OPTIMIZING POWER CONSUMPTION FOR HEART RATE MONITOR APPLICATION ON ANDROID PLATFORM

by

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With the increased variety of Android mobile applications, reducing power consumption for smartphones on Android platform is a major challenge. Recently, technological advances have illustrated a novelty Android application: Heart Rate Monitor (HRM). HRM is applied for detecting heart rate in people's daily life, utilizing the PPG algorithm to detect heart rate in real time through monitoring changes in transparency of fingers via the built-in flashlight and camera of a mobile device. However, HRM applications often consume high power and even result in overheating of smartphone, which will damage the hardware especially the battery of smartphone. In this thesis, we explore power saving strategy based on PPG algorithm, which is used in original HRM applications. A start timepoint and a safe period are found to close hardware devices during monitoring process with ignorable accuracy loss. Monsoon power monitor is used in experiment to measure the power consumption of optimized heart rate model, and a variety of Android smartphones have been detected on Monsoon power machine to validate the practicability of optimization including Google Nexus 5, Huawei P9, and Samsung S5. We perform an evaluation on 21 subjects with optimized HRM applications and for each user make comparison of heart rate

between original power model and optimized power model. Through a comparative study, the start close point and safe close period are successfully found. After the optimized HRM model is built, the power consumption is reduced by 31% with unnoticeable influence on performance.

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PREFACE

The theme of thesis power consumption is based on Android platform. Since my strongly interested in Android smartphone, I decided to write a thesis with the fundamental of Android knowledge. The relative knowledge I have acquired and the experiments I have finished equipping me with what I will need in the coming days. To achieve the aspiration of my thesis, exclude putting significant efforts in the courses study, I spent much time on Android applications research and thesis. I appreciate to my mentors and classmates in my master thesis creature period. Firstly, I want to thank Dr. Zhi-Hong Mao. He is the mentor of my thesis research and give me countless help in my research process. And I would like to express my appreciate to Dr. Murat Akcakaya and Dr. Ervin Sejdic for their participation and patient guidance for my defense. Then, I want to thank Dr. Yiran Chen for provider of equipment so that I can continue my research, and Dr. Jingtao Wang for his provider of application. I also want to thank Kent Nixon and Hsinpai Cheng for them dedicate help and advice. Finally, thanks all my mentors and classmates, without their generous help I cannot finish my master thesis smoothly.

1.0 INTRODUCTION

The popularity of smartphones and applications are increased with the development of communications. A growing number of mobile applications and services are at the same time be motivated in turn, which are having a significant influence on people's daily life. However, reducing the power consumption utilized by smartphones applications is always a major challenge for hardware production on smartphones [16]. Recent technological advances have illustrated a novelty application: heartrate monitor (HRM) application to predict the pulses rate of heart [1]. The distinctive algorithm is used to monitor users' heart rates through detecting changes of transparency of fingers using the built-in flashlight and camera [6]. However, such applications usage during heart rate detection is often power consumption even result in smartphones overheated. Thus, it should receive more attention in reducing power consumption. This observation motives us to study power saving for HRM on Android platform.

In general, the power consumption on Android platform is larger than other mainstream mobile operation systems, the reasons should be traced back to internal system and characteristics of operation system on Android [9]. The characteristic of open system management for Android is the reason Android enjoy a high popularity, while this management approach also result in Android system's particularly vulnerable to malicious programs. The Android application file, called the Android application package, is commonly referred to APK, encapsulates many different small modules in an APK file, including advertisement modules [17]. As Android, free games App for example, in addition to including game programs itself, an advertising module is contained within APK file as well. So many advertising modules contain a similar virus behavior and unrelated programmers intentionally or unintentionally [8]. However, promoting advertisements with sound and vibration function have a significant impact on power consumption. For Android phones, there are two forms of advertising: in-line push advertisement, and full-screen push advertisement. While for iOS operation system, in-line push advertisement is the only form of advertising. What’s more, although the iPhone promotes messages for advertisement, the function only includes send text which has restrictions for time and the numbers, this not cause overuse to mobile phone power [7]. As a comparison, Android phone’s specific full-screen push advertisement in accordance with the designer's idea, can be displayed at different times. Some games even be inserted into full-screen ads when they are turned on, or be inserted while waiting for the game to load. Some full-screen advertisings may make frequent detection of the user's location or download text content, resulting in power consumption exaggerated than the game itself [8]. Therefore, compared to IOS, Android OS itself is more power consumption.

The reason we decided to explore the power saving based on HRM model is that heart rate is one important sign for our physical body. For general people, physical training, and competitive sports use heart rate to track their exercise every day. People’s physical state could also be predicted from continual monitoring of heart rates, including physical and the health of mental situation. Thus, for the health of physical body, mental stress and activities, a precisely detection of heart rate can be of great significance. With the development of applications on Android platform, it is possible to monitor heart rate (HR) frequently and comfortably at home. Moreover, measurements can be made anywhere and at any time, sending real time heart rate date to users or to wearable devices.

Unfortunately, traditional heart rate measurement methods are not convenience and that not cheap such as Electrocardiography (ECG) [9]. For example, periodical heart beating pulse obtained from fingers may be time consuming and is also not accuracy [18]. These heart rate monitoring devices have at least three shortcomings: the high costs of ECG restrict the number of people who can use these devices, not wearable of device, result in inconvenient to apply the devices in anywhere and in anytime.

The exist HRM is an application based on Android platform which could overcome shortcomings of traditional heart detect methods. The HRM is based on PPG algorithm, the build-in flashlight is used for light source supplement and camera is continuously capturing the picture with framerate, then discompose every pixel into RGB bands, through crest detection of green band's light intensity, the heart pulse rate could be detected [9]. The Photoplethysmogram (PPG) signals can be choose to obtain by reflecting light through the user's fingertips. At each heart beating cycle, heart pumps the blood through the body, a pulse peak appears in PPG signal, this being possible to calculate the heart rate [18]. Android smartphones, equipped with high configuration hardware especially a high-resolution camera and enough processing power, can be used to obtain PPG signal [15]. Such convenient application will play a significant role for people's daily life.

While, the shortcoming of HRM cannot be ignorable: build-in hardware of smartphone need to be open in whole detection process, which may cause overheating to smartphones. Since the high hardware configuration prerequisite for HRM, the popularity of HRM may also be shirked.

To overcome the drawbacks of original HRM application techniques, we have construct an optimization method in fundamental of PPG algorithm to achieve power saving goal. The kernel of optimization is to find a safe period to make hardware equipment to cyclical closure, with the build-in hardware be closed cyclical, HRM applications can achieve a significant reduction in electricity consumption [7]. The implementation for optimized HRM model is applied based on PPG algorithm. Original PPG algorithm is optimized in power consumption part by applying start timepoint and safe close period to control status changes in smartphone hardware, analysis of reflective green light intensity is required in optimization. The reason to use green band for analyzing heart rate is the low signal to noise ratio characteristic of green light [10]. The contributions of optimizing power consumption for HRM are listed as follow. First, we optimized the power consumption in PPG algorithm working process by applying timepoint (start time to close build-in hardware) according reflective green light intensity, and set safe closure time to close application periodically [19]. This part involves the measurement of hardware adjustment time on several smartphones. Second, we measure the power saving after implementing the new HRM model. Third, we discuss proposed method implementation problem that arise from including the optimized HRM for same users. The result validates the practicability of new HRM model, which means after implementing the optimization method and monitoring power consumption, the goal of power saving is successfully achieved. Finally, as for accuracy consideration, we conducted a series of experiments and calculated the accuracy loss compared with original HRM. The experimental results provided further insights into power saving for HRM applications on Android platform.

