close to our skin like near our palm or neck etc. Later, he told us how various physical activities affects the HR changes and hence the amount of blood pumped to our face also varies. Further he added that blood absorbs different amount of light during different HRs depending upon the different amount of blood pumped per second. The normal HR is 60-100 bpm. So we asked the possibility of this extraction using the heat maps and other techniques and he confirmed that it would be feasible to do so.

He told that this project would help detect heart arrhythmia (abnormal heart rhythms)[6], which would help in detecting when our HR would be decreased below the minimum of 60/40 bps and this is a very risky condition as this wouldn't be detected normally without running an ECG scan. But, the increase of HR is a common possible condition to happen because, HR usually increases when there is an adrenaline rush in our body like during exercises. So, it would help an individual to keep track of his pulse rate. But, if it increases above 150 and so on, it would also be risky situation and this way of detection would definitely help.

Also, he told that, detection of heart attack through this process is a 50-50 chances because, only during some heart attacks there is a detectable variation in HR. In other cases, it would be a sudden thing and undetectable through HR.

2.2 Research papers and articles

Presently, the most popular way of detecting a pulse rate (which is the direct measure of HR[7]) is through the heart rate monitor [8]. To measures the electrical activity of the heartbeat a ECG/EKG is used. An electrocardiogram — abbreviated as EKG or ECG — is a test that measures the electrical activity of the heartbeat. With each beat, an electrical impulse (or "wave") travels through the heart. This wave causes the muscle to squeeze and pump blood from the heart. A normal heartbeat on ECG will show the timing of the top and lower chambers.

An ECG gives two major kinds of information. First, by measuring time intervals on the ECG, a doctor can determine how long the electrical wave takes to pass through the heart. Finding out how long a wave takes to travel from one part of the heart to the next shows if the electrical activity is normal or slow, fast or irregular. Second, by measuring the amount of electrical activity passing through the heart muscle, a cardiologist may be able to find out if parts of the heart are too large or are overworked[7].

But the cost of a HR monitor starts from Rs.4,000 and a ECG machine varies from Rs.40,000 to Rs.1,05,000, while a ECG test costs from Rs.150 to Rs.300. Hence, our aim is to reduce these painful costs and build a cost effective system.

The heart rate monitor bands which many of the athletes and health care personals advice to wear, nowadays monitors the heartbeat of just a single instance but fails to give a continuous output of the bpm.

With the advent of powerful computer vision processing libraries, such as OpenCV, and advanced signal filtering techniques, it is now possible to extract accurate HR measurements through facial recognition and independent component analysis (ICA)[9].

Photoplethysmography is used to detect blood volume changes in the microvascular bed of tissue at the skin surface. It is a non-invasive,simple and low-cost technique. As stated in [10] the PPG waveform comprises a pulsatile ('AC') physiological waveform attributed to cardiac synchronous changes in the blood volume with each heart beat, and is superimposed on a slowly varying ('DC') baseline with various lower frequency components attributed to respiration, sympathetic nervous system activity and thermoregulation.

This electro-optic technique can provide valuable information about the cardiovascular system such as heart rate, arterial blood oxygen saturation, blood pressure, cardiac output and autonomic function. Typically, PPG has always been implemented using dedicated light sources (e.g. red and/or infra-red wavelengths), but recent work has shown that pulse measurements can be acquired using digital camcorders/ cameras with normal ambient light as the illumination source[11].

It is also observed that, extraction HR from the colour variation in the facial skin due to cardiac pulse and the implementation has been done using a simple webcam in indoor environment with constant ambient light[5]. They have concentrated more on how to achieve the extraction of HR using MATLAB. They have extracted the HR and recorded it for 5 minutes for 10 different people in real time using webcam and cStress system using ECG sensors.After 5 minutes the real time session was over and HR was extracted again in offline using the saved film sequences. The evaluation was made using 2 important statistical parameters such as RSQ (R-squared) and CORREL (Correlation Coefficient) for both real time and offline HR extraction considering cStress system. Both the RSQ and CORREL values were close to 90% or more than 90%. CORREL function gave better results than RSQ both in real time and offline. The average RSQ and CORREL values of 10 subjects were also calculated for real time HR methods and offline HR methods by applying three algorithms and presented through bar charts [5].

According to the work done by [12] the amount of head movement in the video sequence is crucial for the accuracy of a heart rate estimate. They conducted the experiment of HR detection in which the performance measurement during different natural moving situations were considered , and the data was collected in three conditions depending on the type of head movement. They were still (only very small, natural movements), panning (the head changes position but is always facing the camera), and rotation (The head is rotating and is not always facing the camera). It was shown that the general performance on still subjects was acceptable, but decreased when the head was panning or rotating in the camera frame. This was partly because it was more difficult to track a moving face, but more importantly because of the introduction of motion artefacts.

CHAPTER 3

Detailed Design

3.1 Software Model

we are using the waterfall model in which the whole process of software development is divided into separate phases. In this Waterfall model, typically, the outcome of one phase acts as the input for the next phase sequentially.[13]

