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JEVA

Journal homepage: http://publisher.uthm.edu.my/ojs/index.php/jeva

e-ISSN : 2716-6074

Journal of Electronic Voltage and Application

Contactless Heart Rate Measurement System Based RGB Camera, Cascade Object Detector and Independent Component Analysis

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DOI: https://doi.org/10.30880/jeva.2022.03.01.007
Received 3 February 2022; Accepted 22 June 2022; Available online 30 June 2022

Abstract: This paper focuses on the development of non-contact heart rate measurement based on video analysis. This project implements an RGB camera (OV2640 with ESP32 Cam) and an FTDI Programmer which enables the sensor to record videos from a subject at a distance of 20 cm. The Region of Interest (ROI) of the facial skin tissue was detected by using Cascade Object Detector (COD) which can detect object categories whose aspect ratio does not vary significantly. Then, the Independent Component Analysis (ICA) was applied by extracting distinct source signals (red, blue and green channels) from the observed mixed colour signals. Next, the average pixel of ROI was calculated based on red, green and blue facial pixel at given time. Finally, the heart rate was extracted from the frequency spectrum of the average pixel. The performance of the developed contactless system was compared with the fingertip pulse oximeter (Oxitech) by means of percentage of error (PE). The lowest range of PE is between 0 to 5.62 % whereas the highest PE is 22.54 %. The highest error was due to incorrectly captured ROI of facial skin area as well as due to the movement made during the recording session. Meanwhile, the average time for the developed system to process the heart rate of the subject is 4.51 minutes. In future, a robust ROI algorithm can be adopted to reduce error contributed by incorrectly ROI selection. Other than that, this project has a potential to contribute to the area of contactless measurement of oxygen saturation.

Keywords: RGB Camera, Heart Rate, Region of Interest (ROI), Cascade Object Detector (COD), Independent Component Analysis (ICA)

1. Introduction

Coronavirus disease 2019 (COVID-19) has made a major impact on the world through health care services in both developing and developed countries. COVID-19 caused by severe acute respiratory syndrome coronavirus 2 (SARS- CoV-2) is a global pandemic that initially started in Wuhan, China, and spread extremely quickly making its way to over 180 countries [1]. It attacks all ages especially patients with chronic diseases. The effects of COVID-19 on the patient include hypoxia, which is described as a drop in blood oxygen levels because of damage to the alveolus. This occur when the patient experiences shortness of breath and breathes more quickly than normal while doing tasks

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or moving around. Fever, nausea, lack of appetite, loss of smell, muscle weakness and sore throat are some of the signs that patients experience as they become infected with the infection.

Pulse oximeters are little chip-like devices that are attached to a body part, most commonly a finger to measure pulse rate and oxygen saturation. The ratio of ratios model is the most used model of pulse oximeters. A normal patient's heart rate ranges from 60 to 100 beats per minute (bpm) [2]. In general, a lower heart rate at rest implies more efficient heart function and better cardiovascular fitness. For some people, a heart rate below 60 beats per minute (bpm) indicates abnormally slow heart action which is known as bradycardia. According to some researchers, COVID-19 can cause irregular or high heart rates over 100 beats per minute [2-4].

It is very important to know the heart rate and oxygen saturation status of COVID-19 patients because it has been related to the fact that high pulse rate (more than 100 bpm) and low oxygen saturation (less than 95 %) among COVID-19 patients can be an early warning sign that special medical attention is needed [5-7]. Throughout this pandemic COVID-19, pulse oximeter has been used extensively in measuring heart rate and oxygen saturation of COVID-19 patients by placing the sensor on a finger or at the earlobe of the adult patient and baby patient, respectively. However, this method posed the risk of COVID-19 infection and skin discomfort. Considering this, one of the techniques that can be used to reduce contact is by using the RGB camera. The proposed technique used a colour model refer to as red, green and blue (RGB) imaging to obtain a signal from several distances [8]. It is a visible light camera with three channels where one wavelength will be used to get the reading of heart rate. By using MATLAB software, the heart rate can be determined by using the video recorded from the RGB camera.