2.0 BACKGROUND

Mobile devices heart rate monitor has been a topic of research from 2014. Many researchers presenting distinctive results calculating the heart rate using built-in flashlight and camera hardware. In Chapter 2, background and related works are introduced, we also provide related background knowledge that is relative to understanding the concepts discussed in later chapters with the motivation behind the research of thesis. Traditional electrocardiography (ECG) is the most widely used traditional method for heart rate monitor. The devices of ECG detecting heart rate of people by connecting equipment and fingertips. Unfortunately, most heart rate measurement methods are either time consuming, or require special measurement equipment that may not be easy to use anywhere like Electrocardiography (ECG) [6]. These traditional heart rate monitoring devices have more than three disadvantages. First, the costs of these devices are expensive, it will restrict the popularity for most people. Second, the devices are not easy to be applied anywhere, it is inconvenient to carry and use the devices in any environment. Last but not the least, traditional methods don't support enough motivation for people to monitor heart rate.

From 2014, several wearable devices are released recently such as Android Gear Fit 2 and Apple Watch provide a more convenient method, the cost of products is drop down for such devices, they are still not available for most users.

Recently, with the development of technology improvement, a heart rate monitor application is released to detect people's heart rate in real time, it seems that all shortcomings of traditional detect method have been solved. However, the disadvantage of such kind HRM is apparently: the build-in flashlight and camera need to be kept opening all the time through detect process, which cause amount of power consumption. Furthermore, keeping build-in flashlight to open status around several minutes is not sustainable to typical Android smartphones even may result in hardware damage on smartphones. Since the high hardware configuration prerequisite for HRM, the popularity of HRM has been restricted. To overcome the limitation of exist HRM application, we demonstrate a power optimization method in fundamental of PPG algorithm to achieve power saving goal.

The preliminary of HRM is rely on build-in flashlight and camera to detect heart rates, this technique is essentially based on the fundamental of Photoplethysmography (PPG) algorithm. The PPG extracted signal can be divided into two categories, transmitted signal, and reflective signal, which are separated by the comparative location of light source and sensor. Light source and sensor are in the same side is called reflective PPG, whereas on different sides is named as transmitted PPG [11]. The most common heart rate monitor used in hospital is ECG, which utilized the transmitted PPG signal. The PPG signal captured by HRM is the reflective one, which means the light source (build-in flashlight) and the sensor (camera) are on the same side.

The underlining principle of PPG is that in every heart beating circle, the heart beat blood to the capillary vessels of a extremity, including fingertips [7]. For each heart beating circle, the heart pulse of heart can be divided into five parts (Figure1). Since the amount of blood is increased and changes the transparency of fingers, and since the transparency of fingertips is correlate directly with heart rates, and camera can detect the changes by capturing image when people covers the camera with his fingertips. However, this original HRM required that smartphone should have enough CPU power during monitor process and provide enough power supply to built-in flashlight and camera to run mobile device. What's more, the temperature increasing will be caused by HRM model when applied on Samsung, Google Nexus and Huawei. And it may be overheating of build-in flashlight and camera is another hazard when applying HRM applications [12].

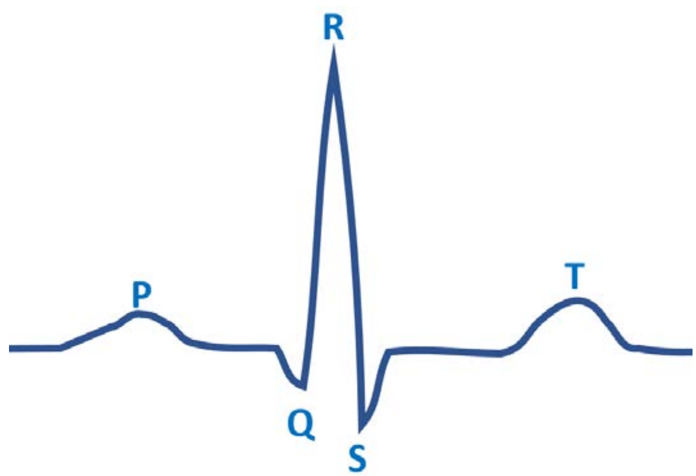


Figure 1. The pulsation image.

The kernel of HRM is PPG algorithm. In HRM detection process, the camera is keeping open mode, capturing color images at a rate of 24 - 30 frames per second. The automatic focus function and the automatic white balance function are disabled in terms of avoiding influence of these functions [14]. When a finger covered, heart rate is detected, the PPG algorithm extracts heart rates [13]. Based on PPG algorithm, a typical heart rate cycle includes several different stages (Figure 2): (1) rapid increase; (2) rapid decrease, (3) small pulse; and (4) rapid drop down [1].

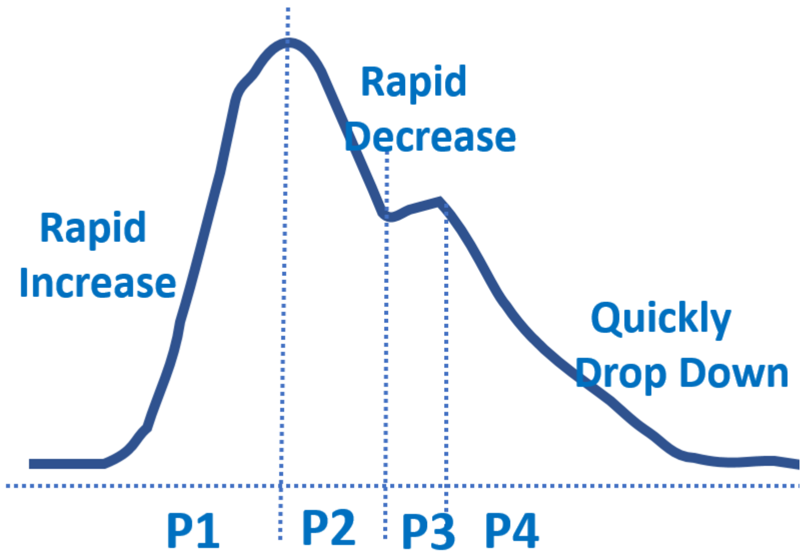


Figure 2. One-cycle waveform.

The most significant step is to extract PPG signal. After the built-in camera captured pictures, CPU will responsible for image process section. To acquire a PPG signal from the smartphone some functions have been proposed, most of them have the same principle: each pixel captured with the camera is decomposed in its three colors components (red, green, and blue), PPG value is extracted from those bands. In the HRM prototype, PPG is compute by measuring color distribution in green band [10]. Whenever a finger is placed into the camera, the greyscale value components of the captured images are shirked to a small set of its color range – from 0 to 255(Figure 7). It becomes possible to predict heart rate when the user's finger position is in place (Figure 3). The method used is based on the value of the average of the green band is verified.