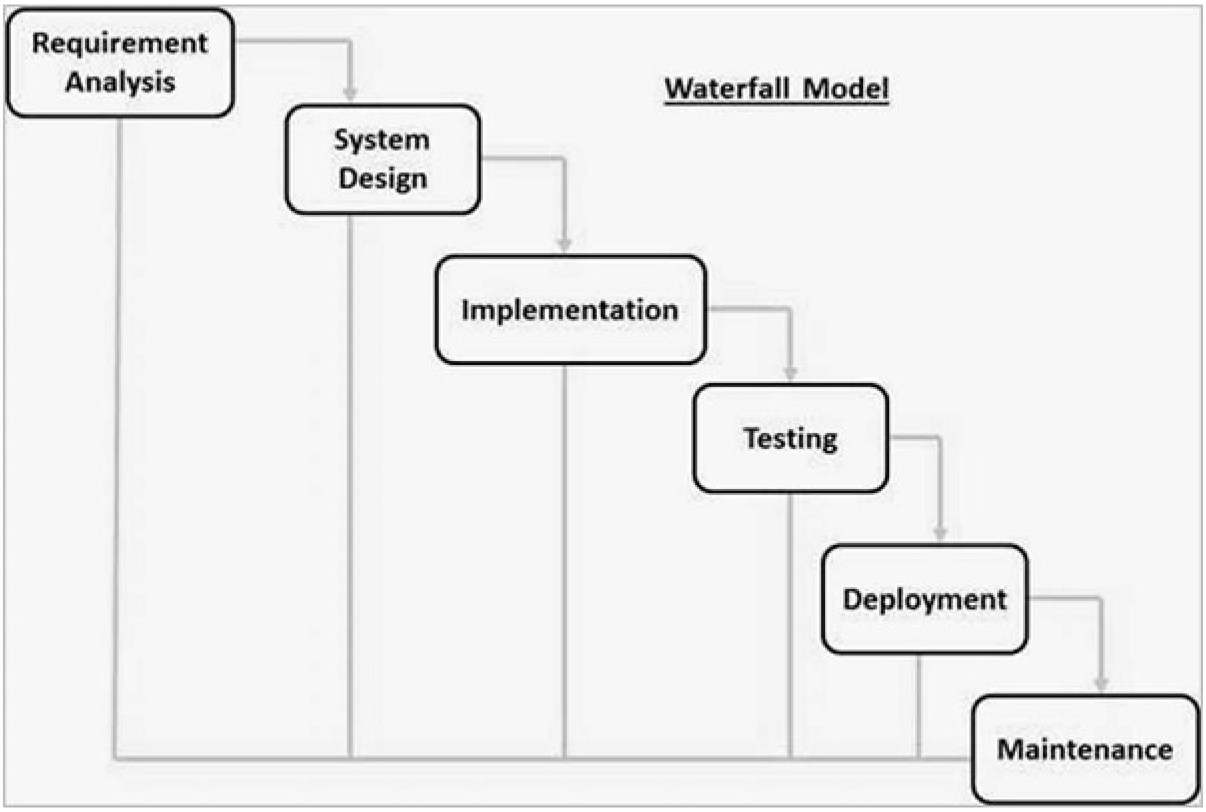


Figure 4: Waterfall Model SDLC

3.2 Use Case Description

Use Case: Identifying one's HR via video or camera

Summary: The application measures the HR of an individual when a person is in front of the camera or when a video of a person's face is given to it.

Actors: End User, Other video recording applications

Preconditions: The application is waiting for the user to face the camera or to input a recorded video.

Description: User starts the application. The application verifies that a camera is present and is available. The application creates an appropriate sized frame to contain the video feed. Once analysis has begun, the face is separated and displayed in a separate frame within the application window, and the Region of Interest (ROI), the cheek region is shown with a green rectangle. The necessary algorithms(PCA,ICA) and FFT is applied and the HR is shown through a graph and a continuous value of HR is also displayed.

Exceptions:

Camera not supported: If the application cannot detect a camera or the camera is not supported, the user is notified via an error message.

No face detected: If the application can't detect the face of the user, an error message is shown.

Post-conditions: The application is waiting for the user to either show his/her face or to give a recorded video as input.

3.3 Use Case diagram

The Use Case diagram for various use cases given below[1]

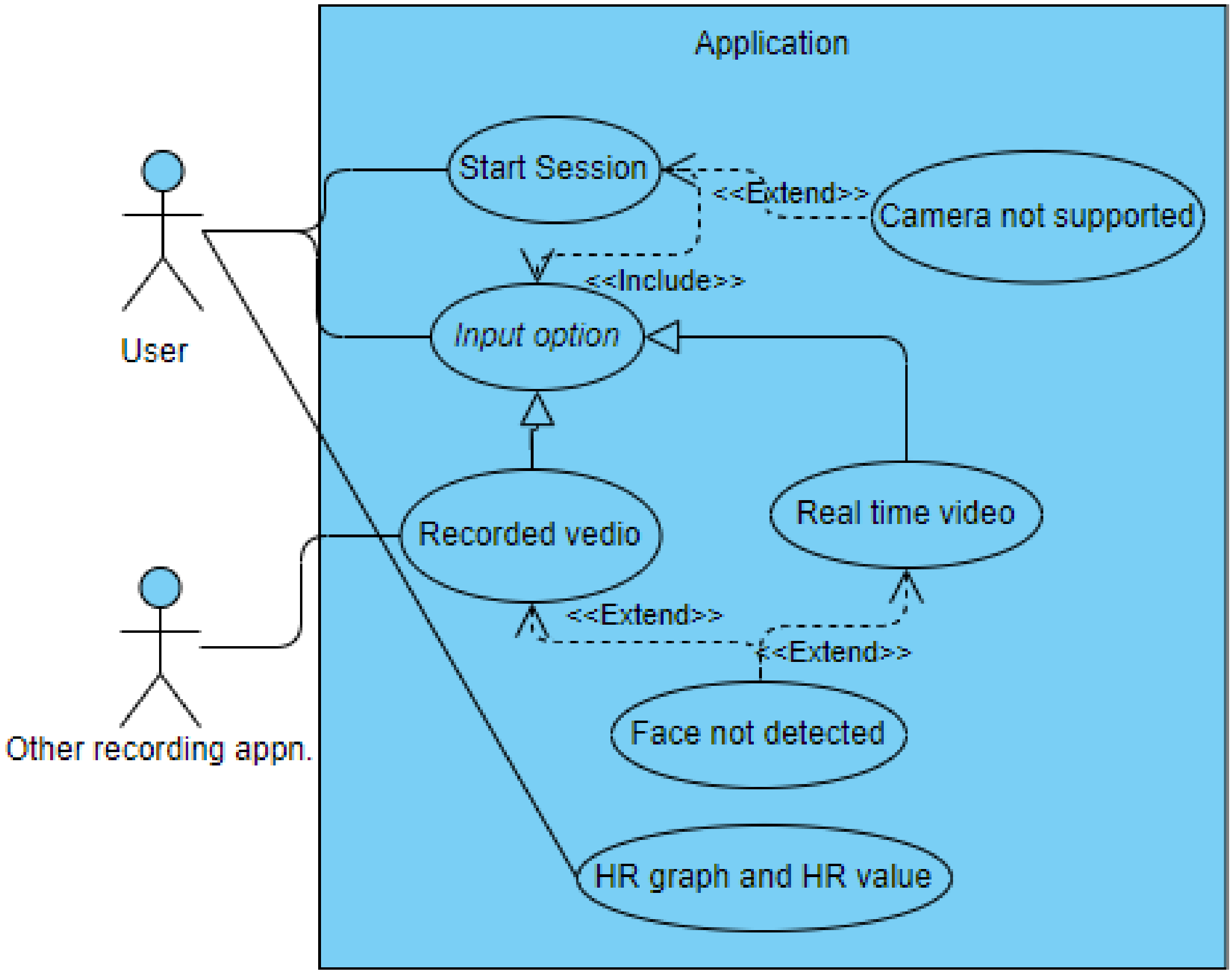


Figure 5: Use Case diagram

[1]Built using Visual Paradigm Online Express Edition [14]

3.4 Sequence diagram

The sequence diagram for various use cases given below[2]

