Saint Petersburg Electrotechnical University (ETU)

**Field of study**

12.04.04 – Биотехнические системы и технологии (Biotechnical Systems and Technologies)

**Programme**

Биотехнические системы и технологии в протезировании и реабилитации (Biotechnical Systems and Technology for Prosthetics and Rehabilitation)

**Faculty**

Faculty of Information Measurement and Biotechnical Systems

**Department**

Department of Bioengineering Systems

**Admitted for defense**

Head of the department

Yuldashev Z.M.

---

**MASTER’S THESIS**

**Topic:** Бесконтактный мониторинг частоты сердечных сокращений, дыхания и эмоционального состояния пациентов посредством видеокамеры

(Non-contact monitoring of pulse rate, breathing and emotional state of patients using video camera)

---

**Student**

________________

Mhanna M.

Signature

**Supervisor**

________________

Aksenov A.Y.

PhD in engineering science

Signature

**Academic Advisors**

________________

Ivanov A.N.

PhD in engineering science, Docent

Signature

________________

Semenova E.A

PhD in engineering science, Docent

Signature

---

Saint Petersburg

2018
TASK FOR THE MASTER’S THESIS

Approved
Head of the department
____________ Yuldashev Z.M.
«___»______________20___ .

Student
Mhanna M.
Group 2500

Student
Mханна М.

Topic: Non-contact monitoring of pulse rate, breathing and emotional state of patients using video camera

Institution: Saint Petersburg Electrotechnical University (ETU)

Initial data (technical requirements):
The main requirement is to study different non-contact methods of obtaining heart, and breathing parameters and compare them to develop a new method with improved efficiency

Contents of the thesis:
A brief description of content is recording the signals obtained from different methods, comparing them with reliable results, and analyzing relations between heart and breathing parameters with emotional states.

List of report materials: explanatory note, illustrations, main content, defense presentation, and software program

Additional sections: special aspect of safety, appendix A

Task given on
«12» February 2018.

Submitted for defense on

Student
Mhanna M.

Supervisor
Aksenov A.Y.

PhD in engineering science
PROJECT TIMELINE FOR THE MASTER’S THESIS

Approved
Head of the department

________________________ Yuldashev Z.M.
«___»______________20___ .

Student  Мханна М.
Mhanna M.  Group  2500

Topic: Non-contact monitoring of pulse rate, breathing and emotional state of patients using video camera

<table>
<thead>
<tr>
<th>№</th>
<th>Stages</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Literature review</td>
<td>12.02 – 28.02</td>
</tr>
<tr>
<td>2</td>
<td>modeling and building methods</td>
<td>01.03 – 30.03</td>
</tr>
<tr>
<td>3</td>
<td>Comparing methods and analyzing data</td>
<td>01.04 – 01.05</td>
</tr>
<tr>
<td>4</td>
<td>Special aspects of safety</td>
<td>27.04 – 15.05</td>
</tr>
<tr>
<td>5</td>
<td>Explanatory note</td>
<td>01.05 – 25.05</td>
</tr>
<tr>
<td>6</td>
<td>Illustrations</td>
<td>01.05 – 25.05</td>
</tr>
</tbody>
</table>

Student  Мханна М.
Mhanna M.  Supervisor  Aksenov A.Y.

PhD in engineering science
SUMMARY

Explanatory note, 86 pages for work, 41 figures, 8 tables, 20 equations, 57 sources and Appendix A.

KEY WORDS: MIT method, color-based method, PPG, developed method, Heart parameters, mood states.

Goal of the GQW: In this paper, we develop a new method by comparing two previously studied methods depending on motion variations, or color variations of the face. Hence, concluding a more advanced method, which has more additions to be suitable for several environments in the outdoor and indoor environment as well, and takes advantages of improving two previous methods.

Subject of the GQW: This method works on detecting HR, HRV, and RR in real time by recording the face area of the person in front of the webcam, then detects the ROI, which is concluded to be in the forehead area.