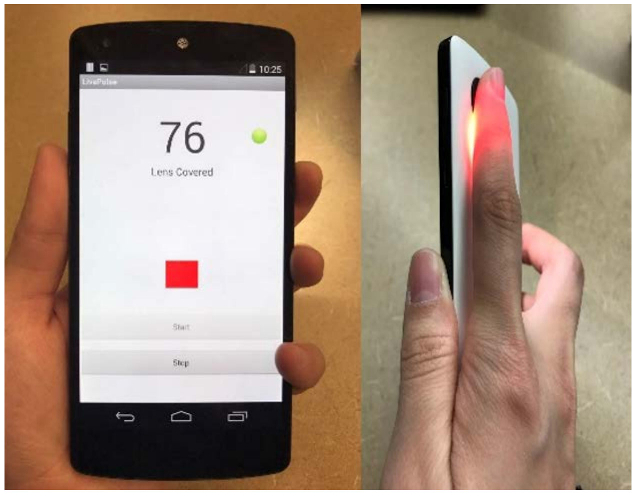


Figure 3. Application screenshot, along with correct finger placement.

The significant reason for choosing green light is based on signal-to-noise ratio considerations. Assume that the PPG signal:

$$y = a + b \cdot \sin(x) + c. \tag{1}$$

The PPG signal is composed of a mean and a fluctuating amount [6]. Variable b is the beat, a is the mean reflectance, c is the noise. The mean reflectance is corresponding to a, reflectance pulsation corresponds to *b/a*, and the approximate noise level corresponds to *c/a*. The result shows that that the *b/a* is greater and more than *c/a* near the wavelength of green light [8]. The pulsation is more noticeable than the noise, and the pulsating signal are interested in is more likely to be observed. The power consumed by HRM is dominated by the built-in flashlight and camera capturing pictures. It can be assumed that the power consumption is linearly proportional to the HRM monitor time [15]. In the whole monitor process, flashlight is always open, camera is capturing pictures with specified framerate, and stay in idle excluded capturing time. For mathematic representation of original power consumption model, for example, power consumption of LED on variable *l*, power consumption of camera total consumption *d*, power consumption of camera capturing *a*, power consumption of camera idle *b*, power consumption of CPU capturing *c*, framerate variable *f* and total time *t*, the output of the average power consumption *p* can be calculated by:

$$p = (l + d + c) \cdot \frac{t}{t} = l + d + c \tag{2a}$$

$$a = t \cdot f \cdot d \tag{2b}$$

$$b = (1 - f) \cdot t \cdot d. \tag{2c}$$

The power depletion of flashlight is keeping open, the power consumption of camera is consisting of two part: camera capturing part and camera idle part. Camera capturing part also includes the image processing part done by CPU. Although cyclical closure of hardware can save power, it could affect the accuracy if close period is not appropriate. Exploring start close time and suitable close period is called an assignment. An assignment is feasible if two conditions are satisfied: (1) Determining the appropriate slope for green band intensify to close hardware. (2) Calculate the hardware adjustment time to find the safe close period.

3.0 PROPOSED METHOD

3.1 ALGORITHM

As previous mentioned in Chapter 2, the build-in hardware is the major cause of power consumption loss on HRM. In other words, if we can find an appropriate period to close hardware cyclical, the power loss should be reduced accordingly. For achievement of power consumption target, the exploration of correct timepoint to close hardware and safe close period to keeping hardware close are two most essential chapters. The optimized code snippet is display as follow.

Table 1. Algorithm Design.

Algorithm: Optimized PPG algorithm

Input: slope variable S, camera trigger time $Camera_{trigger}$, camera deactivate time $Camera_{deact}$, flashlight trigger time $LED_{trigger}$, LED deactivate time LED_{deact}.

When S >= 0 get previous pulse time;

if (previous pulse time > ($Camera_{trigger}$ + $Camera_{deact}$)) deactivate camera;

if (previous pulse time > ($LED_{trigger}$ + LED_{deact})) deactivate flashlight;

To had better understand the power saving, the most appropriate timepoint to close hardware necessarily to be found. The grayscale value for green band reflects the light absorption amount of green light by blood (Figure 4). The dotted line signifies the heart pulse variety with the increase of time, solid line shows the intensity of reflective green light.

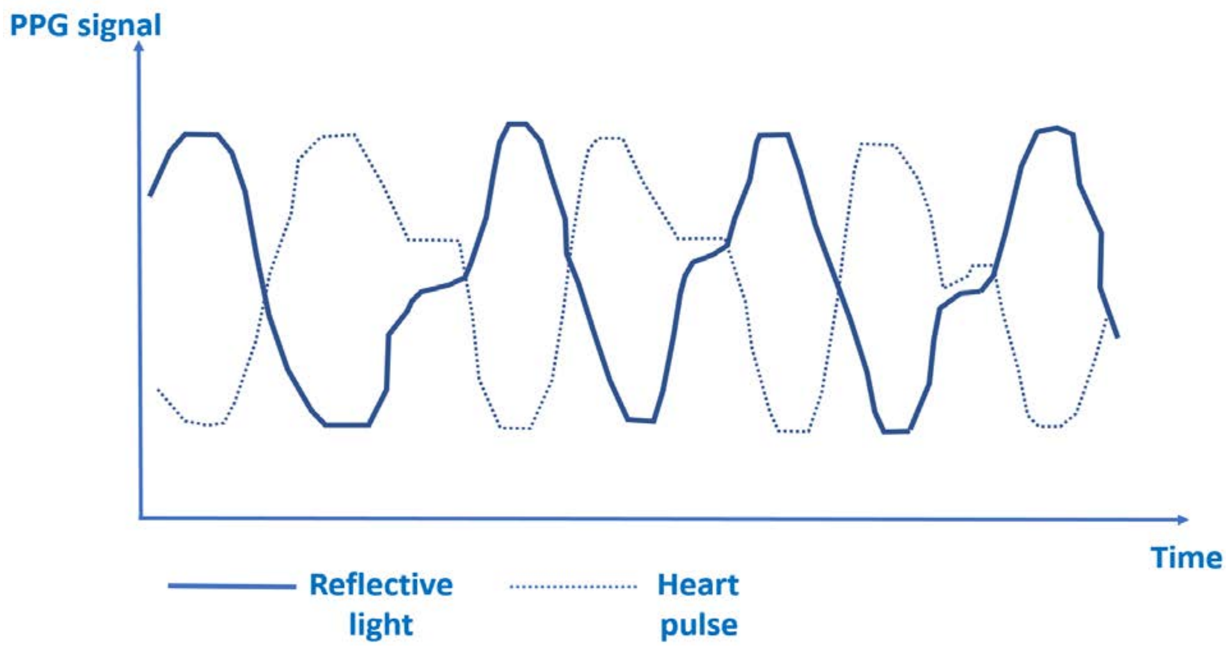


Figure 4. The relationship between pulse and reflective light.

The reflection light intensity is inversely proportional to blood vessel volume in blood vessels, the blood amount is proportional to heart pulse rate (Figure 4). The gray value in green channel figure can be drawn based on PPG signal. Before the exploration of safe close period and start close timepoint, the auto focus and white balance on camera need to be disabled, this can shorten the hardware adjustment time and made exploration process been curtailed. The close of hardware is started when the gray value of green band is reach maximum, the slope at maximum gray value will begin to decrease from positive to negative, therefore, the best timepoint to close flashlight and camera is at the time when slope is equal or smaller than 0. Through applying start close timepoint at the time when slope is equal or smaller than 0, the experiment result shows that the start point setting method as above can achieves a good accuracy.