Based on the problem statement, the aim of this research is to develop a low-cost hardware based RGB camera for contactless measurement of heart rate. Three objectives are formulated which are to investigate the optimal distance for suitable Region of Interest (ROI), to measure heart rate based on Cascade Object Detector (COD) and Independent Component Analysis (ICA) and finally, to evaluate the performance of developed contactless system with the reference system (Oxitech pulse oximeter). The scopes of this research can be divided into three phases. Phase 1 covers the development of hardware in which the RGB camera is used as the sensor to capture and record videos directly from the subjects within suitable distance. Next is Phase 2 which is the development of heart rate algorithm using MATLAB programming. The ROI is determined using COD whereas ICA is used to separate the mixed colour signals into three separate channels (red, green and blue). The facial skin tissue area is chosen as the ROI whereas the heart rate measurement is determined from the frequency spectrum of the best component-coherence value. Phase 3 is the performance evaluation of developed system by comparing it to the reference system which is Oxitech pulse oximeter. Ten healthy volunteers (without COVID-19 symptoms) were recruited in this experiment as it is too risky to use real COVID-19 patients to be as the subject. In addition, their consent forms were recorded via Google form application.

2. Methodology

This section presents the development of hardware of the contactless heart rate measurement-based video analysis. This section also discusses the algorithm flow charts for heart rate determination as well as the performance evaluation of the developed system. Fig. 1 shows the summary of main process of the development of low-cost RGB camera for contactless heart rate measurement.

Fig. 1 - Summary of main process of the contactless heart rate measurement

2.1 Development of Low Cost RGB Camera System

An RGB camera is a camera that uses a regular Complementary Metal Oxide Semiconductor (CMOS) sensor to take colour images of people or things. In this project, the OV2640 with ESP32 Cam module was chosen to record the video of volunteers. This is because this type of camera sensor module is one of the inexpensive microcontrollers from Espresif and AI Thinker with advanced features of Bluetooth, Wi-Fi, and multipurpose General-Purpose Input Output (GPIO) ports. As the ESP32Cam module does not have a USB interface, thus this project needs an external programmer called FTDI to upload code to MATLAB via serial pins. Fig. 2 shows the connection between the OV2640 with ESP32Cam module and FTDI Programmer whereas Table 1 describes the wiring connection to connect the OV2640 with ESP32Cam to the FTDI Programmer.

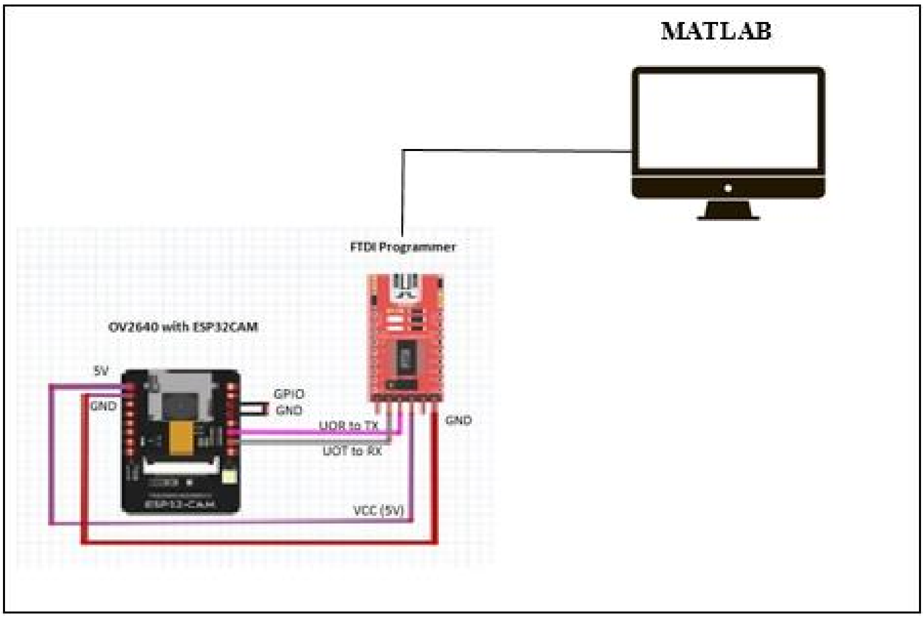


Fig. 2 - OV2640 with ESP32Cam interfacing FTDI Programmer and connection to MATLAB software

