Non-invasive Heart Rate Measuring Smartphone Applications using On-board Cameras: A Short Survey

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***Abstract*—The rapid improvement in smartphone technology has produced many medical applications [1]. Cellular phones now offer several advantages over desktop or laptop computers in tele-monitoring applications like individual's fitness, instant diagnosing and systems for monitoring an individual's medical conditions. Heart rate is one of the most important vital signs of human body. Although cellular phones in combination with other sensing devices (like ECG meters) are able to capture heart rates, there exist a myriad of applications that use only smart phone and its associated accessories (such as on-board camera) to detect heart rates within acceptable accuracy limit. Theoretically, any body part can be used to measure heart rate, although fingertips are commonly used. The fundamental technique of measuring heart rate through smartphone applications is based on image or video processing. In this short survey, we discuss the basic mechanism of heart rate measurement using *only* smartphone *cameras* and compare the performance of some notable state-of-the-art smartphone applications available for such purpose. Our experiments show that most of the applications are able to capture heart rate with acceptable accuracy under various body conditions such as normal and waking up after sleep.**

***Index Terms*—Heart Rate Measurement, Smartphone Application, Vital Signs, Image Processing, Photoplethysmography, PPG, HRV.**

I. Introduction

Vital signs such as heart rate, blood pressure, respiratory rate and body temperature are the indicators of a person's essential body functions. *Heart rate*—the number of times heart beats per minute—is a typical measure of heart conditions. Although heart rate varies with body fitness, the normal range of heart rate among adults is 60-90 beats per minute (bpm) [2]. Heart rate indicates how well the heart is functioning. It helps finding the causes of symptoms, such as an irregular or rapid heartbeat (palpitations), dizziness, fainting, chest pain or shortness of breath. Heart rate also helps to detect diseases like tachycardia (a medical condition where heart rate exceeds the normal range) and bradycardia (a medical condition where heart rate is under the normal range). High heart rate can cause cardiac arrest [3]. During physical exercise it is extremely essential to monitor heart rate [4]. During exercise or immediately after exercise, the heart rate can provide information about one's cardiovascular fitness level and health.

Another important fact about heart rate monitoring is Heart Rate Variability (HRV) which is the physiological phenomenon of variation in the time interval between heartbeats. HRV has significant effect on sudden cardiac death, hypertension, psychiatric disorders [5] [6] [7] and it has additionally been used as an indicator of acute and chronic stress [8]. One way to measure HRV is the statistical method in which heart rate monitoring is involved [9]. Due to this enormous importance of heart rate monitoring, many smartphone applications are available for the measurement and analysis of heart rate.

In this paper we focus on smart phone applications that measure heart rates using on-board cameras in a *noninvasive* way. Detecting heart rate using *only* cameras has an added advantage because in such case the users do not require any additional accessories and/or skills to measure heart rate rather than simply placing his body parts infront of the camera and capturing image/video. Almost all of these applications are based on similar techniques that we describe later in the paper. Although there exist a notable volume of research on how to detect heart rates using smart phone cameras, no study has been conducted to compare the accuracy and performance of such available smartphone applications. Although the main focus of this study is related to the performance analysis of these applications, this short survey also answers few important (and exciting) questions to the research community: (1) what smartphone applications are available for detecting heart rates using attached cameras only, (2) what accuracy level do they offer, (3) what are the underlying techniques/algorithms to detect heart rates using simple image/video analysis, (4) are these applications able to capture heart rates accurately under various body conditions, such as sleeping and waking up, and (5) does the accuracy level varies based on smartphone's associated operating system.

II. Background

There exist several techniques for measuring heart rate. Most traditional methods manually measures heart rate by feeling pulse at the spot on the body where artery is close to the surface. Two most common spots are *radial artery* at the wrist and *carotid artery* at the neck. However, this manual method requires a little skill to locate the pulse first and then counting precisely the subsequent rate. Although manual methods are the most popular, sometimes it can provide inaccuracy in the result, specially when pulse rates are self-counted.