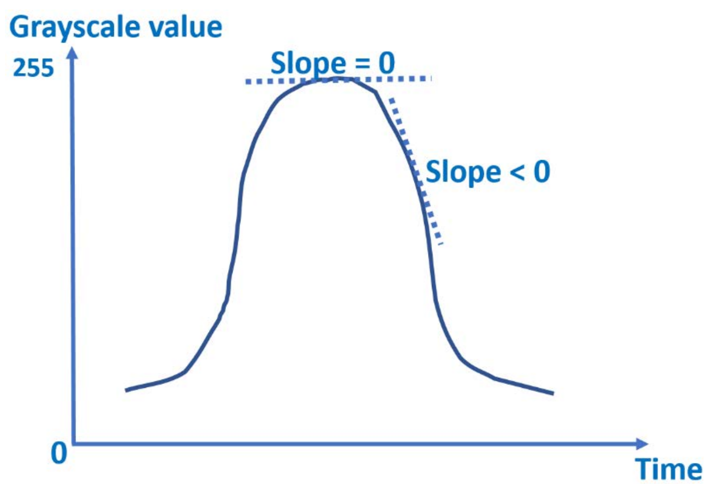


Figure 5. Grayscale value for green band.

After the exploration of hardware close timepoint, the safe time to close hardware need to be found. The safe period should be close two crest on PPG signals, while for more precisely computing, the hardware trigger and close time need to be calculated firstly. The relationship within three continuous gray value change correspond to heart pulse activity can be used to explore the safe close time calculation (Figure 5).

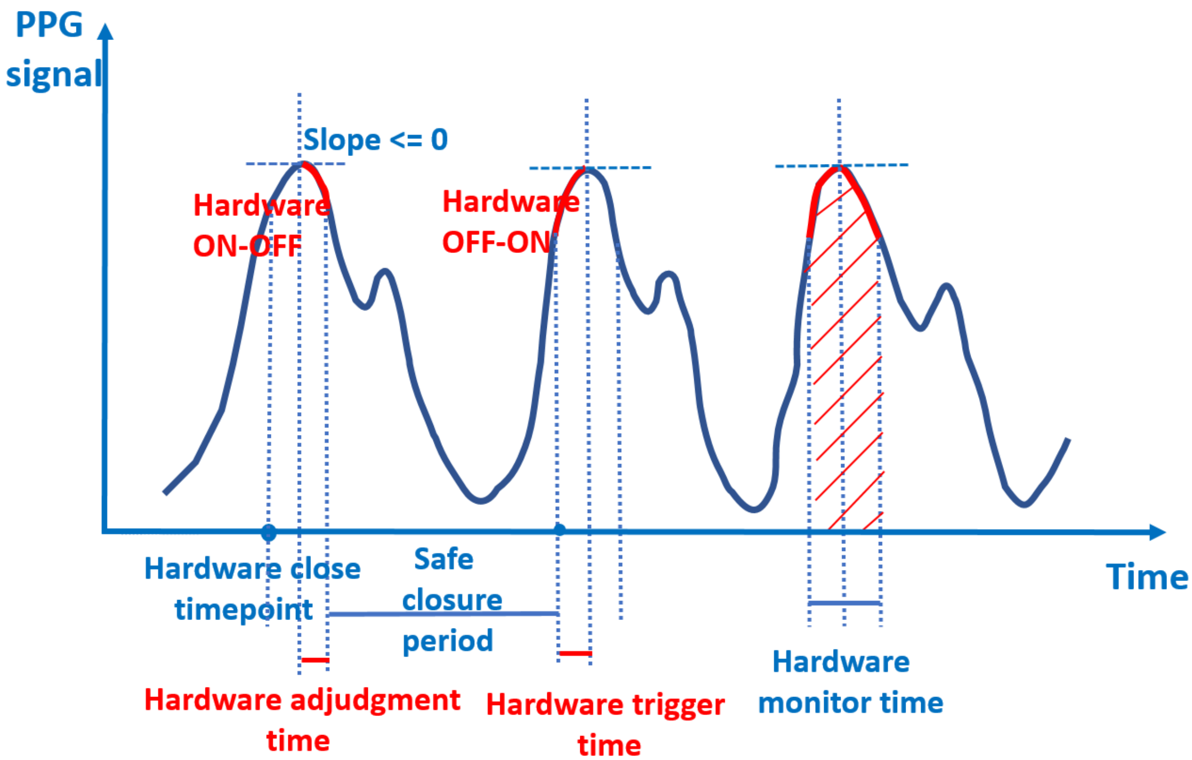


Figure 6. HRM model optimization.

After the slope of gray value curve is equal of smaller than 0, we begin to close the build-in LED and camera. The red region on curve is the hardware adjudgment time which status of hardware changing from on-off. After the safe closure time, the flashlight and camera will be triggered for next monitor cycle, the red region on second pulse is hardware's trigger time for status off-on. Therefore, the safe period to close hardware is begin at hardware status on-off adjusted to begin trigger the hardware as the blue curve shows between first and second pulse (Figure 6).

The above analysis inspires the thinking that if we can intentionally close hardware at specified timepoint last explored close time, we shall be able to reduce the accumulated power consumption in whole heart rate detect process as well as the average power consumption per second. Based on these two applications, the Monsoon power monitor is applied to monitored the power consumption of status change and time used in status changing between activate and deactivate was also be detected. From collecting statuses change time on Android Studio software, the time latency for transferring status of flashlight and camera be obtained.

The above figure demonstrates that for build-in flashlight, status changing from on to off is around 0.4s, status changing from off to on is around 0.1s. As to camera, the closure time is 0.14s, camera trigger time is 0.04s. The time delay of build-in flashlight is around three times larger than camera. As for the large time delay compared with total power consumption in HRM detective cycle, the goal to achieve power saving through cyclical close hardware is practicable.

The start close point and safe close period can build the power consumption (Equation 3), For mathematic representation of optimized power consumption model, power consumption of LED on vector l, power consumption of LED duty cycle g, power consumption for camera capturing a, power consumption of camera duty cycle b, activate time for LED t_1, deactivate time for LED t_2, activate time for camera t_3, deactivate time for camera t_4, open time for camera t_5 and the output of the average power consumption p can be calculated by:

$$p = (l + g + a \cdot b) \tag{3a}$$

$$g = (t_1 + l + t_2)/t \tag{3b}$$

$$b = (t_3 + t_5 + t_4)/t. \quad (3c)$$

Several hardware power consumptions can calculate the average power consumption. The power usage by flashlight includes the trigger and illumination. The power consumed by camera is consists of camera capture consumption and camera idle consumption. Both two parts power consumption contributes to the total power consume. The algorithm 1 is based on the power consumption formula given in Equation (3).

3.2 POWER MONITORING

The power monitor is implemented by applying Monson power monitor on HRM applications. After connected the power monitor and smartphones, the power consumption can be obtained through Monsoon software on PC [20]. The average power consumption need to be detected for both original HRM and optimized HRM in terms of make comparison with the optimized one [20]. Before the power monitor process is begin, all unrelated software on smartphones need to be uninstalled.

Implementing the connection of Monsoon power monitor and Android smartphone, the power consumption can be detected in real-time. The expected figure is displayed as Figure 8, the average power depletion for original HRM is around a constant.