Table 1 - Connection pin between ESP32Cam and FTDI

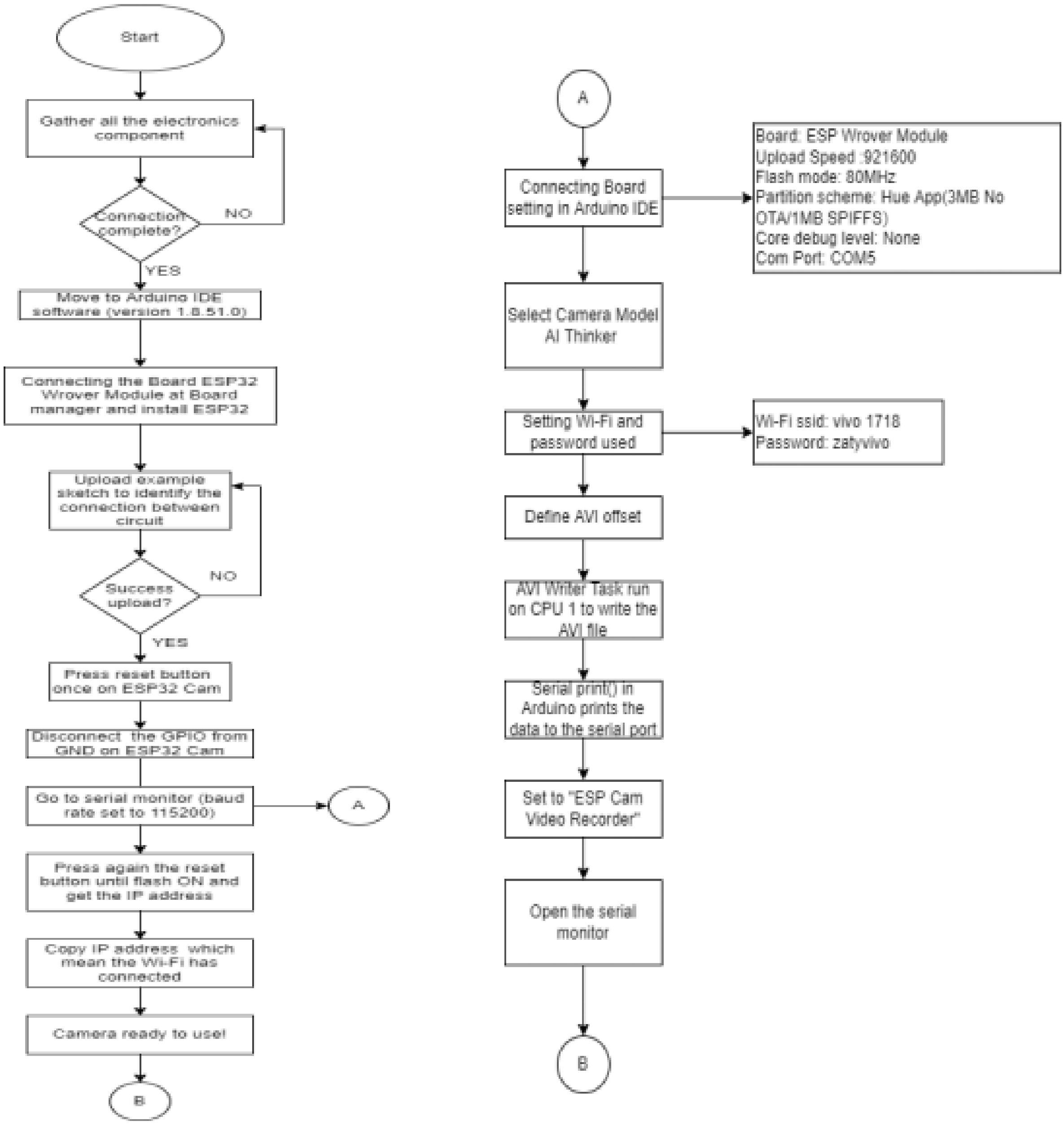
ESP32Cam	FTDI Programmer
GND	GND
5V	VCC (5V)
UOR	TX
UOT	RX
GPIO 0	GND

Meanwhile, Fig. 3 shows the measurement setup to find the optimal distance for the best facial ROI selection. In this project, three distances were selected: 10 cm, 20 cm and 30 cm. The distance was measured by using a measuring tape starting from the endpoint of the camera's prototype to the subject's face.