Now-a-days, special devices, such as electrocardiographs, heart rate monitors and pulse oximeters are being widely used to measure heart rate. Among these devices, the working principle of a pulse oximeter is very interesting and is based on the so-called *photoplethysmogram* (PPG)—an optically obtained *plethysmogram* [10]. Ususally the term 'plethysmogram' is a volumetric measurement of an organ and 'photoplethysmogram' is simply an optical way of measuring such volume. More specifically, photoplethysmogram captures the change in blood volume by illuminating the finger with a light-emitting diode (LED) and measuring the changes in skin illuminated light by transmitting it through a photo diode. The change in blood volume is synchronous to the heart beat, so it can easily be used to detect the heart rate.

There are two basic types of photoplethysmography: transmittance and reflectance. Reflectance photoplethysmography is used in these smartphone applications. When the fingertip is illuminated by the source, three things will happen depending on the volume of blood in the fingertip: (1) certain amount of the light will be absorbed, (2) certain amount will be transmitted, and (3) certain amount will be reflected. The intensity of the reflected light varies with the volume of blood in the fingertip, which in turn varies in accordance with heart beat. From this varying intensities heart rate can be easily calculated [13].

Smartphone applications for measuring heart rate use almost the similar idea of pulse oximeter [12]. These applications are becoming popular because they require neither any costly equipment like pulse oximeter nor any special skill to measure heart rate in manual method. The requirement for heart rate measurement using smart-phones is just a phone with an on-board camera equipped with a flash (the quality of the camera does not influence much) and a special application installed. If the phone does not have flash then the measurement needs very well-lit condition to get accurate results. There are mainly two ways to measure heart rate via smartphone applications: (i) Contact method (usually suggests to use fingertip) (ii) Non-contact method (usually uses the front camera). In the first method, as the name suggests, a close contact of a body part and the camera is needed. On the other hand, in non-contact method such contact is not necessary. The algorithms and process of measurement in each category are discussed in the next section.

III. Algorithms

In this section we describe the working principle of contact and non-contact method of heart rate measurement.

A. Contact Method

The working principle of the contact method closely matches with the Eulerian Video Magnification (EVM) [11]. EVM is one way to record motion in video that is imperceptible for a human to see with the naked eye. A sequence of spatial decomposition and temporal filtering is applied to a video file and the resulting file contains all details with magnified motions. As stated earlier, the smartphone application utilizes an imaging acquisition concept similar to the *pulse oximeter*. The subtle difference between a pulse oximeter and the smart phone using contact method is, the former one uses infrared light to determine oxygenated and deoxygenated blood based on the blood opacity, but the later one captures and analyzes images (i.e., video frames) to determine heart rate based on blood opacity.

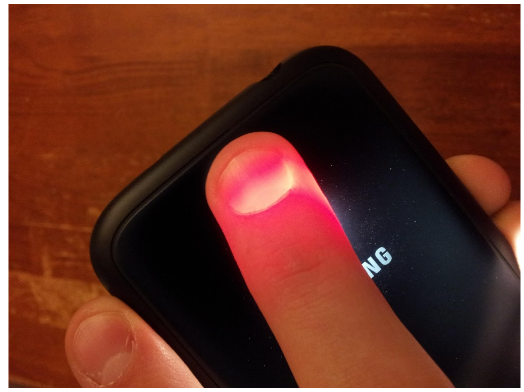

Fig. 1. How to place the finger while measuring heart rate

The process works by placing the subject's index finger on the smartphone camera in such a way that it covers both the camera and flash as shown in Figure 1. The finger should not be pressed too hard because it may stop blood circulations. After placing the finger the application starts to capture the frames keeping camera flash turned on. Every time the heart beats, it pushes blood to every part of the human body. When the capillary is full of blood, it will block the amount of light that can pass through. When the blood retracts, more light can pass through the tissue. Clearly this changes in opacity affects the color of the skin and can be detected either by analyzing average red components of the RGB values of the frames as in [14] [15] or the average green components of the RGB values as in [17]. Thus a PPG wave shape can be obtained by plotting average red/green values in the subsequent frames as shown in Figure 3 [20]. Observe how the signal contains *sharp* local maxima called peaks that quickly changes from large positive values to large negative values. Each peak corresponds to a single heart beat.

