# Mobile Heart Rate Monitor

Subham Das
*IISER Bhopal*
*EECS Department*
subham18@iiserb.ac.in

***Abstract*—Cardiovascular disease is one of the leading causes of death worldwide. Preventive cardiology is one of the most promising approaches to tackle this problem. We will use a non-invasive, easy-to-use, and widely available device to process and provide essential data. Mobile phones with their multiple inbuilt sensors can be used to design and develop applications to collect different biomedical signals. In this paper, we propose to use a mobile phone's camera to estimate heart-rate. This is achieved by using the phone's ability to record and detect variations in color signals on the fingertip placed in contact with its optical sensor, i.e., camera. The intensity measured varies with the blood flow, and we will calculate the average value of all the pixel's intensity. The accuracy of this application is confirmed by comparing the results obtained to that of standard heart-rate monitors available in the market under different conditions.**

***Index Terms*—Photoplethysmography, heart-rate monitor, mobile, sensor, BPM**

## I. Introduction

Smartphones are becoming more popular, powerful and even have a variety of sensors available to capture information from the outside world, process the data in real-time, and transfer information remotely using wireless communications. Extensive research is being conducted to monitor various physiological parameters without any need for additional hardware. These factors make smartphones an ideal choice, and their potential has been explored for many medical applications.

There is a need for low-cost physiological monitoring solutions that are easy to use, accurate, and can be used in home or ambulatory settings.
Current mobile phone technology extends beyond simply monitoring and measuring with ease for a patient; it could also be used to relay the information to medical professionals. This gives a patient the ability to carry an accurate physiological monitor anywhere, without additional hardware beyond what's already included in many consumer mobile phones.

Optical video monitoring of the skin with a digital camera and an external flashlight can be used to extract information related to the subtle color changes caused by a cardiac signal as the blood flows in and out (contain a pulsatile signal). The rate at which this color change occurs can be used to determine the heart-rate of the person.
Given the illumination of the area with a white LED mobile phone flash, this type of imaging can be described as reflection photoplethysmographic (PPG) imaging.

Heart rate helps to detect such diseases as tachycardia and bradycardia. The main idea of measuring heart rate using a mobile phone is to detect variations in finger skin color and brightness that occur due to blood pulsation using on-board phone's camera. The detection is made by analyzing average red component values of the frames, or part of the frames, taken by the camera.

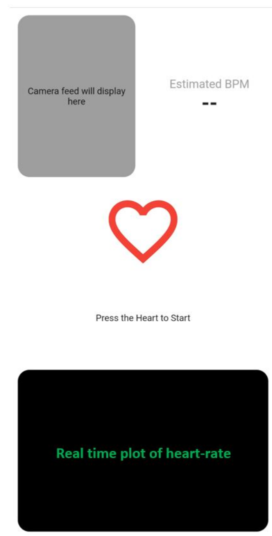


Fig. 1. Interface

## II. Algorithm

Periodic fluctuations in the received DC light on the receiver can be used very easily to estimate the heart-beat. Each heart-beat corresponds to an increase in brightness (red DC level) following a period of reduced brightness. If the number of peaks of DC light in a specific period of sampling is known, we can use this as per the formula. The main challenge is to implement this algorithm using only a smartphone.

Heartrate = (No of peaks in DC Red Level in a sampling period *60 / Sampling period)

Fig. 2. Conversion Formula

Every valid image is processed, and the most interesting parameters are stored. Only the number of red pixels from the image is analyzed. If the number is higher than in the previous image, then we can assume that the heart is now beating.

The frame is not black but slightly red. The ambient light is travels through the finger tissues and reaches the camera sensor. Despite the image looking like an almost static red frame, the periodic oscillations of the blood flow in the vessels produce weak brightness variations that are undetectable for the naked eye but can be discovered with signal processing. Shining a light into a blood irrigated tissue, we can measure the variability of reflected light and extract blood flow variation. As we all know, blood flow is dependent on the heart rate, so we can calculate the heart rate using the blood flow variation.