Fig. 3 - Measurement of optimal distance for the best ROI

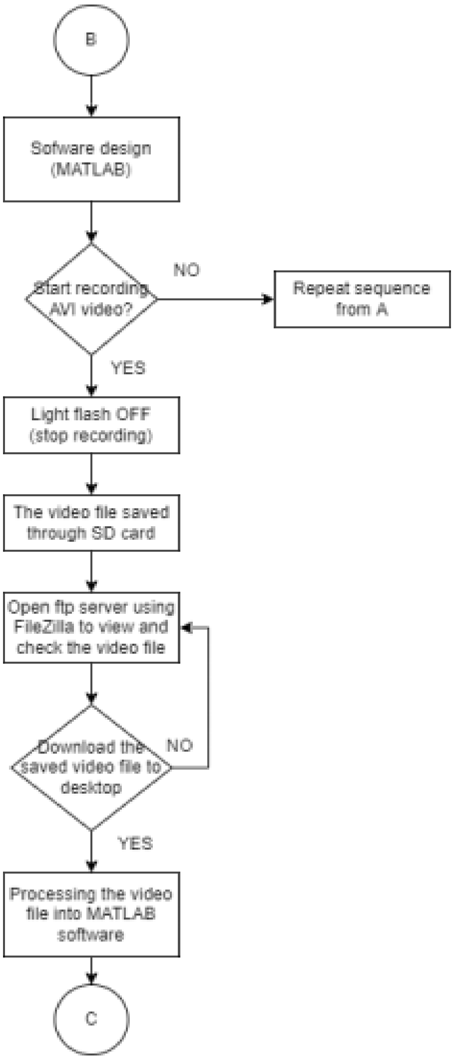
2.2 Development of Heart Rate Algorithm

Before discussing the methods to determine the heart rate, the process flowchart to connect the RGB camera (OV2640 with ESP32Cam) to Arduino IDE and the process to extract the video from the RGB camera are elaborated here. Figure 4(a) shows the process of connecting the hardware module of OV2640 with ESP32Cam to the Arduino IDE software. This process is to ensure that the Arduino IDE has installed the add-on for ESP32 so that when uploading code, the process can run successfully. Meanwhile, Fig. 4(b) shows the process of extracting the video obtained from the OV2640 with ESP32Cam module via FTDI Programmer. The Wi-Fi connection is important in these steps as the procedure depend on it. The function of the serial monitor from Arduino IDE was used to get the IP address to initiate the recording of the camera. Once the camera finishes its 30 seconds of recording, the video was saved in the SD card. The SD card was then accessed and viewed through the ftp server. From here, it can be downloaded to the desktop for further analysis in MATLAB.



Start
Gather all the electronics component
Connection complete?
NO
YES
Move to Arduino IDE software (version 1.8.51.0)
Connecting the Board ESP32 Wrover Module at Board manager and install ESP32
Upload example sketch to identify the connection between circuit
Success upload?
NO
YES
Press reset button once on ESP32 Cam
Disconnect the GPIO from GND on ESP32 Cam
Go to serial monitor (baud rate set to 115200)
A
Press again the reset button until flash ON and get the IP address
Copy IP address which mean the Wi-Fi has connected
Camera ready to use!
B
A
Connecting Board setting in Arduino IDE
Board: ESP Wrover Module
Upload Speed :921600
Flash mode: 80MHz
Partition scheme: Hue App(3MB No OTA/1MB SPIFFS)
Core debug level: None
Com Port: COM5
Select Camera Model AI Thinker
Setting Wi-Fi and password used
Wi-Fi ssid: vivo 1718
Password: zatyvivo
Define AVI offset
AVI Writer Task run on CPU 1 to write the AVI file
Serial print() in Arduino prints the data to the serial port
Set to "ESP Cam Video Recorder"
Open the serial monitor
B

(a)