3.4.1 A real time video

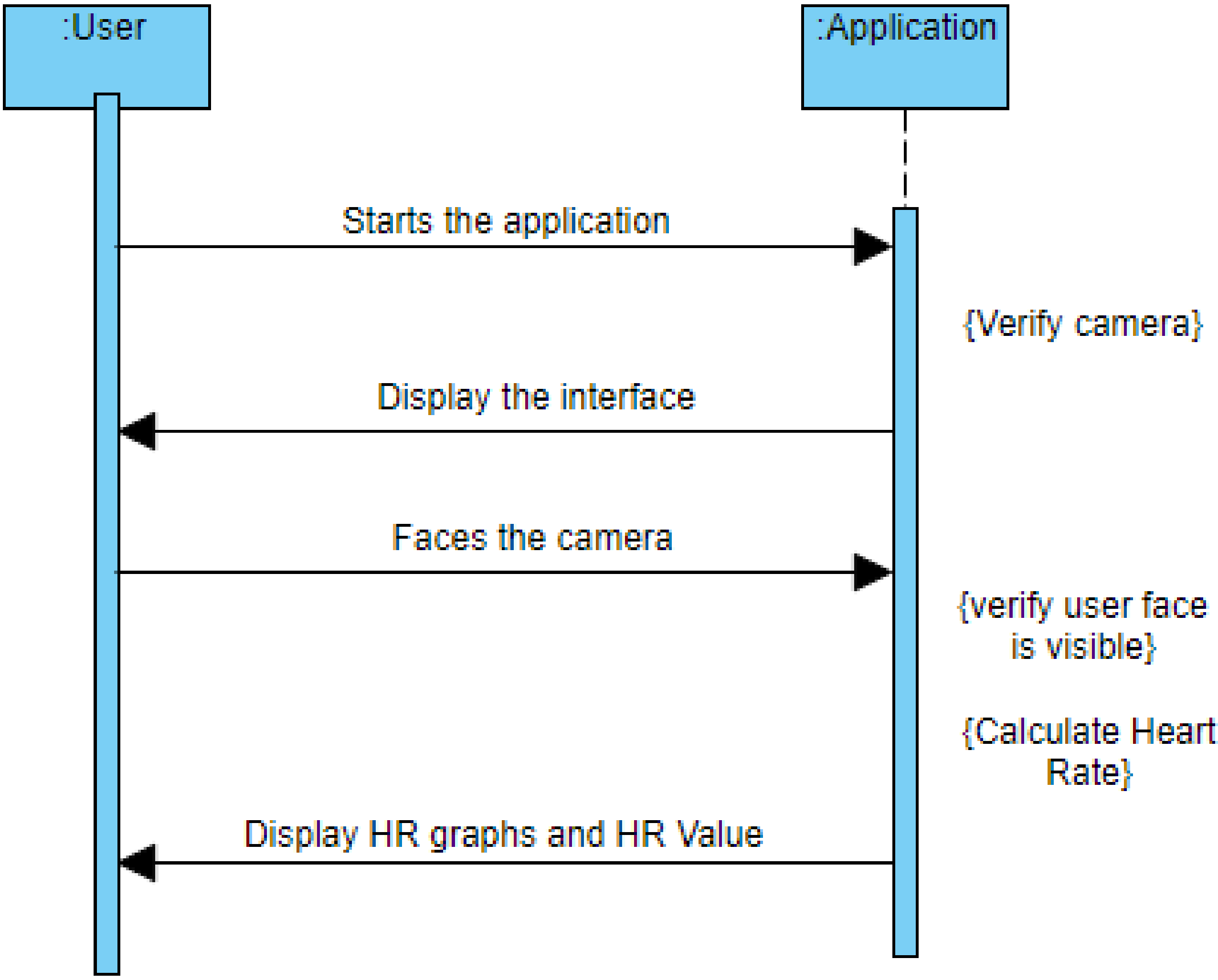


Figure 6: Sequence diagram explaining when input is a real time video scenario

[2] Built using Visual Paradigm Online Express Edition [14]

3.4.2 A Recorded video

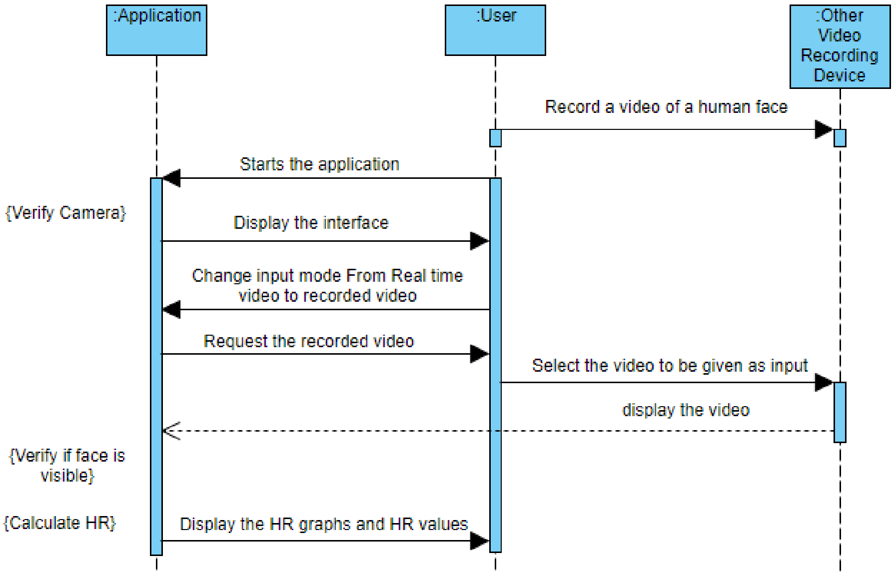
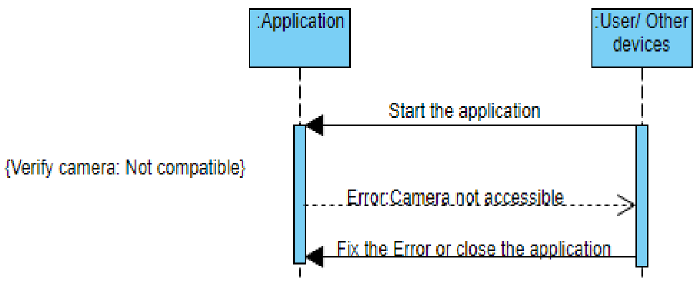
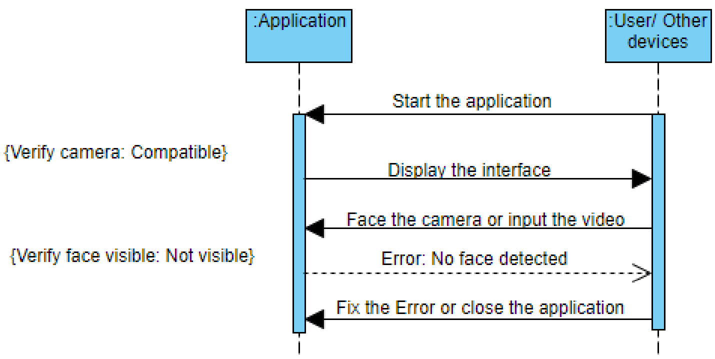


Figure 7: Sequence diagram explaining when input is a recorded video scenario

3.4.3 Exceptions



(a) Camera not accessible



(b) Face not detected

Figure 8: Sequence diagrams for exception cases

3.5 Architecture diagram

The figure below describes the architecture diagram[3]