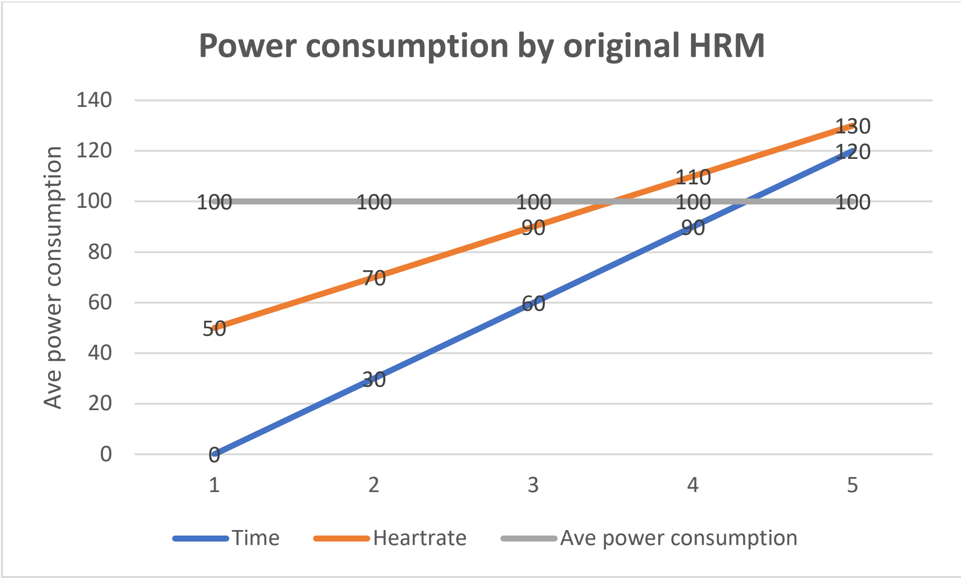


Figure 7. Power consumption by original HRM.

The power consumption will keep at a relatively stable value since the opening status for build-in flashlight and camera.

The power consumption of build-in flashlight and camera will also to be detected by Monsoon power monitor in term of inspecting the power consumption of two type of hardware we expected. Power depletion by hardware will be detected to compare with the difference of original and optimized HRM in terms of exclude the influence caused by other hardware I didn't take into consideration. Two separate applications are made to activate and deactivate the camera and flashlight (Figure 8).

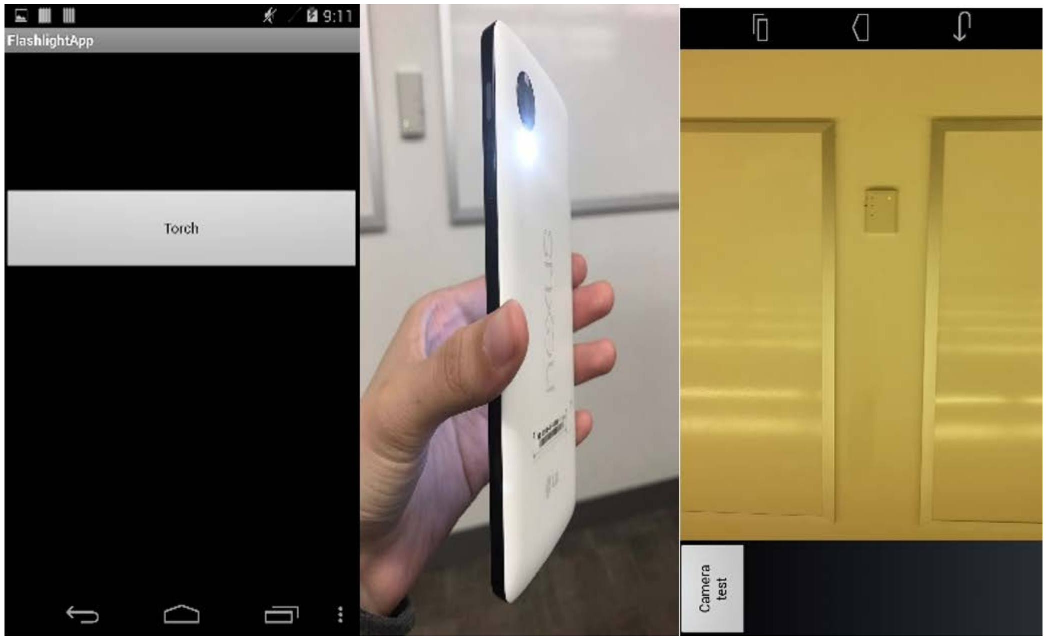


Figure 8. Auxiliary applications.

The auxiliary applications were built on Android Studio software, the function only includes trigger hardware and close hardware in terms of exclude unnecessary interference [19]. Through connecting the build-in flashlight and camera with Monsoon power monitor, the power depletion by hardware could be detected precisely.

The auxiliary applications are used for verifying the power consumption difference between original HRM and optimized HRM if the LED and camera are mainly additional power loss for whole process. After the invalid detection part been removed, the power consumption for whole HRM process will be detect through applying the start timepoint and safe close period to original PPG algorithm on Monsoon power monitor.

The expected comparison figure for average power consumption could be obtained. We carried out two kind of studies to evaluate the power consumption. In the several Android smartphones studies, we investigated the different of power used and made comparison in average power usage with different independence variable: time and heart rate. With the increase of heart rate, average power depletion by optimized HRM is increase as well keeping smaller than original HRM, in contrast, original HRM's power consumption is always a stable value (Figure 9).

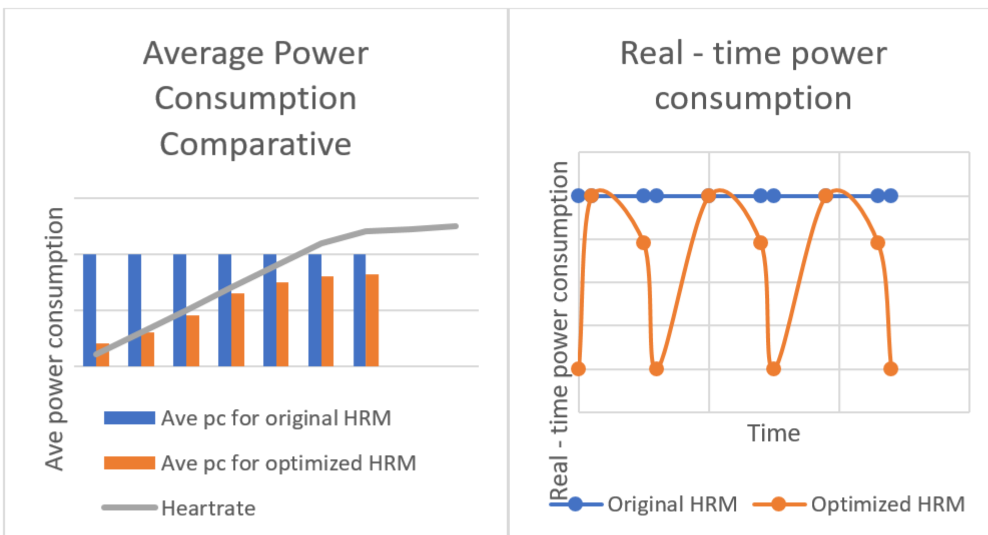


Figure 9. Power consumption comparison.

Through implementing the optimized code snippet, the hardware built in smartphone which were used for HRM applications will change status cyclical. According specified characteristic, flashlight and camera only keep open in crest detection period, the power consumption by optimized HRM should increase with the higher frequency of heart rate in terms of the more frequency for status change in hardware, power depletion by original HRM keep stable in terms of an uninterrupted power usage (Figure 9).