However, the original captured signal is ususally too noisy and may contain fake peaks due to movements of the finger above camera lens. So the next step is to detect the real peaks. For this purpose the captured signal is usually normalized using smoothing differentiation [18] and then filtered with a moving average filter [19]. Heart rate (HR) can be measured from the time interval between the peaks. The time difference between consecutive peaks is computed which is known as R-R interval (RRI). From the RRI values the HR is estimated using Equation 1 given below.

$$HR = \frac{60}{RRI} \tag{1}$$

The RRI in Equation 1 is measured in seconds, therefore the

Fig. 2. User interface of an application which utilizes non-contact method

TABLE I
DESCRIPTIVE CHARACTERISTICS OF THE SUBJECTS

Sex	Age	Height (in)	Weight (lb)
F	25	62	112
F	18	63	110
F	33	59	154
F	23	61	123
F	49	65	154
F	19	64	128
M	23	69	138
M	31	70	165
M	55	66	172
M	38	70	170
M	19	69	128
M	48	64	180
M	28	65	137
M	33	73	202
M	26	69	198

numerator is 60 seconds. Sometimes the heart rate can be measured by directly counting the number of peaks present in the PPG. Further improvement on the algorithm was proposed in [20] which is being used by some of the applications.

B. Non-contact Method

This process works by placing the subject's face in front of the smartphone camera in a predefined way as shown in Figure 2. The subject has to hold still for a few seconds to get the measurements. The underlying principle for calculating heart rate is similar to contact method. Heartbeat causes micro color changes on the subject's face. The software uses camera to detect these micro changes, with beat-to-beat accuracy. The algorithm is built based on reliable non-contact photolethysmography concept [11] [22] which is validated by Kwon et. al. [23] later on.

IV. METHODOLOGY

In this section we describe the experimental set up used for data collection.

A. Subjects

A convenience sample of 15 adults, aged 18-55, volunteered and participated in this study. The diverse sample of participants consisted of 6 females and 9 males. The subjects' weight and height were measured before the study. Descriptive characteristics of each subject are presented in TABLE I.

B. Devices and Applications Used

Three different smart-phones were used to measure the heart rate of the subjects. The devices are *Samsung Galaxy S II* (8 MP primary camera), *Walton Primo D2* (2 MP primary camera) and *iPhone 4S* (8 MP primary camera). The former two use Android Operating System and the later one uses iOS. All of these devices are equipped with flash and front camera.

Smartphone applications can be found at App Store [24] and Google play [25] for the iOS and the Android platform respectively. For this study five applications were selected for the Android platform based on their rating, number of rating and number of installs. Four of the applications use the contact method and the remaining one uses the non-contact method. Description of the applications are presented in TABLE II according to the information of Google Play. Out of the five applications, four have the iOS version which were used to conduct study on iOS platform.

These applications were installed in each of the above mentioned smart-phones. However, it was observed that for the same application the collected data does not vary much with the model of the smartphone being used. For the same application, mean of the readings was noted down which will be discussed in the later sections.

C. Procedure

As shown in TABLE II *Instant Heart Rate, Runtastic Heart Rate, Heart Beat Rate* and *Heart Rate Monitor* use the contact method. For these applications, both the camera and flash of the smartphone were covered with a finger of the subject as shown in Figure 1. It is worth mentioning that positioning the finger inappropriately may produce incorrect result. For each subject, two different sets of heart rate measurements were taken. One set was taken just after the subject woke up in the morning and another set was taken at another time during the day while resting.