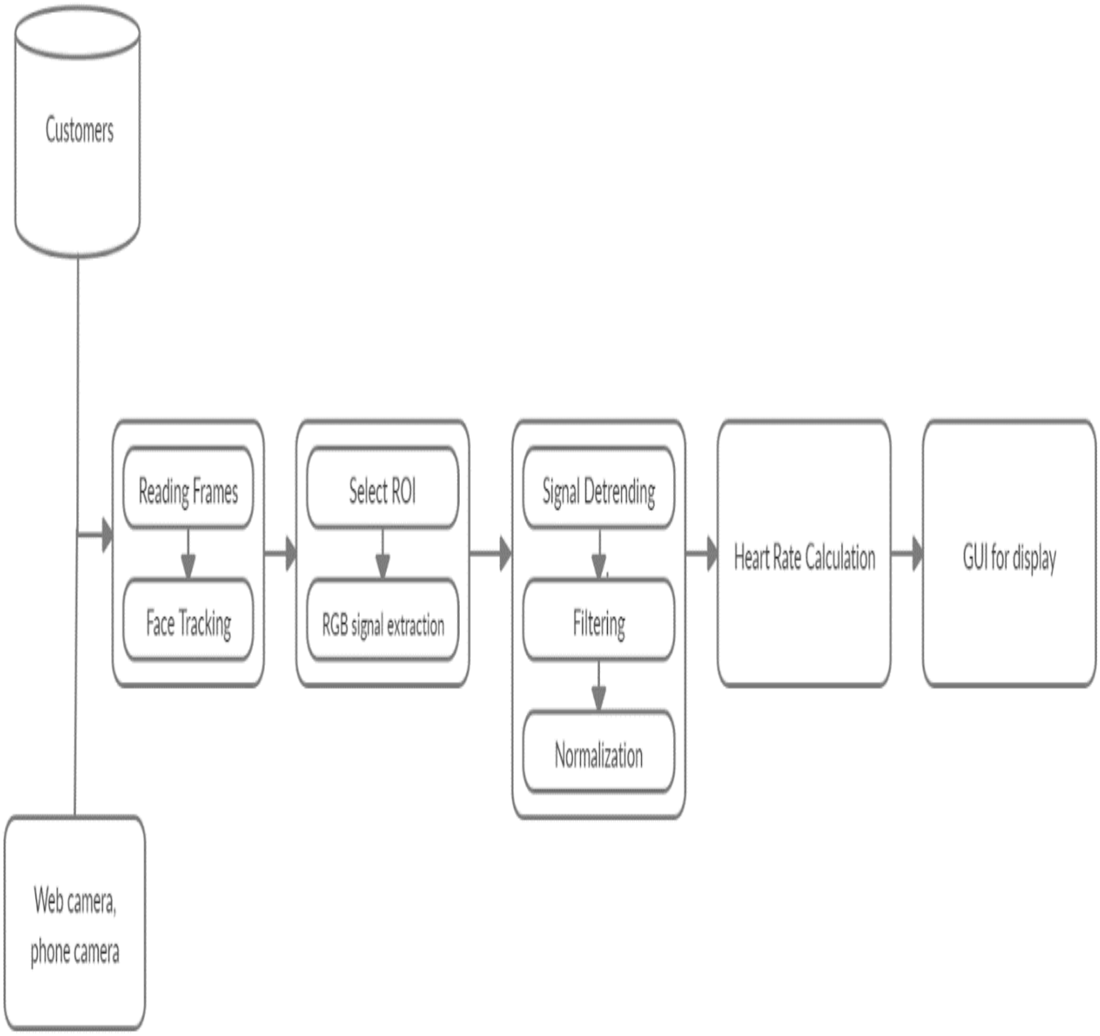


Figure 9: Architecture diagram

1. **Web Camera, phone camera, video:**
    - These help to take the inputs which are images of a person captured in a time frame.
    - should be made sure that the video must be consisting of face since that is of our part of interest.
2. **Reading Image Frame:**

[3] Built using Creatly[15]

- An image frame is the fundamental part of a video or any image source that indicates the start and end point of a video which represents a silent part of that video.
- It is also important to notice that the resolution of the video should remain same during each image frame extraction for further calculations.

3. **Face Tracking:**
   - After extracting an image frame in real time, the automatic face detection should be done.
   - This is done by the built in functions in the dlib library.
4. **Select ROI:**
   - To identify the coordinates of the cheek location in the first frame and corresponding frames.
   - The x and y-coordinates along with the height and width that define the ROI should be separated from the entire facial image for further calculation.
5. **RGB signal Extraction:**
   - Similar to calculating the pixel value of each frame in the image.
   - Each PI $= 3 * 1$ matrix colour consisting of RGB composition is reproduced in 2 phases.
   - Average RGB colour calculated for each image.
   - RGB signal is calculated by average RGB colour value indicated by ROI which becomes digital signal for a period of time.
6. **Signal detrending:**
   - Here, unwanted trends and noise signals are removed from the series of the RGB signal.
   - Example,
     - When feature is distorted.
     - When environment parameters like changes in temperature and external noise.

7. **Filtering:**

   - Digital signals are filtered by hamming window point.
   - Hamming window point is a window of all possible values of the heart rate of a person.

8. **Normalization:**

   - Signals have to be normalized for each RGB value and then compute the standard deviation [5]

9. **HR Calculation:**

   - Now the FFT, PCA and ICA algorithms are applied to get the continuous HR values. These values are displayed graphically and finally we find the HR by calculation of the maximum height obtained of the analog signal in the graph in that second.

Chapter 4

Project Specific Requirements

4.1 Functional requirements

1. The camera is used to capture the real time video or video which is uploaded from a computer.
2. The detected region of interest i.e. cheeks is selected.
3. Colour variation is seen in the face and its pixel value is calculated.
4. Heart rate is calculated through pixel value by using algorithms.
5. Heart rate detected and varies according to the emotion of a person.

4.2 Non Functional requirements

1. **Usability:** The usage of the system and detection of heart rate must be simple and easy.
2. **Functionality:** To detect and display the heart rate variation.
3. **Reliability:** The system must be able to detect the heart rate and display it at any situation.
4. **Convenience:** The screen must be clearly visible to user to know the heart rate.
5. **Performance:** The system must be able to detect the heart rate at a good speed and must be immune to sudden variations.
6. **Accuracy:** The system must be able to detect the heart rate with highest accuracy and detection accuracy decides the performance of the system.

4.3 Software requirements

1. Python v3.5 or above [16].
2. OpenCV – Open library for computer vision [16].
3. Flutter or reactnative – mobile application as front-end [17][18].
4. Firebase server – backend [19].
5. Visual studio or android studio – text editor, android collaborator

4.4 Hardware requirements

1. Processor - Intel core i3 or above.
2. Cores - 4 or more for image processing.
3. Graphic card – minimum speed of 2GHz for OpenCV API for faster capture of the RGB colours.
4. RAM – 4GB or above
5. Camera – 10 Mp or above

Chapter 5

Implementation

5.1 Working

1. The camera is set or a recorded video is made available.
2. The user faces the camera.
3. Find the location of the users face, then isolate the cheek region.
4. This is done by measuring average optical intensity in the cheek location, in the subimages green channel alone (a better colour mixing ratio may exist, but the blue channel tends to be very noisy). Physiological data can be estimated this way thanks to the optical absorption characteristics of (oxy-) haemoglobin [4].
5. The green channel of the face must be projected on a frame with the ROI, then calculate the average Pixel Value for each cell of the frame.
6. The signal from the pixel value calculated must be detrended means to remove unwanted noise and later filtered using the butter bandpass filter and finally normalised means rescaling real value numeric attributes into the range (-1 , 1).
7. Finally, FFT, PCA and ICA algorithms are applied to the normalised signal and the peak point of the ICA is computed to obtain the heart rate.