Many previous studies have been published to develop non-invasive Heart Rate and Breathing Rate during measurements in different activities, because of how important these parameters are on the human being and how uncomfortable, and unsuitable to measure these parameter with wires and probes placing on the person during these activities. The system measures HR, HRV, and RR in real time and shows the results on the screen. About 15 samples are taken in this study to compare between the three different methods. Each method tracks the heart beats in real time, draws the signals on the screen, then calculates HR, HRV, and RR to compare them with each other and with the results from an Oximeter to detect the reliability of each method. This study has significant potential applications in telemedicine and personal health care, as it gives a sufficient improvement and development of previous studies.
РЕФЕРАТ

Многие исследователи работают сейчас над разработкой бесконтактных методов измерения таких показателей как частота сердечных сокращений, величина дыхания курс, параметры вариабельности сердечного ритма, записывая и анализируя небольшие отрывки видео лица человека для получения всей необходимой информации. Данный проект направлен на сравнение двух методов: первый заключается в анализе движений головы, причиной которых является сердечный выброс, а второй — в изменении цвета кожи лица. В работе были программное реализованы их алгоритмы и проведена их оценка точности. На основе этих двух методов был предложен третий, показавший более высокое значения точности. При исследовании цветового метода сравнивались результаты анализа трех областей лица: лба, щек и губ, при этом цветовое изображение раскладывалось на несколько каналов: зеленый, синий и красный. Для каждой области лица была оценена точность и выбрана наилучшая; расчеты производились в среде MATLAB. Далее был реализован метод микродвижении, а также более совершенный, сочетающий в себе два других. После этого проводился сбор и анализ данных при 15 различных состояниях человека; использовались три разработанных метода и сравнивались с эталонным для оценки эффективности и точности расчета частоты сердечных сокращений, дыхания курс и вариабельность сердечного ритма. Данная работа демонстрирует разработанный наиболее точный алгоритм бесконтактного измерения показателей сердца и дыхания, который может применяться в различных областях здравоохранения, в том числе телемедицинских системах.
# TABLE OF CONTENTS

INTRODUCTION.................................................................................................................. 10

1 Theoretical REVIEW OF THE BIOENGINEERING SYSTEM .............................. 11

1.1 Introduction on the problem.................................................................................. 11

1.2 Previous work in the same field......................................................................... 12

1.3 The goal of the project ....................................................................................... 14

1.4 Objects and the subjects of the project ............................................................ 15

1.4.1 The objects of the research ......................................................................... 15

1.4.2 The subject of the research ....................................................................... 15

1.5 The background information........................................................................... 16

1.5.1 Heart Rate and Heart Rate Variability ...................................................... 16

1.5.2 Indications of heart rate variability............................................................... 19

1.5.3 Respiratory Rate.......................................................................................... 20

1.5.4 The principle of detecting the changes in color......................................... 20

1.5.5 Color transformation of an image, Light, with two color channels........... 23

1.5.6 Ideal band-passing filter.............................................................................. 24

1.5.7 Peak Detection in the signal....................................................................... 24

1.6 Conclusion........................................................................................................ 25

2 MODELING AND DESIGNING THE GENERAL METHOD FOR OUR BIOENGINEERING SYSTEM.......................................................... 26

2.1 The structure of the biomedical system ............................................................ 26

2.2 The control loop............................................................................................... 27

2.3 The planned level of development in this thesis............................................. 29

2.4 The data acquisition technic............................................................................. 29

2.5 Voila and John method for face detection..................................................... 30
2.5.1 Mathematical explanation of Voila and John algorithm ......................... 32
2.6 The region of interests and the face detection ............................................ 34
2.7 Positive feedback and negative feedback .................................................. 38
2.8 Classification of the bioengineering system ............................................. 39
2.9 Conclusion ............................................................................................... 40
3 ANALYZING THE MAIN METHODS AND THE PRACTICAL SUPPORT OF
OUR BIOENGINEERING SYSTEM ............................................................... 42
3.1 Massachusetts Institute of Technology method of detecting movement of the
head to obtain heart rate ............................................................................. 42
  3.1.1 The basic approach of the method ..................................................... 42
  3.1.2 Frames processing .......................................................................... 42
  3.1.3 Principle of motion magnification .................................................... 43
  3.1.4 Mathematical explanation ............................................................... 44
  3.1.5 Application of the method ............................................................... 46
3.2 The second method depends on color variations without magnification ..... 48
  3.2.1 Basic approach of this method ......................................................... 48
  3.2.2 Frame processing ........................................................................... 48
  3.2.3 Mathematical analysis ................................................................... 49
  3.2.4 Application of the method ............................................................... 50
3.3 The third algorithm .................................................................................. 52
  3.3.1 Mathematical Support ................................................................... 53
  3.3.2 Application of the method ............................................................... 54
3.4 Metrological support .............................................................................. 56
3.5 The sustainability: .................................................................................. 57
3.6 Comparison of the methods .................................................................... 57
3.6.1 Comparing between two methods of magnifying video from motion-based magnification and color-based magnification ........................................ 58
3.6.2 The compare between the three methods, and statistics analysis .......... 59
3.6.3 Analytical and statistical analysis of the results ................................. 63
3.6.4 Study of relation between heart parameters and mood changing .......... 65
3.7 Conclusion .......................................................................................... 70