3.3 ACCURACY CONSIDERATION

The optimized code snippet may result in negative influence on HRM for an error close timepoint or unsuitable close period of hardware. Taking heartrate detect accuracy of optimized HRM model into consideration, we used 21 subjects to test two HRM model at the same time. According standard heart rate expectation, normal heartrate arranges for female between age 22 to 30 is around 60 to 90, for male the normal heart rate is around 55 to 85.

After recording the heart rate values in 60 seconds, the average heart rate has been calculated. After the standard deviation for two group heart rate records was computed, we deducted the error rate. The error rate is about 8.01%. With the ignorable error rate, the start close time and safe close period should be accurate to apply on original application model.

4.0 EXPERIMENTATION

4.1 EXPERIMENTAL SETUP

Aiming at thoroughly verify the power consumption of original HRM and optimized HRM applications, and gain insights into power saving for HRM applications, we evaluated the power consumption for hardware including build-in flashlight and camera.

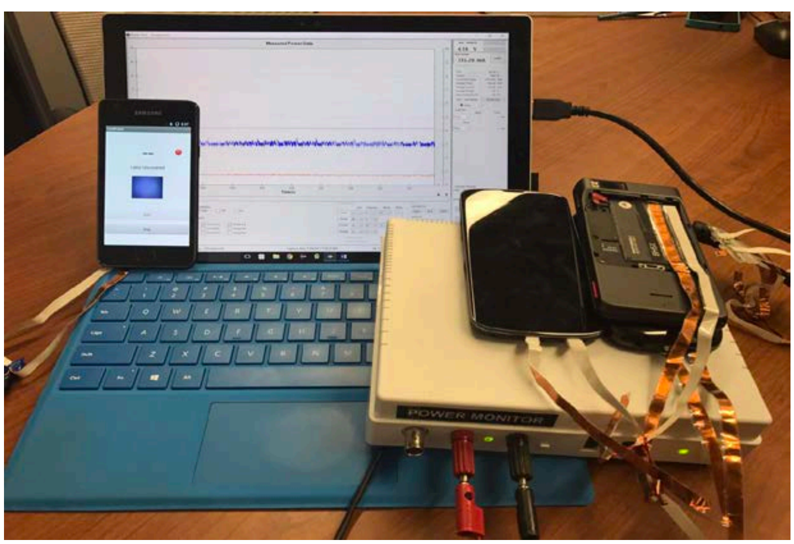


Figure 10. The experimental environment.

The hardware consumption part will verify the correctness of optimization. The performance of the two type of HRM model is also explored via several different Android smartphones including Google Nexus, Huawei, and Samsung. In the case studies, we adopted the same heart rate monitor applications. A comparison also be done to highlight the actual power consumption during whole HRM process.

The mobile application program was installed on Android smartphones, equipped with build-in flashlight and camera. The supplementary software of Monsoon power monitor was download from web to detect monitor and display power measure result on PC. Battery in smartphone need to be removed, the only power supply should be from Monsoon power monitor [19]. Two metal conductive strips are connecting with Monsoon power monitor and smartphones in terms of providing continuous power and detect power usage in application working period. Before trigger the power source of Monsoon, open supplementary software, set the voltage be 4.2v, electrical current be 8A, these voltage and electrical current will give stable power supply for smartphones [20].

For hardware consumption experiments, flashlight and camera trigger applications are installed on smartphones, after applying applications, the power consumption by hardware will display on the supplemental software interface.

For overall power consumption detection, we disable the automatic focus function and the automatic white balance function to avoid interference with our algorithm. After all equipment are ready to work, trigger the power source of Monsoon power monitor, implement original and optimized HRM application alternatively. The real-time power depletion curve will automatically display on software interface (Figure 10).

4.2 POWER EVALUATION

After applying the hardware trigger applications, the measured power data is displayed on the supplemental software interface. From figure, time begin at 2 second to 7.7 second is in statue LED on with a high-power consumption of 2.8w. Time from 8 second to 11 second is LED off with 0.8w power usage. The power consumption in LED close status is 0.8w/s, for LED open status the power consumption has reached 2.5 to 3.0w/s. The power saving from flashlight on to off could reach 1.9w/second in average (Figure 11).

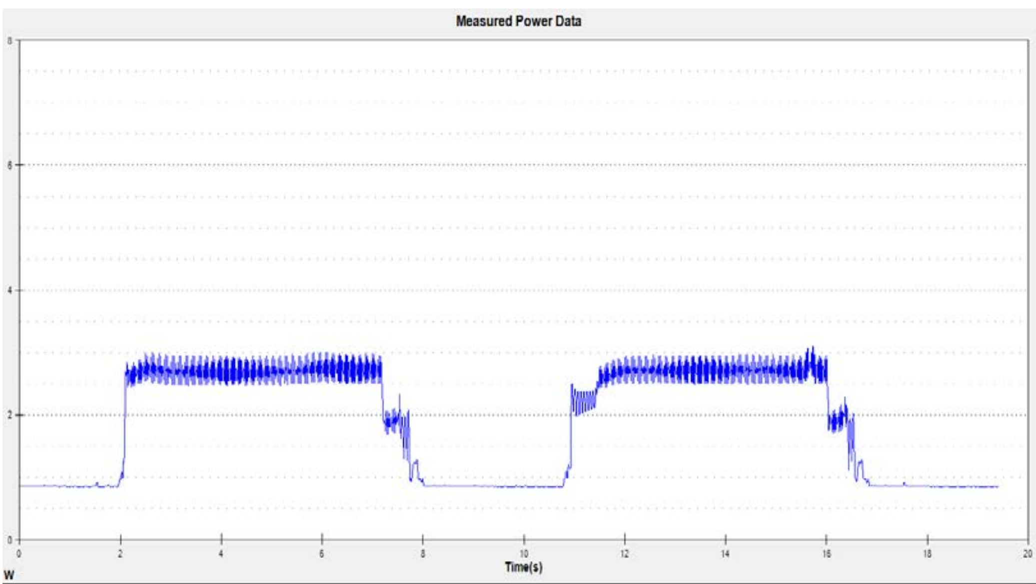


Figure 11. Power consumption by build-in flashlight.

With implementation of camera trigger applications, the power depletion for camera was demonstrated. From above figure, the camera is on from 41.7 to 45.8 seconds with average power usage of 0.75w. While from 45.8 to 47.9 seconds the camera is off with power usage of 0.35w. The power saving between power on and off is around 0.35w in average. Trigger action of camera every 7 seconds, each time after the trigger movement is finished, measured power data will have an extreme pulse. The status change time is shorter than LED. The power consumption in camera close status is 0.4w/s, for camera open status the power consumption has reached 0.8 – 1.2w/s. The power saving from camera on to off could reach 0.5w/second in average (Figure 12).