5.2 Face Tracking, and ROI selection

5.2.1 Face Tracking

The image of the Face is the main input of our system. We are using the face detection and facial landmark detection tool of dlib library to achieve the face detection as well as feature extraction [20].

The resolution of the video is important and should not change during image frame extraction for all the required calculations. Hence we have used the novel key frame video extraction algorithm to maintain the resolution which reads the image frame automatically one by one.

Once the face has been tracked successfully and is shown in a separate box.

5.2.2 ROI selection

The Region of Interest selected is the cheek region as it is easier to detect the variation in the amount of light absorbed by the blood vessels around the cheek region. Only the ROI is selected by creating a boundary of 10x10 pixel area around the cheek region and this region is used for further calculations.

5.3 RGB signal extraction

The main features of the system is to calculate the HR using the 3 independent signals which are called Red signals, Green signals and Blue signals and these signals are extracted from the red, blue and green color values of each pixel of all the facial image frames.

Each pixel of the image has 3x1 matrix of color values which consists of Red (R), Green (G) and Blue (B) color of the image. Then the three desired signals Red, Green and Blue signals are produced in two phases. In the first phase the average R, G and B color values are calculated for each image frame, and in the second phase the red, green and blue signals are calculated from the summation of all the averaged R, G and B color values.

Next the Colour value of only green color is extracted as the other two signals were found to be not very feasible for our calculations The blue signal was found to produce the maximum noise signal [4], while the red signal would confuse and mix the values with the minute vibrations produced by blood when it flows through the face.

5.4 Signal Detrending, Filtering, and Normalization

5.4.1 Signal Detrending

Detrending is an important signal processing concept which is used to remove unwanted trend from the series. Detrending of signal is useful when it is thought that a feature is distorted from the relationships of interest[21]. In our case, when environmental parameters changes such as temperature, lighting or external noise, the collected RGB signals will be drifting and noising. Therefore the signals needs to be detrended.
The RGB signal has been detrended based on Smoothness Prior Approach[22] with the smoothing parameter $\lambda = \mathbf{10}$ and $\mathbf{cutofffrequency} = \mathbf{0.059Hz}$.

5.4.2 Filtering

Before applying FFT, PCA,and ICA the Green signals formed from green image frames are filtered by Hamming window (128 point, 0.6-2 Hz, for normal HR 36-120) for HR.
The Gaussian Pyramid concept of Image pyramids[23] of OpenCV is applied to downsample the image to reduce the resolution and the pixel value of green signal is calculated. Then, it is amplified by an amplification index of 70.
Next, the Laplacian pyramid concept of Image Pyramid[23] is applied to reconstruct an upsampled image from an image lower in the pyramid (with less resolution obtained from Guassian Pyramid).
Next, Band pass filter is applied with $\mathbf{fl} = \mathbf{0.8Hz}$ and $\mathbf{fh} = \mathbf{3Hz}$, which are 48 and 180 bpm respectively.

5.4.3 Normalization

The signal needs to be normalized and the normalization has been performed according to the equation of normalization formula as shown below:

$$X_g(t) = \frac{Y_g(t) - \mu_g(t)}{\sigma_g} \tag{5.1}$$

where μ_g is the mean and σ_g is the standard deviation of Y_g.
Average color value of ROI in each frame is calculate pushed to a data buffer which is 150 in length.

5.5 Algorithms

5.5.1 Fast Fourier Transform (FFT)

The Fourier Transform in general are used to switch between real space(step function) and frequency space(Sync functions). The Fourier Transform is an extension of Fourier series which is suitable only for periodical continuous signal i.e. signal with only similar values and no noise.

FFT is suitable for various non periodic signals as well i.e. it can work on a messy signal which contains a number of waves overlapped on to one another.[24]. In our system there is a messy and complicated set of waves of our face which would consist of R,G,B signals along with some noise and minute blood vibrations. So by using FFT we can separate these mess of waves for calculations of HR.

The FFT users the Cooley Tukey algorithim over the DFT equations shown below:

$$F_k = \sum n = 0^N - 1 f_n e^(- 2\pi i \frac{k_n)}{N} \tag{5.2}$$

where,

F_k is the Frequency function,

k is the frequency space element,

i is the imaginary term.

Hence, the normalized signal is given to the FFT algorithm which applies Equation 5.2 to obtain the frequency values.

5.5.2 Principal Component analysis(PCA)

Principal Component Analysis (PCA) is a technique for reducing the dimensionality of datasets, increasing interpretability but at the same time minimizing information loss. It does so by creating new uncorrelated variables that successively maximizes the variance[25]. This is done by finding the eigen values and eigen vectors of the corresponding covarience

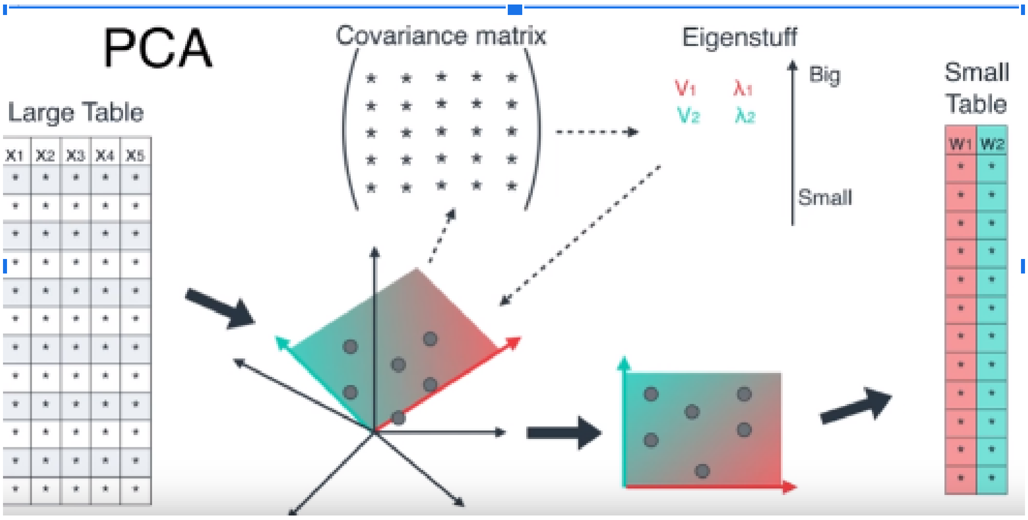


Figure 10: Dimension Reduction

matrix. The highest eigen values and vectors is where we need to reconstruct the dimensions and retain maximum information as it can be seen in Fig. 10.