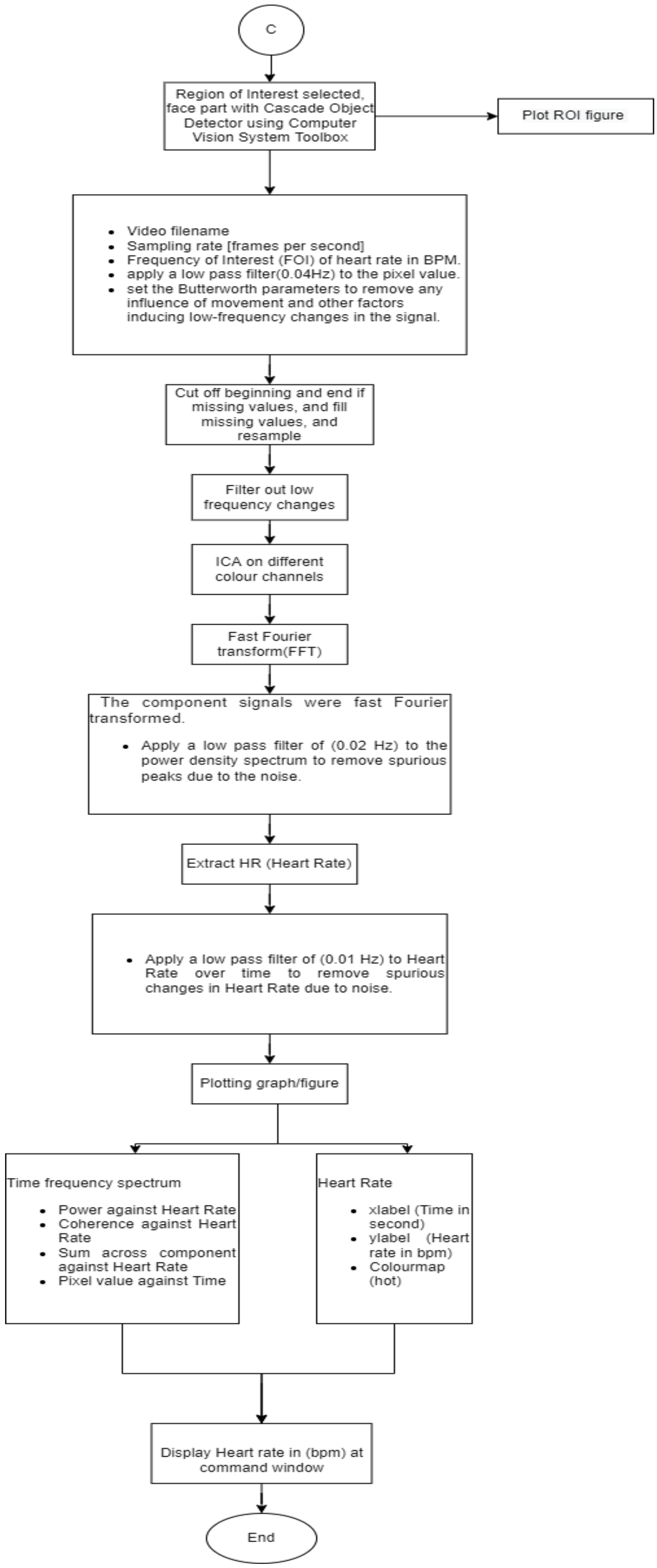


(b)

Fig. 4 - (a) Connection setting for ESP32Cam to Arduino IDE and (b) Video extraction from FTDI Programmer

Next, Fig. 5 describes the sequence to obtain the ROI and the heart rate measurement. In this process, the COD was used to detect the selected region. The COD in the MATLAB's Computer Vision Toolbox can recognize item types with a constant aspect ratio. As a result, faces were recognized automatically and each footage was cropped to a specific zone of interest, removing any distracting background items. The next step is to set all parameters needed which include the video filename for each subject, and sampling rate in frames per second (fps) and applied a low pass filter (0.04Hz) pixel value to remove artifacts caused by movement illumination. Next, the ICA was used for separation of mixed colours to three components (red, green, and blue) and the Fast Fourier Transform (FFT) was applied to the resulted component signals.

The FFT converts the component signals into an estimation of power spectra (squared magnitude) that indicates which oscillatory sine-wave frequencies were represented most powerfully in each component signal. A high peak in power at a certain frequency means that the component was made up mostly of a sine-wave at that specific frequency. This frequency is in most cases a reflection of the detected heart rate. In most circumstances, this frequency is a mirror of the observed heart rate. So, power is represented as a function of heart rate rather than frequency. Previous research had used a time-frequency analysis to show how well the frequency spectrum varies as a feature of recording [30], but the short-time Fourier transform produced no clear heart rate signal with the current data, which is likely due to the limited recordings and low signal-to-noise ratio in so many videos. Then, two low pass filters of 0.02 Hz and 0.01 Hz were employed on the power density spectrum to remove spurious peaks and spurious changes of heart rate, respectively. Finally, the heart rate was determined using the power density spectrum based on the best component – coherence signal.