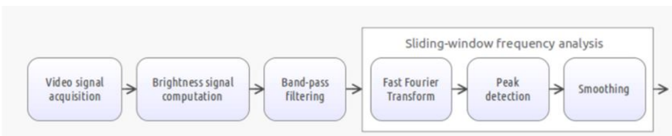


Fig. 3. Flow Diagram of Process

## III. Implementation

The time series of average red component values of the frames are considered as input signals for heart rate measuring. The signal contains "sharp" local maxima called peaks. Each peak corresponds to a single heartbeat. The number of heartbeats and length of the measurement is all that is needed to calculate the heart rate. Unfortunately, the original signal is too noisy and may contain fake peaks or data loss due to movements of the finger above the camera lens and changes in surrounding light level during the measurement. That is why we cannot rely on the number of raw signal peaks for heart rate calculation. We need to use algorithms that receive signals as input and give calculated heart-rate on the output.

In the code of the application, the function **_scanImage** calculates the average of the camera image's red channel and adds the value to the data list, which is then displayed on the chart. The number of points on the data list has been limited to 50 values.
We do not need to process every frame; therefore, we can select a sampling rate. We have used a sampling rate of 30 samples/second. This has been implemented using a boolean, **_processing**, which becomes true once the **_scanImage** function is called and stays that way for 1/30 seconds, then returns to false. The **_scanImage** function will only be executed if the boolean **_processing** is false.
Heart rate, which is the frequency of the plotted signal, is measured as the average and the max along our window data. Then we set the threshold to the mean of these values and detect the peaks above that threshold. It then updates the BPM value with an attenuation coefficient, so we don't have abrupt changes.

We have a real-time plot of red DC mean data from the image. The values show variation of received intensity of red color with time, and this can be used to calculate the heart-rate.

TABLE I
Heart-rate Measurement using App and Mobile Phone

| S No. | Average Heart-rate Value | | |
|---|---|---|---|
| | *Application* | *Smart Watch* | *Activity* |
| 1. | 76 BPM | 72 BPM | Resting |
| 2. | 103 BPM | 100 BPM | Workout |

Fig. 4. Comparing values between conventional sensors and our application


Fig. 5. Values Observed

## IV. Drawbacks

A good Signal-to-Noise Ratio (SNR) is essential to accurately detect the heart rate signal. It can be improved by either reducing the noise or increasing the signal power. In our case, the noise affecting the measurement comes from three sources basically:

- **Image noise**: It originates in the camera sensor. By averaging all the pixels for the brightness calculation, we are filtering out a big part of its spatial component. There will always be some level of this noise in the band of interest.
- **User behavior**: The pressure variations of the fingertip against the camera lens may show up in the signal. If the user has shaky hands, it is better that they use a finger of the hand holding the phone.
- **Lighting changes**: Any change in the light sources or in the scene reflecting that light towards the camera may introduce noise. For instance, moving the phone in the air while recording the video sequence may introduce artifacts if the scene parts in the field of view have very different light intensities.

There are few other factors that can cause a wrong reading that cannot be mitigated by the software or algorithm itself. Such factors include:

1) Contact area may change continuously affecting the average reading.
2) Unexpected pulse amplitude variations.
3) Ambiguity of converting from light intensity to RGB measurement of the camera.

## V. Observable Errors

The most common types of errors that can occur while taking a reading are improper placement of finger (partial covering of camera), applying too much or too little pressure, and covering only the camera and not the torch. What are the effects of these errors on the final reading, and what is the deviation from standard values? This is what we will try to observe in this section.

The experiment was done over a period of 30 minutes, taking a reading every minute and subsequently checking the readings on a standard heart rate monitor. The heart rate observed is that for a patient in a resting and seated position.