Again referring to TABLE II the application named *What's My Heart Rate* uses non-contact method. Well-lit environment is a very important requirement for this application. The subject was asked to sit in a bright place and the heart rate was measured using the front camera as shown in Figure 2.

For both the methods the actual heart rate was measured manually (from wrist) for benchmark purpose immediately after measuring with the applications. To authenticate the working procedure, the applications were run on some invalid inputs other than human organs to see whether the applications provide any *false negative* in the results. A white piece of

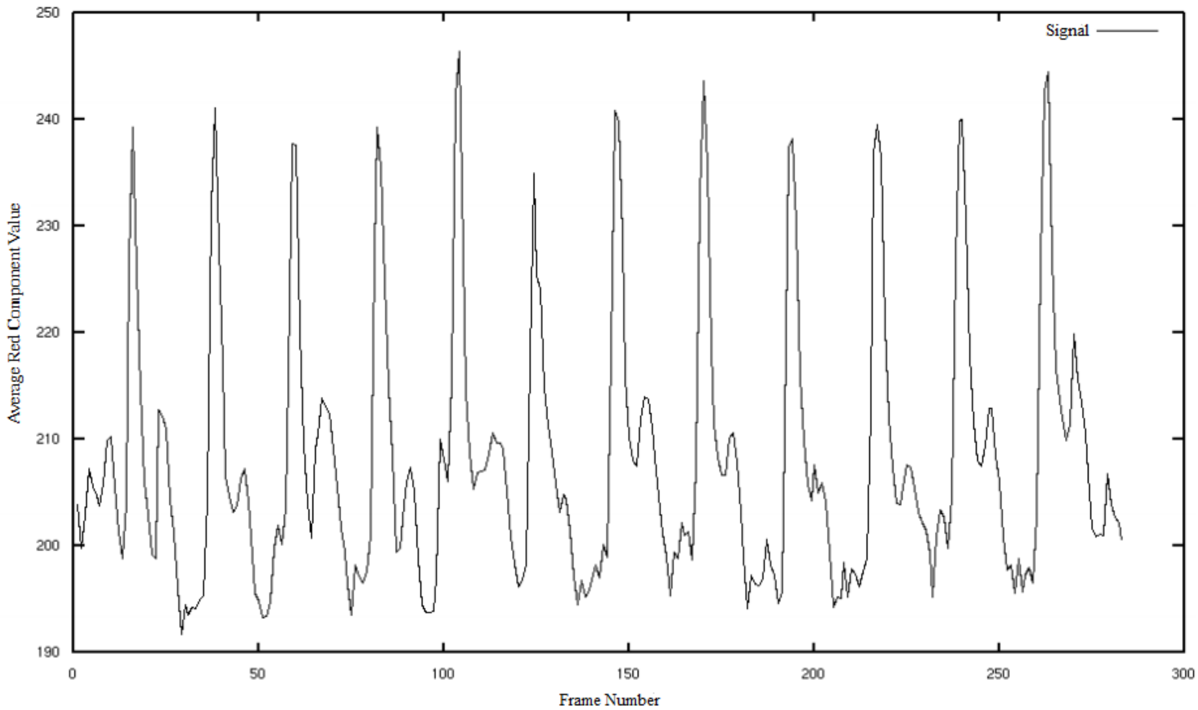

Fig. 3. Time series of average red component values of the frames

TABLE II
APPLICATIONS USED

Name	Method	Developer	No of Rating	User Rating	No of Installs	iOS version
Instant Heart Rate[26]	Contact	Azumio Inc.	174969	4.3	10,000,000 - 50,000,000	Yes
Runtastic Heart Rate[27]	Contact	Runtastic	97536	4.4	1,000,000 - 5,000,000	Yes
Heart Beat Rate[28]	Contact	Bio2Imaging	10801	4.2	100,000 - 500,000	Yes
Heart Rate Monitor[29]	Contact	Mobile Essentials	7744	3.5	500,000 - 1,000,000	No
What's My Heart Rate[30]	Non-Contact	ViTrox Technologies	1404	4.0	100,000 - 500,000	Yes

paper, a black piece of paper, laptop monitor, a blinking LED and a printed image of a human were used as these invalid inputs. This study was taken to ensure whether the applications were able to detect human body or not.