In our project after applying FFT algorithm we need to reduce to the dimensions to ease the calculation for finding the heart rate. Hence, the graph obtained in FFT algorithm is given to the PCA algorithm.

5.5.3 Independent Component Analysis(ICA)

Independent Component Analysis (ICA) is a computational method for separating a multivariate signal into additive sub-components. This is done by assuming that the sub-components are non-Gaussian signals and that they are statistically independent from each other.ICA is a special case of blind source separation[26]. ICA algorithm is a linear transformation of your feature space into a new feature space such that each of the individual new features are mutually independent and the mutual information between the new feature space an original feature space is as high as possible.
$[x1, x2, xi....] - > [y1, y2, yi....]$ such that,
$I[yi; yj] = 0$ $I[y; x] = ashighaspossible.$

Example, if you are in a crowded room and there are many voices that come to you at different samples of time with different frequencies then ICA algorithm sorts these frequencies independently and computes each frequency with maximum information.
In our project after applying PCA algorithm we use ICA algorithm to individually separate the various point obtained from the PCA, which represents heart rate value of every instance. Thus, we can calculate HR with a good accuracy.

5.6 Snapshots of Implementation

5.6.1 When application starts

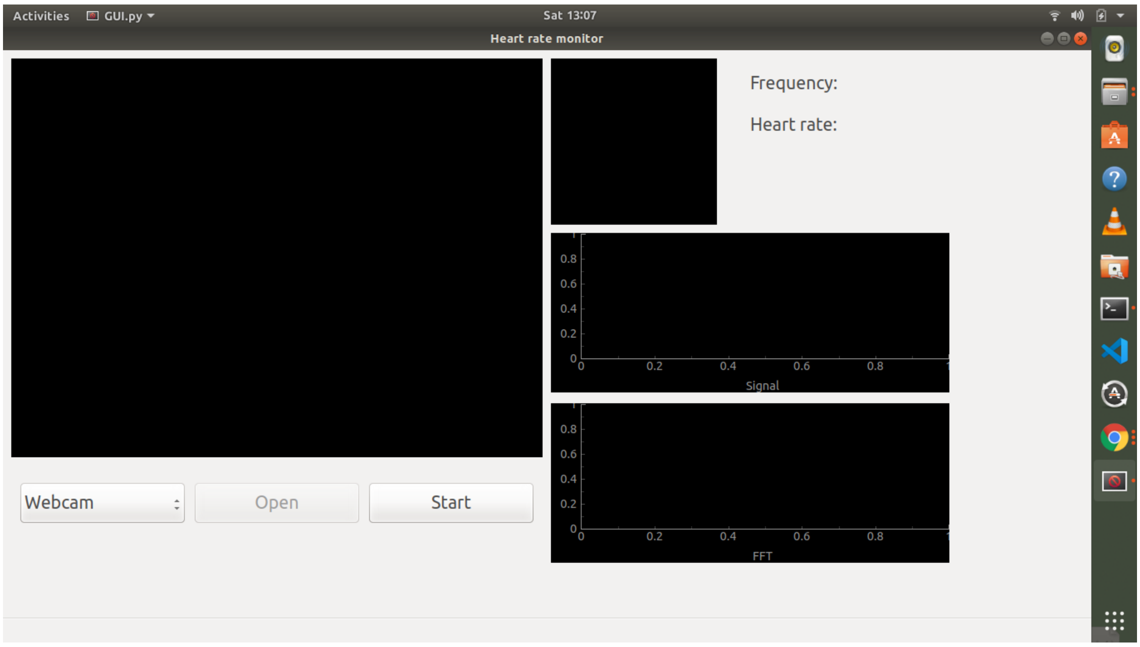


Figure 11: GUI when the Application starts

5.6.2 When video is just uploaded

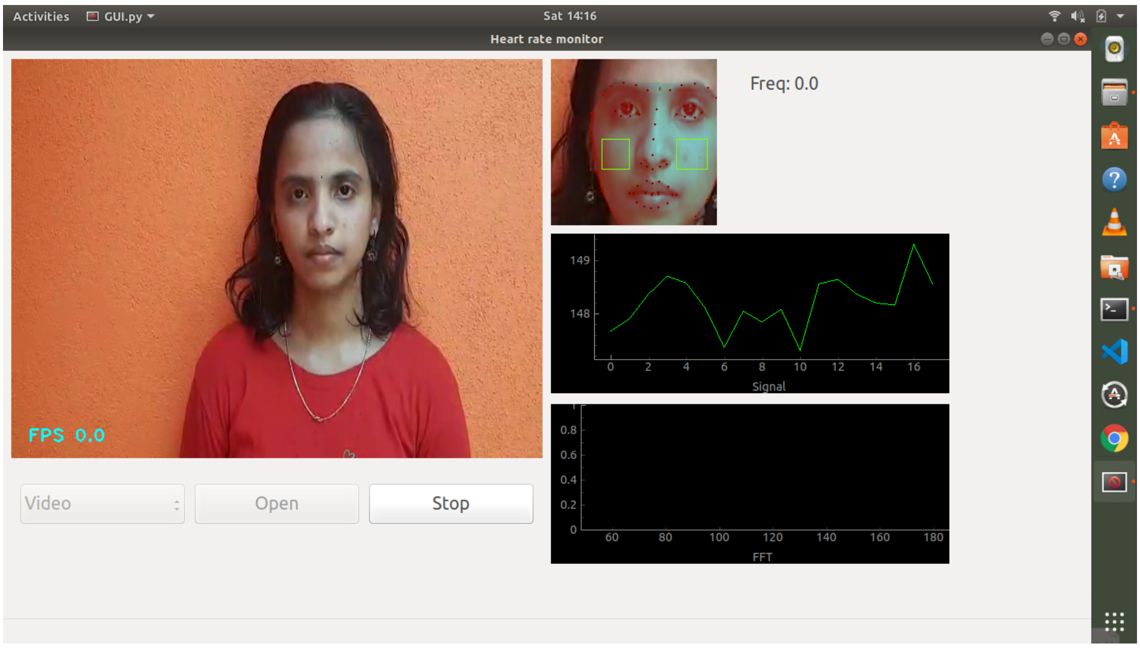


Figure 12: Recorded video is uploaded

5.6.3 When the system starts receiving signal and starts plotting the frequency.

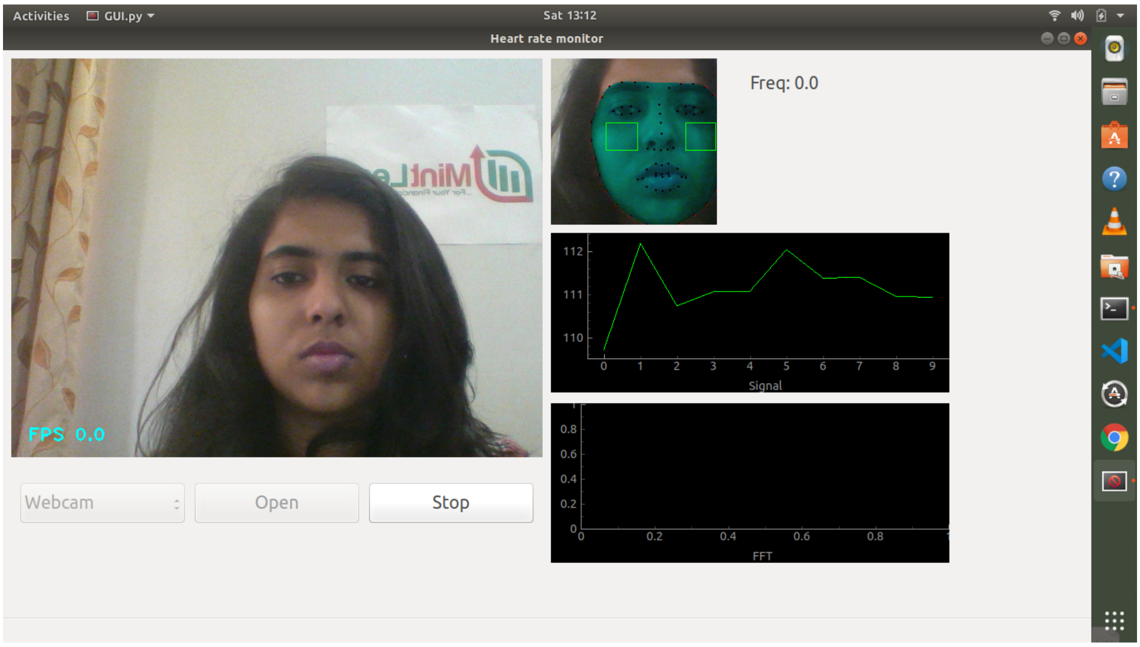


Figure 13: Signals received

5.6.4 Process of normalization

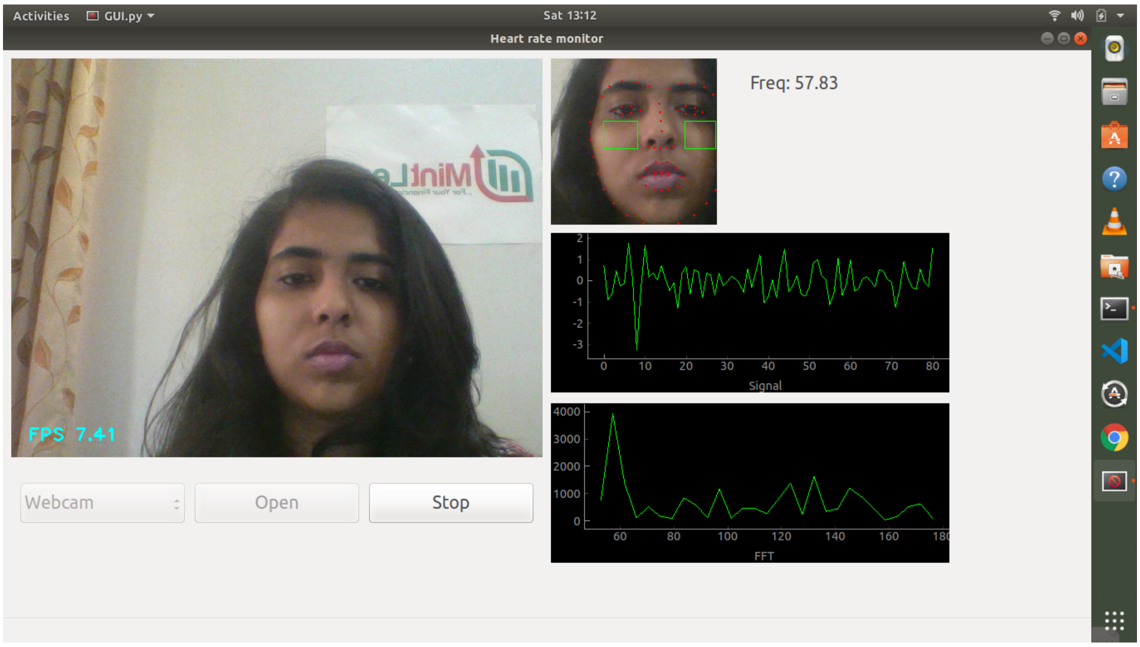


Figure 14: Normalization

5.6.5 HR of the uploaded video

Figure 15: HR of uploaded video

5.6.6 HR of real time video

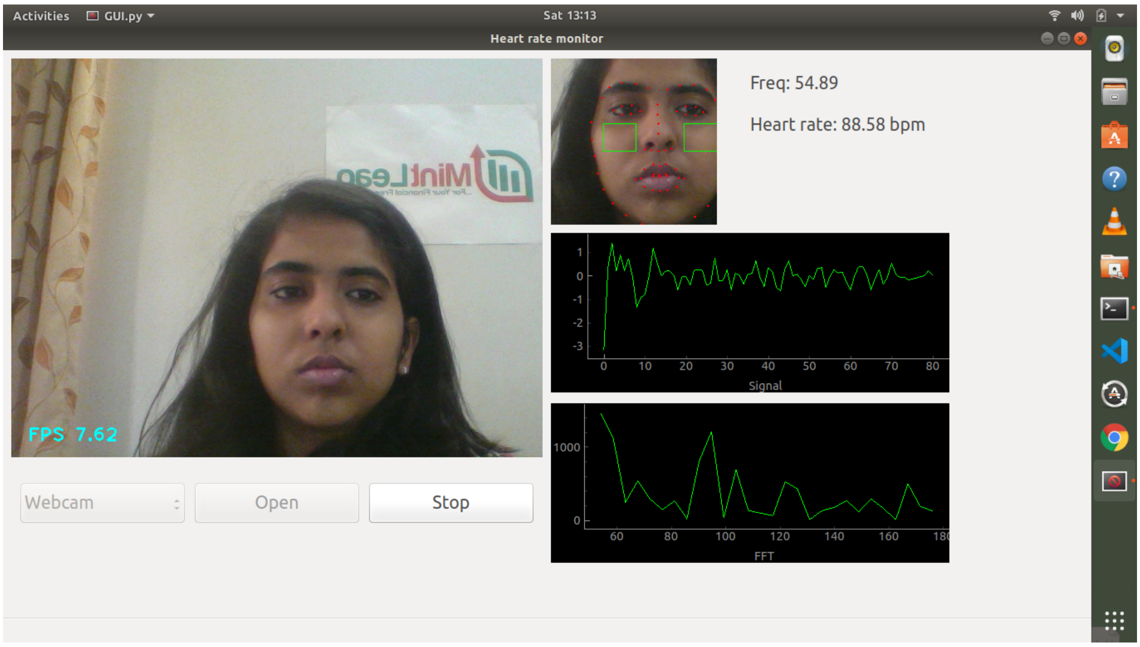


Figure 16: Real time HR

5.7 Referring papers

Image showing the cardio-vascular system is available in [1].