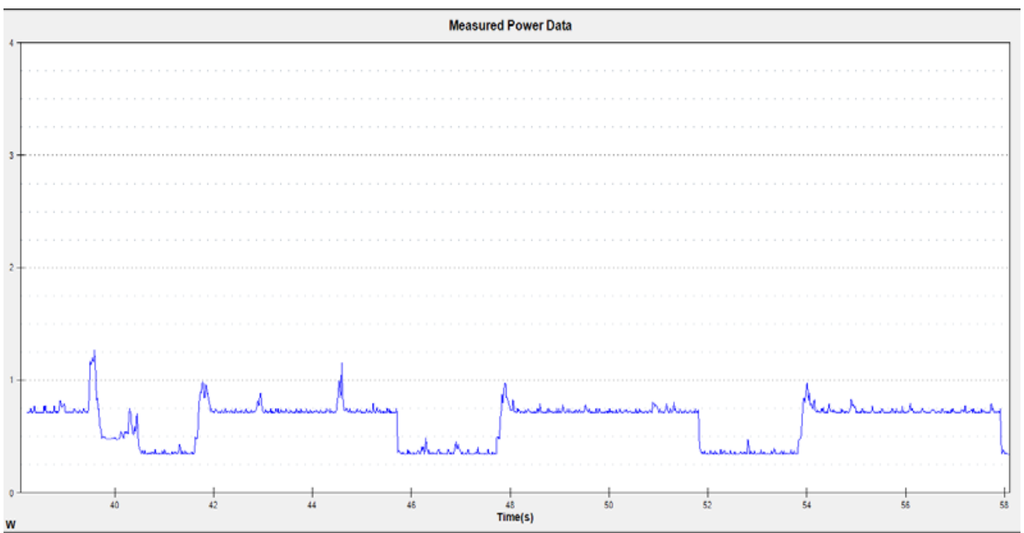


Figure 12. Power consumption by camera.

Through the hardware power consumption detection, the power consume difference between OFF status to ON status varies a lot. The goal of power saving is practical to reach by periodically close hardware after crest detection within every heart pulse.

According previous verify result, the ultimate power consumption results are detected by Monsoon power monitor to make comparison of power saving. As provided, the power consumption by original HRM applications is around a constant during the stable heart rate detection process (Figure 13).

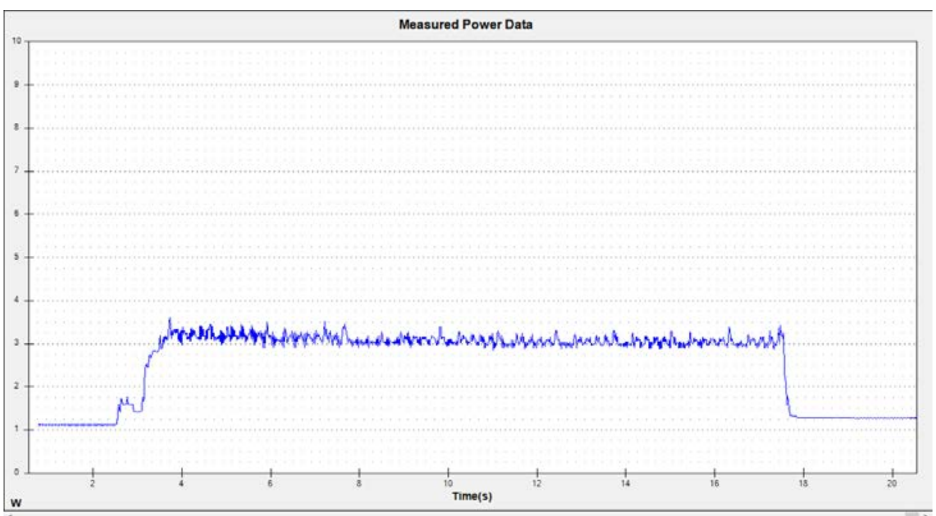


Figure 13. Original power consumption.

After the application are triggered to working, a small power pulse is appeared count for the power consumption of trigger movement. When the application gradually stabilized, the power changes become no longer obvious. In stable detection phase, the power consumption was almost straight in terms of no external factor involved. At 17.8 seconds, application is ready to shut down, and the power consumption quickly drops from the peak to the initial state. The whole power change process is the same as we predicted. In case of optimized HRM application, the power loss varies much and have a complex process to accomplish. As for the original power model power consumption is keeping in a stable value, while the power usage by optimized HRM mode is changing with the hardware activate and deactivate.

At first the power consumption is maintained at a fixed value. After triggering the application at 1.5 seconds, there was a small power pulse. The small power pulse is the power consumption for trigger movement.

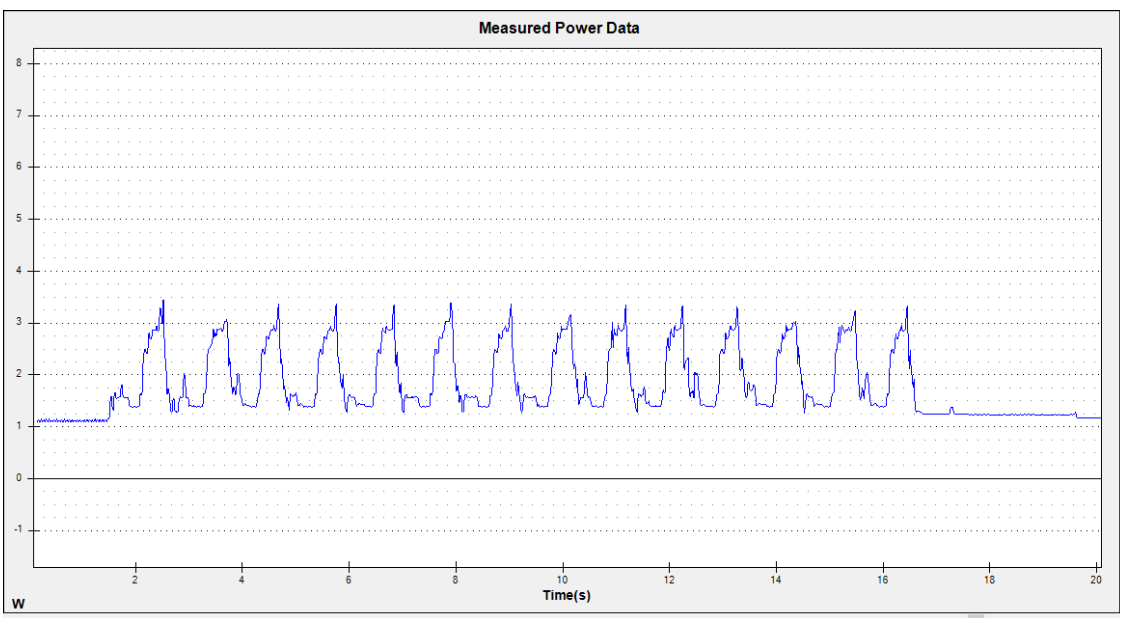


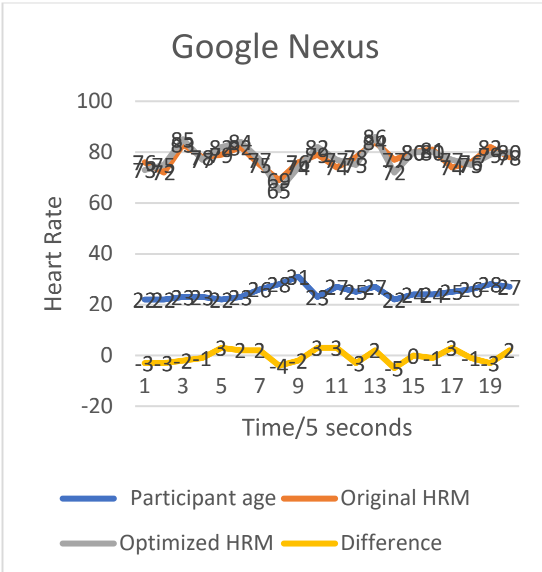
Figure 14. Optimized power consumption.