1) **Covering only the camera:** This reduces the amount of light falling on the finger placed, thereby making the image darker than it needs to be. A darker image results in an overall higher value, as observed in the table below. Since the torch is always on (by default), some amount of light is shone on the finger.
The average reading 39 BPM more than the required average value obtained from a standard heart rate monitor, which is an error of almost 46%, and hence should be avoided.

| Sno. | Reading from App | Reading from Smart watch |
|---|---|---|
| 1 | 141 | 82 |
| 2 | 142 | 88 |
| 3 | 146 | 84 |
| 4 | 117 | 86 |
| 5 | 104 | 84 |
| 6 | 78 | 85 |
| 7 | 132 | 88 |
| 8 | 140 | 83 |
| 9 | 124 | 81 |
| 10 | 118 | 87 |
| Avg | 124 | 85 |

Fig. 6. Covering only camera

2) **Partially covering the camera:** By partially covering the camera, the algorithm takes into account the colors present in the background while calculating the average. In order to find out the range of error, ten readings have been taken simulating different cases, i.e., placing a tiny part of the finger all the way to leaving out only a small part of the required region. Depending on the situation, the readings could be as low as 77 BPM or as high as 133 BPM.

| Sno. | Reading from App | Reading from Smart watch |
|---|---|---|
| 1 | 95 | 85 |
| 2 | 102 | 81 |
| 3 | 130 | 87 |
| 4 | 102 | 86 |
| 5 | 77 | 83 |
| 6 | 108 | 89 |
| 7 | 96 | 88 |
| 8 | 133 | 84 |
| 9 | 130 | 82 |
| 10 | 111 | 89 |
| Avg | 108 | 85 |

Fig. 7. Partially covering camera

Since the algorithm takes the average value of colors present and also takes into account the previous reading, there is no particular trend that can be observed. The average reading, in this case, is 23 BPM more than the average value obtained from a standard heart rate monitor, which is an error of almost 27%, while lower than the previous case, the range observed is extremely high despite the algorithm taking into account such changes.

Covering only the flashlight would have no effect as the algorithm is such that it requires a minimum amount of red to start taking a reading which would not be possible unless the finger is placed on the camera up to some degree or there are lots of red elements in the background.

3) **Applying improper pressure:** Constantly changing the pressure applied by the finger can also affect the final reading. To observe the changes, we first applied high pressure and obtained five readings, then substantially reduced the applied pressure and took five more readings. While there are no observable trends that can be

observed, we notice that the subsequent readings are not stable and have significant variations. However, the effect due to this type of error is considerably low as compared to the above two cases, as finger placement and lighting on the finger are optimal.

| Sno. | Reading from App | Reading from Smart watch |
|---|---|---|
| 1 | 71 | 88 |
| 2 | 83 | 87 |
| 3 | 71 | 89 |
| 4 | 70 | 84 |
| 5 | 79 | 83 |
| 6 | 77 | 87 |
| 7 | 73 | 85 |
| 8 | 76 | 81 |
| 9 | 87 | 86 |
| 10 | 83 | 87 |
| Avg | 77 | 86 |

Fig. 8. Applying different pressure

The average reading, in this case, is 9 BPM more than the average value obtained from a standard heart rate monitor, which is an error of almost 10.5%, which is much lower than the above two errors. While the effect is low, a better and more stable value may be obtained by mitigating this sort of error.

We observe that any type of reading with the above three abnormalities will lead to a very different reading from the actual value. These errors cannot be taken into account by changes in the algorithm. So, it is advisable to get the heart rate checked by a standard heart rate monitor in case the patient feels that the reading is not normal, as in some cases it may be due to an actual heart-related issue, but it could also be because of taking an incorrect reading.

## VI. Results and Future Work

Work is being done to incorporate other factors to calculate the heart rate accurately. The photoplethysmogram (PPG) in the android app works similar to conventional sensors with an error of $\pm$7-10% (not always). Also, analyzing the heart rate can help us identify different heart defects, such as arrhythmia, by calculating the standard deviation for the time between each heartbeat. The time between each beat would be quite different for a person who has an arrhythmia disease.
From the results, it can be observed that the application shows values very close to that of standard devices under different conditions (rest/work/etc.).

## VII. Conclusions

Preventive cardiology holds a lot of promise, but easy-to-use and widely available hardware are necessary to make it an effective tool against cardiovascular diseases. In this paper, we show that a mobile camera can be effectively used for recording important parameters like heart rate. We collected and verified the results under different conditions. While the technology is not at a level to replace conventional heart rate monitors, it can prove to be useful in providing a quick reading and informing whether further action needs to be taken. Overall the results look very promising.

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