(c)

Fig. 5 - Sequence to obtain ROI and determination of heart rate reading

2.3 Performance Evaluation

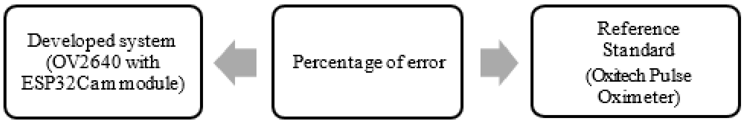


Fig. 6 - Percentage of error between developed contactless system and Oxitech Pulse Oximeter

Fig. 6 shows the percentage of error is computed by comparing the heart beat per minute (bpm) of the developed system (contactless) with the Oxitech pulse oximeter (direct contact). In terms of contactless which is from the developed system, the system used an RGB camera as the sensor to detect heart rate by capturing and recording videos from the volunteers tested whereas the sensor is directly in contact with the skin of the volunteers through the fingertip in the case of Oxitech pulse oximeter. The formula to compute the percentage of error (PE) can be found as below:

$$PE = \frac{|reference\ value - experimental\ value|}{reference\ value} \times 100\ \% \qquad (1)$$

where PE is percentage error, reference value is the reading from the Oxitech pulse oximeter and experimental value is the reading from the developed system. From [9], the accepted error percentage is within limits of 5% only.

3. Results and Discussion

This section consists of the final results and the discussion of the developed system. In this project, the development of a low-cost hardware-based video is to reduce contact with low-risk COVID-19 patients by using the RGB camera measurement technique. Ten healthy subjects without any COVID-19 symptoms were recruited to participate in this study since it is too risky to test on real COVID-19 patients. An informed consent in the form of google form was priorly obtained from all recruited volunteers.

3.1 Prototype and Optimal Distance Experiment

Fig. 7 shows the prototype of the developed system whereas the corresponding labels description of each component is shown in Table 2. It can be seen that the camera module is attached to the camera stand so that the height of the camera can be adjusted according to the subject's height. Next, Table 3 shows the resulted of facial skin area captured by the camera based on several distances:10 cm, 20 cm and 30 cm. This experiment was conducted to obtain the optimal distance for the best facial ROI selection. From this experiment, it is found that the best distance to be used in this project is 20 cm as the facial skin area of the subject can be detected clearly from the camera compared to the other distances which is either too closed or too far from the camera.

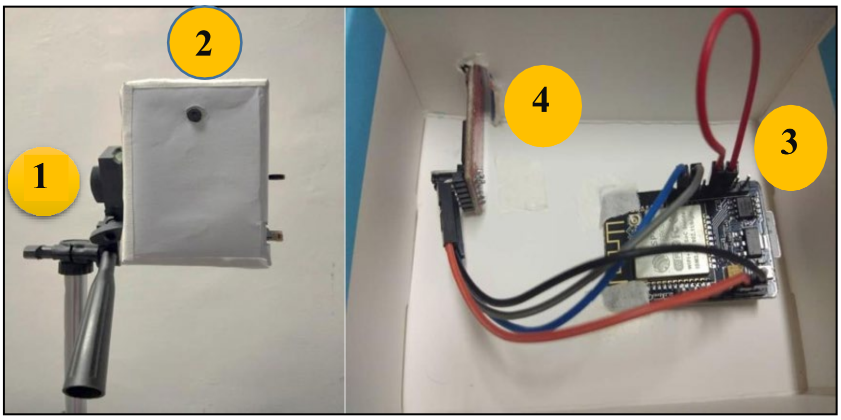


Fig. 7 - Front view of prototype and the position of ESP32Cam module with OV2640 and FTDI programmer

Table 2 - Description of the components

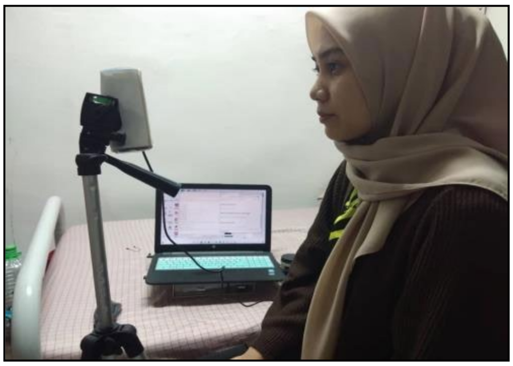
Label	Description
1	Tripod stand.
2	OV2640 camera.
3	ESP32 Cam Module with micro SD card.
4	FTDI Programmer.