Following is a large power pulse, which means that the camera and LED are turned on and in capturing pictures status, PPG have started process the image with the crest detection. The final drop in power consumption is the optimize code snippet we have done in terms of saving power. The last small power pulse for stopping CPU from image processing. This is the optimized application overall the entire power change process (Figure 14).

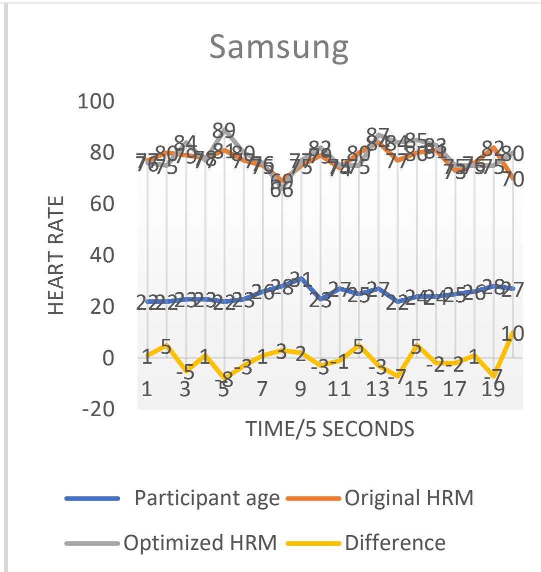
Through comparing above power graphs, the optimized application basically achieves the predetermined target, saving about 31 percent of the power as expectation. While the accuracy of the application is still a question we have doubts. Whether the algorithm can accurately measure the heart rate after applying new code snippet.

4.3 PREDICTION ACCURACY

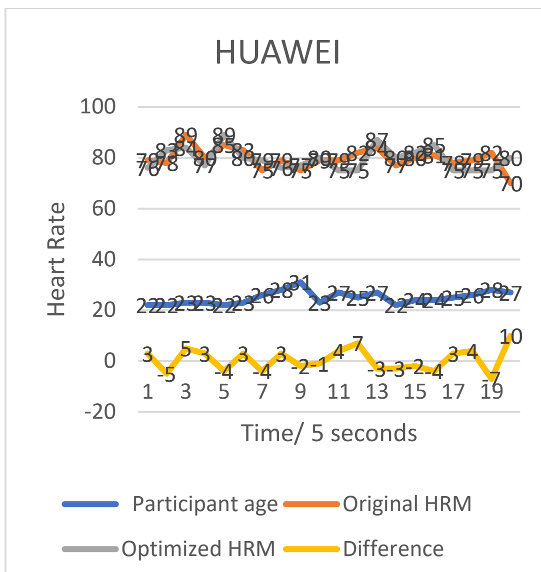
We have used 21 subjects in our study. The two HRM application were used on different smartphones separately for 1 minute detection at same environment. The Google Nexus, Samsung and Huawei smartphones are used running Android 5.1 in the experiment. During learning, we recorded the heart rate every 5 seconds and finally calculate the average heart rate. After collected heart rate data, the comparison table has been created to compute to accuracy of optimized power model (Figure 15).



(a) Google Nexus.



(b) Samsung.



(c) Huawei.

Figure 15. Accuracy comparison of (a) Google Nexus, (b) Samsung and (c) Huawei.

4.4 DISCUSSION

Through the real-time power consumption detection monitored by Monsoon power monitor on original and optimized HRM applications, the power saving in every pulse cycle is obviously (Figure 18). Thus, the provided optimization method is practicable to implement in power consumption for HRM applications.

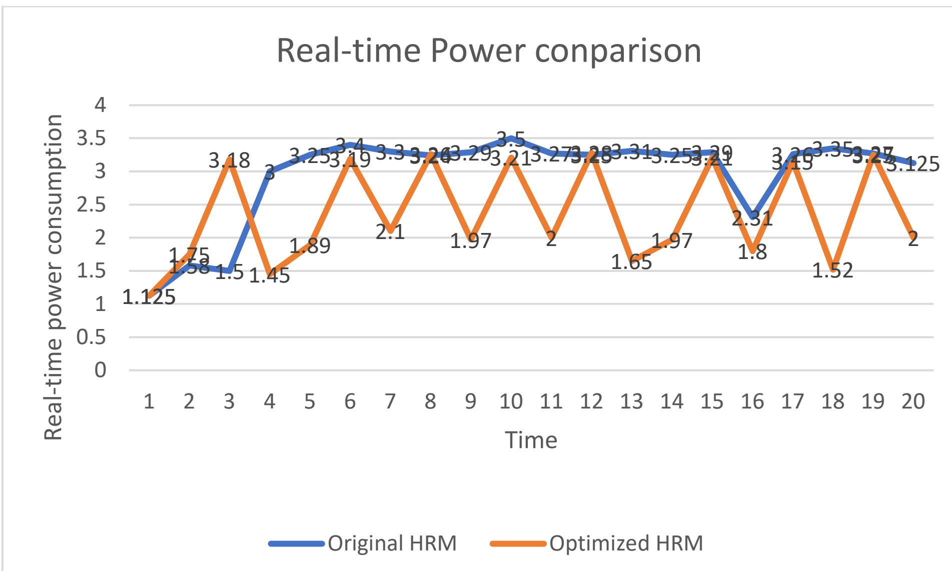


Figure 16. Real-time power comparison.

Optimized HRM model performed in most cases, returning a valid PPG signal to calculate the heart rate. Through comparing above power graphs, the optimized application basically achieves the predetermined target, saving about 31% of the power as expectation. While the accuracy of the applications is still a question we have doubts. Whether the algorithm can accurately measure the heart rate after applying new code snippet. Some pitfalls could also influence the accuracy estimation. For accuracy consideration, through the experiments on three different smartphone brands, the average error rate of optimized HRM application is obtained.

Table 2. Real-time power comparison.

Brand	Google Nexus	Samsung	Huawei	Average
Error Rate	5.29%	8.85%	9.89%	8.01%

The error rate on the Google Nexus is the smallest, round 5.29%. The error rate on the Samsung mobile phone is much higher than the Google Nexus, the error rate is 8.85%. The biggest error rate appeared on the Huawei mobile phone, reaching 9.89%. In summary, the average error rate for optimization HRM application is 8.01%.

5.0 CONCLUSION AND FUTURE WORK

This thesis proposes an approach that minimizes the power consumption incurred by the build-in flashlight and camera when users applying heart rate applications. To solve the problem, we propose insert start close time and safe close period in PPG algorithm, and prove that power savings can be achieved through auto control the status of hardware. To validate the practicability of the approach, based on the algorithm, we implemented the mobile application program and applied the monsoon power monitor on power models. With the application installed, the Nexus mobile phone achieved power savings of 31% on average. In addition to the above results, a series of accuracy testing experiments provided significant suggestions for optimized heart rate detect applications on Android smartphone.

Further samples must be retrieved. For the accuracy estimation, more precisely method should be applied and heart rate antithesis data can be provided by electrocardiography(ECG) for better antithesis.

For the power consumption, the start time to close the hardware may be estimated more accurate through analysis the secondary derivative on light intensity on green channel. Furthermore, turning on the LED Flash can improve the finger transparency readings in dark environments, but it is not required in indoor conditions with sufficient illumination. Therefore, the PPG algorithm could be optimized for obtaining PPG value more precisely without LED on.

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