V. Experimental Results

In this section we present experimental results showing the accuracy comparison of various smartphone applications using contact and non-contact method.

For each application, the two sets of collected data were tabulated along with the manually measured heart rate for comparison. The following five graphs (Figure 4 - 8) represent the collation between heart rate measured with a particular application and the corresponding standard value measured manually.

The mean square error (MSE) of each application is presented in TABLE IV.

Response of the applications when non-living objects were used as subject is illustrated in TABLE III.

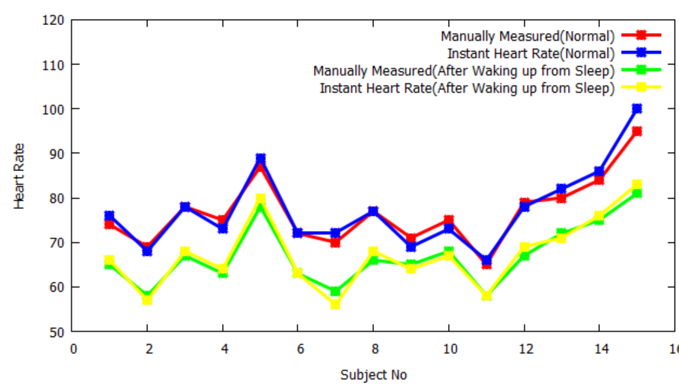

Fig. 4. Analysis of Heart Rate Using *Instant Heart Rate*

VI. Discussion

Referring to TABLE IV, it can be noticed that the MSE value of the applications using contact method vary from

TABLE III
RESULTS FOR INVALID OBJECTS AS INPUT

Application Name	Black Paper	White Paper	Laptop Monitor	Blinking LED	Image of Human Face
Instant Heart Rate	67	96	95	78	NA
Runtastic Heart Rate	No Reading	No Reading	No Reading	No Reading	NA
Heart Beat Rate	No Reading	No Reading	No Reading	No Reading	NA
Heart Rate Monitor	78	91	75	95	NA
What's My Heart Rate	No Reading	No Reading	No Reading	No Reading	56