Table 3 - Optimal distance experiment findings at 10 cm, 20 cm and 30 cm

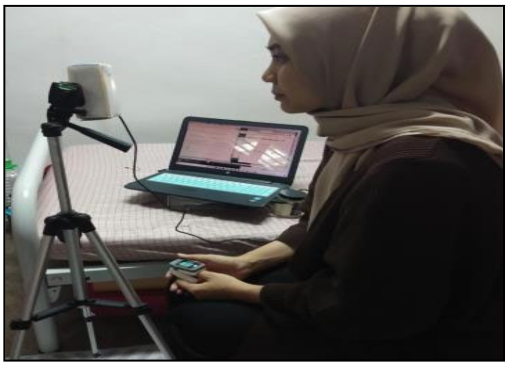
Distance (cm)	Result	Findings
10		The subject was too close with the camera and part of the face was out from the captured image. The camera could not read all the pixel values of skin surfaces images for heartbeat rate detection.
20		This distance was deemed suitable as the subject's facial skin was nicely captured and the facial area to detect the heartbeat rate can be calculated.
30		This distance was not suitable as the subject was appeared way too far and the detection of the heartbeat rate may be interrupted with motion and noise.

3.2 Contactless Heart Rate Experiment

Fig. 8 displays the preparation of the volunteer before taking part in the contactless heart rate measurement. The volunteer was required to sit upright with the facial skin facing the camera. The pulse oximeter was attached at the fingertip to measure the reference reading of the heart rate. During the process of recording, the subject was requested to not move to reduce noises due to motion. Next, Figure 9 describes the results obtained from the heart rate algorithm. Fig. 9(a) represents the selected ROI image of the facial skin tissue captured at a distance of 20 cm. It can be seen that the COD successfully cropped the corresponding facial skin area and remove the unwanted area which was the eye. Next, Figure 9(b) shows the components of the frequency spectrum started with: (a) Power corresponding to Heart Rate, (b) Coherence corresponding to Heart Rate, (c) Sum across component corresponding to Heart Rate and (d) Pixel value corresponding to Time. Then, Fig. 9(c) illustrates the heart rate (bpm) with respect to 30 seconds of recording in a colour map format and finally, Fig. 9(d) shows the final mean value of heart rate displayed on the MATLAB's command window.



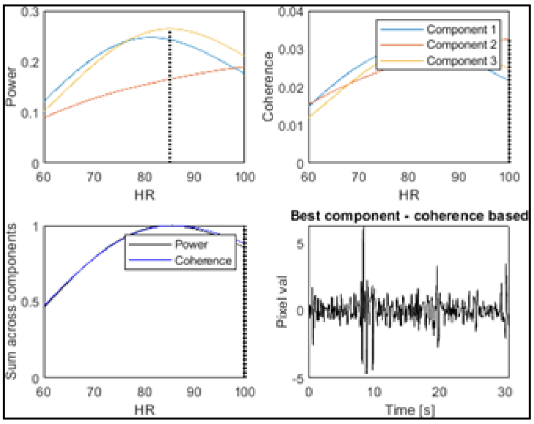
(a)



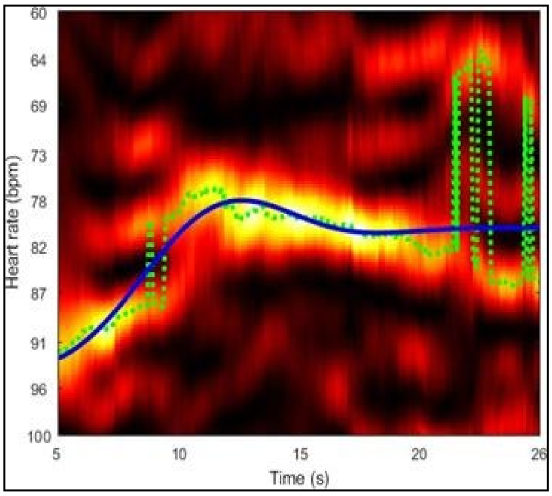
(b)

Fig. 8 - (a) The volunteer was required to sit upright and face the RGB camera; (b) The Oxitech pulse oximeter was clipped at the volunteer's fingertip

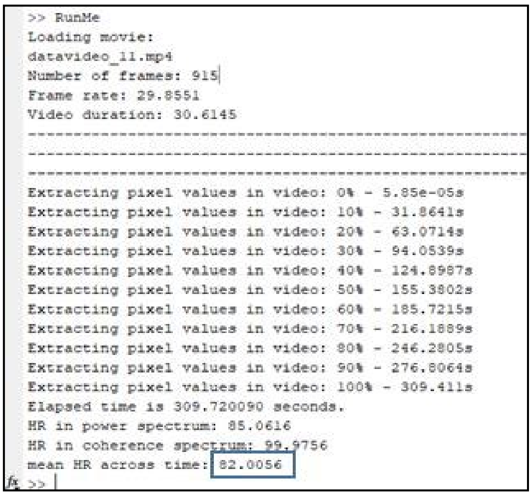
(a)