Image showing Photoplethysmography technology is available in [2].

Image showing the colour variation observed when colour amplified is available in [3].

Information on Remote plethysmographic imaging using ambient light is available in [4].

Information about the Real Time Heart Rate Monitoring from facial RGB color video using webcam is available in [5].

Information on Arrhythmia is available in [6].

Information on ECG is available in [7].

Information on pulse rate is available in [8].

Information on usage of OpenCV libraries for HR monitoring is available in [9].

Information on Photoplethysmography and its application is available in [10]

Information on automated cardiac measurements is available in [11].

Information on the effects of movement of the head on HR calculation is available in [12].

Information on Waterfall model is available in [13]

Online tool to create and build use cases and sequence diagram is available in [14]

Online tool to create and build Diagrams is available in [15]

OpenCV python tutorials is available in [16].

Documentation of Flutter is available in [17].

Information of React Native is available in [18].

Information on Firebase for android is available in [19].

Information on dlib library and fcaial recognition is available in [20].

Information on Detrending and nomalization is available in [21].

Information on Smoothness Prior Approach is available in [22].

Information on Image Pyramids is available in [23].

Information on FFT algorithm is available in [24].

Information on PCA algorithm is available in [25].

Information on ICA is available in [26].

Chapter 6

Test Cases

6.1 Working

The image showing HR of an uploaded video is shown in Fig.15 and the image showing the HR of a real time video is shown in Fig.16.

6.2 Exceptions

6.2.1 When no camera detected

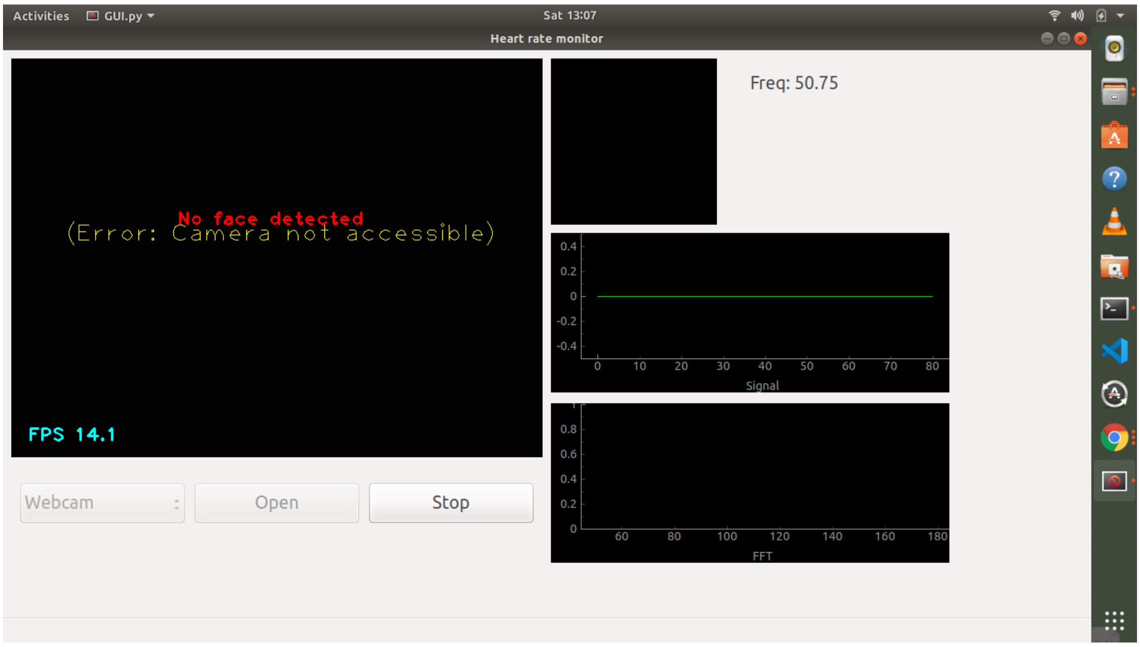


Figure 17: When no camera detected

6.2.2 When no face is detected in Recorded video

Figure 18: When no face is detected in Recorded video

6.2.3 When no face is detected in Real time

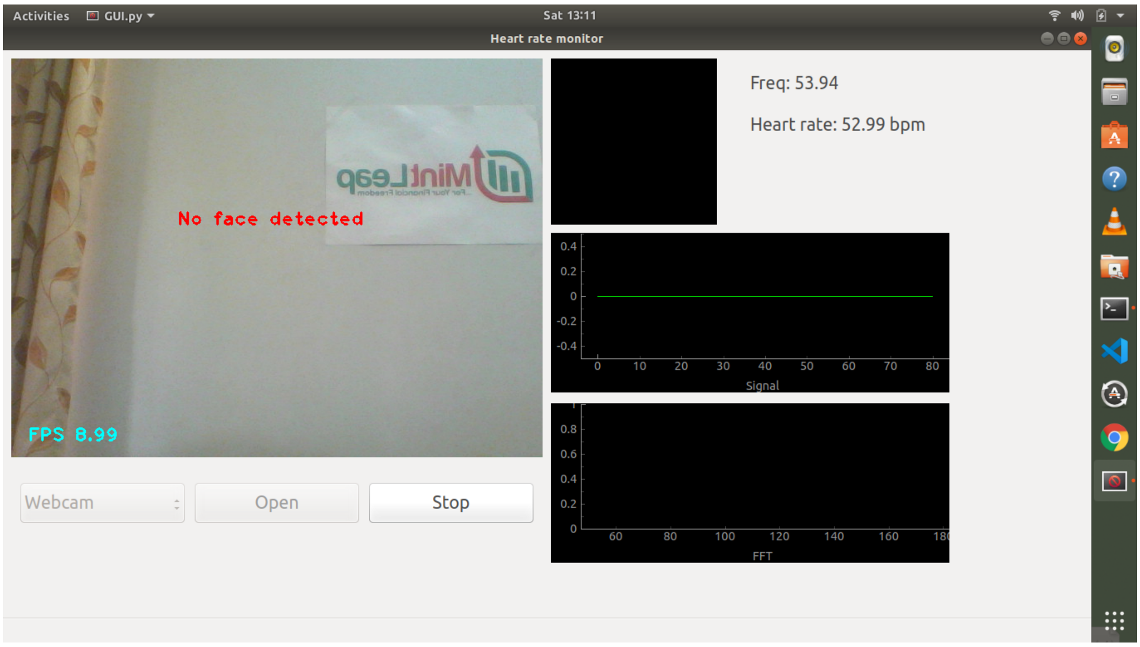


Figure 19: When no face is detected in Real time

Chapter 7

Conclusion

We have successfully completed the calculation of Heart Rate with a good accuracy. This project is helpful for physiological monitoring of drivers which enables us to detect the physiological condition of the person. It is also useful for remote monitoring of heart patients or any other patients. It can also be used as a replacement to the fitbits, fitbands etc..

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