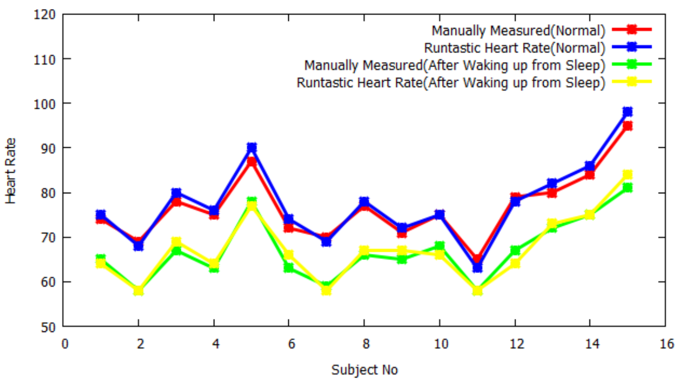

Fig. 5. Analysis of Heart Rate Using *Runtastic Heart Rate*

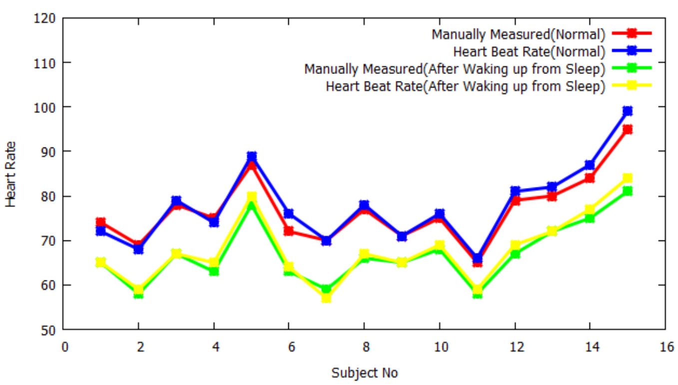

Fig. 6. Analysis of Heart Rate Using *Heart Beat Rate*

Fig. 7. Analysis of Heart Rate Using *Heart Rate Monitor*

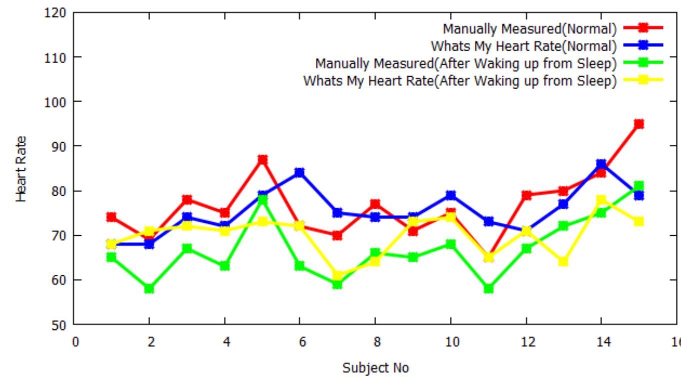

Fig. 8. Analysis of Heart Rate Using *What's My Heart Rate*

TABLE IV
MEAN SQUARE ERROR(MSE) OF THE APPLICATIONS

Application Name	MSE (Normal)	MSE(After waking up from sleep)
Instant Heart Rate	3.4	2.2
Runtastic Heart Rate	3	3
Heart Beat Rate	4.2	2.267
Heart Rate Monitor	135.7	422.7
What's My Heart Rate	48.4	45.53

as small as 2 to a quite large value 422.7. The first three applications *Instant Heart Rate, Runtastic Heart Rate* and *Heart Beat Rate* using contact method seem to produce results in a quite acceptable range. On the contrary, readings by *Heart Rate Monitor* fluctuated irregularly which is the reason for its large MSE value. By careful observation an interesting trend can be noticed from the graphs (Figure 4 - 8) and MSE values (TABLE IV). For each of the applications, deviations tend to be higher for the higher values of heart rates. On the other hand, lower values of heart rates have comparatively lower deviations. This phenomenon can be assumed to be caused by the scaling factor of the time interval used for each application for collecting data. Since the applications take sample for a shorter time period and then convert it into beats per minute, this factor may also be responsible for some of the errors introduced. Fake peaks in PPG signal is another reason for the errors.

Another interesting factor to follow is, *Instant Heart Rate* and *Heart Rate Monitor* responded to an attempt to measure heart rate of non-living objects despite *Instant Heart Rate* provided results very close to accurate value while using fingertip. On the contrary, *Runtastic Heart Rate* and *Heart Beat Rate* did not produce any reading until a valid human body part was detected.

Although the application named *What's My Heart Rate* using the non-contact method provides extra flexibility in measuring heart rate, the performance of the application is not consistent. The effect of ambient light is mainly responsible for this erroneous result. Position and movement of the face and the smartphone may be another cause for this irregular result.

VII. Conclusions and Future Work

In this paper we have investigated state-of-the-art smartphone applications available for measuring heart rates using on-board cameras. The applications used for experiments were selected based on their user ratings and download counts. All applications were broadly categorized into contact and non-contact method. We have presented working principle of each methods. Our experimental results show that contact methods provide more accurate results w.r.t. non-contact method. Some contact method based applications provide very promising results with noticeable accuracy level. Also, the application's accuracy is platform-independent.

As a future work, we plan to survey other mobile applications capturing some other vital signs and comment on their accuracy level and compare their measurement values. Also surveying other mobile applications using external sensing devices to detect heart rate is another immediate possibility.

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