(b)



(c)



(d)

Fig. 9 - Example of main findings from Volunteer 1: (a) ROI from recorded facial skin at 20 cm distance; (b) Power density spectrum (refer to text for further explanation); (c) Heart rate (bpm) versus time (sec) in colour map format; (d) The volunteer 's heartbeat reading was 82.0056 bpm

Meanwhile, Table 4 shows the recorded summary of the average heart rate reading for all ten subjects as displayed in the command window. The recorded heart rate was in the range of 76 to 87 bpm. To evaluate the performance of the developed system, a comparison heart beat reading was done with Oxitech pulse oximeter and the results can be referred to Table 5.

Table 4 - Summary of mean heart rate readings for all ten volunteers

Volunteers	Recorded Mean Heart Rate (bpm)
1	82
2	84
3	79
4	78
5	76
6	87
7	83
8	87
9	77
10	87

Table 5 - Percentage of error (%) of mean heart rate

Volunteers	Mean Heart Rate in BPM (developed contactless system)	Mean Heart Rate in BPM (Oxitech Pulse Oximeter)	Percentage of Error (%)
1	82	84	2.38
2	84	89	5.62
3	79	79	0.00
4	78	79	1.27
5	76	76	0.00
6	87	76	12.64
7	83	80	3.75
8	87	71	22.54
9	77	72	6.94
10	87	71	22.54

Table 5 shows the mean heart rate from the developed contactless system when compared to the mean heart rate from the reference (Oxitech pulse oximeter) and the corresponding percentage of error. It can be seen that some errors were acceptable, and some were not due to the high percentage of errors. The lowest range of PE is between 0 to 5.62 % whereas the highest PE is 22.54 %. Higher percentage of error can be seen on volunteer number 6, number 8 and number 10. Take note that, in the developed system, the heart rate was measured by considering the red, green and blue components in the area of facial skin tissues. However, it was found that the common contributed factor to higher percentage of error in volunteer number 6 and 8 was caused by the camera which was not adjusted according to the correct height of subject. Consequently, the COD was unable to select appropriate facial skin area. The results were noticeable as the volunteers' eyes were not fully excluded and this was counted in the average ROI calculations as well as during the heart rate determination. Meanwhile, subject number 10 did not sit quietly, and his movement caused the motion artifact and hence, contributed to the highest percentage of error. Shcherbina et al [9] highlighted that the acceptable error limits for the heart rate measurements must be within 5 %. It can be safely concluded that this developed device is working fine provided that the facial skin area of the subjects must be captured properly, and the subjects must not move during the experiment. On different note, the average time taken to obtain the heart rate for all ten volunteers using the developed system was equivalent to 4.51 minutes. This result is shown in Table 6. The time taken to process can be considered long and this is also affected by the computer/laptop RAM specification. It is expected that if the computer/laptop has higher specification, the shortest time to process the heart rate algorithm can be achieved.

Table 6 - Average time taken to process the heart rate

Volunteers	Time taken (s)
1	309.72
2	288.58
3	185.98
4	270.03
5	135.93
6	212.56
7	336.69
8	336.12
9	338.52
10	291.49
Average time for ten volunteers	= 2705.62/10/60 = 4.51 minutes

4. Conclusion

In conclusion, all objectives of this project were successfully achieved. The contactless heart rate measurement-based video by developing a low-cost hardware using RGB camera was successfully developed. The prototype was developed using the selected RGB Camera which is OV2640 with ESP32Cam module and the FTDI Programmer. In this research, the heart rate was measured contactlessly from the video based on the facial skin tissues area. The optimal distance for capturing the facial skin area was found to be 20 cm. The COD was used to select the ROI of facial skin and the ICA was implemented to separate the mixed colour signals into three RGB components. Finally, the performance of developed system was evaluated by comparing the results from the developed system with the ground truth reading from the Oxitech pulse oximeter. Ten healthy volunteers were recruited to be the subject of this experiment.

As for recommendations, some improvements can be done in the future. First of all, the cover of the prototype can be developed using a 3D printing model which can give a neater look. In addition, it is a good initiative if the prototype can be stand on its own since currently, a tripod stand was used to move and adjust the height according to the subjects tested. Besides that, different ROI algorithm approach can be adopted to find a more accurate and robust ROI selection. Finally, this project can be upgraded by adding another most important vital sign which is oxygen saturation.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for the financial support.

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