4 SPECIAL SAFETY ASPECTS ...................................................................... 71
4.1 Introduction into safety aspects for our system ...................................... 71
4.2 The areas where the software is applied ................................................ 71
4.3 Temperature, humidity and atmospheric pressure ranges ..................... 72
4.4 Human system interaction .................................................................... 73
4.5 Capability of individualization ............................................................... 75
4.6 Software design and development ......................................................... 76
4.7 Conclusion .......................................................................................... 79

CONCLUSION ............................................................................................ 80
Advantages of using the system ................................................................. 80
Future work ............................................................................................... 81

BIBLIOGRAPHY ..................................................................................... Error! Bookmark not defined.
**DEFINITIONS AND APPRECIATIONS**

We explain some of the abbreviations and definitions that are mentioned in this paper to make the reader familiar with those abbreviations when reading the paper. Next, we give the main definitions that mentioned in our research.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BES</td>
<td>Bioengineering system</td>
</tr>
<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>HR</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>HRV</td>
<td>Heart Rate Variability</td>
</tr>
<tr>
<td>LAB</td>
<td>Color transformation of an image, Light, A, B channels</td>
</tr>
<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
</tr>
<tr>
<td>PNS</td>
<td>Para sympathetic nervous system</td>
</tr>
<tr>
<td>PPG</td>
<td>Photoplethysmogram</td>
</tr>
<tr>
<td>R, G, B</td>
<td>Red, Green, Blue channels in a photo</td>
</tr>
<tr>
<td>ROI</td>
<td>Region Of Interest</td>
</tr>
<tr>
<td>RR</td>
<td>Respiratory Rate</td>
</tr>
<tr>
<td>R-R</td>
<td>Intervals between two peaks of R type in a ECG signal</td>
</tr>
<tr>
<td>SNS</td>
<td>sympathetic nervous system</td>
</tr>
<tr>
<td>SPO2</td>
<td>Capillary oxygenated hemoglobin saturation</td>
</tr>
<tr>
<td>STD</td>
<td>Standard Deviation</td>
</tr>
</tbody>
</table>
INTRODUCTION

Many previous technologies worked on contactless measurements of heart rate (HR), respiratory rate (RR), and heart rate variability (HRV) by recording a short video of the human face to extract all the information required for analyzing. This paper has a new purpose to hold comparison between two main methods (the methods from Massachusetts Institute of Technology (MIT); method of detecting movement of the head caused by the heartbeats, and the method based on detecting the changes in the color of the face. The comparison was hold upon the efficiency and the accuracy of these two methods. In addition, it propose ways of developing several characteristics of these two methods by improving a new method that has better efficiency from others. Firstly, the study focuses on getting the best Photoplethysmogram (PPG) by comparing three different areas of the face, forehead, chicks, and lips. By studying the color map of these three areas and getting the PPG from the channels, Green, Blue, Red, and A channel. Secondly, building a program with three different parts in MATLAB illustrating the three different methods; the two methods mentioned above and the final one, which has the best improvements from both of them. The next step is to compare the results obtained from all the methods with reliable results taken at the same time of fifteen samples in different situations, analyze them and study the errors and accuracy regarding HR, HRV, and RR. Finally, analyzing the relations between the mood changes and the health states of the person with the parameters variation obtained from the three methods. This research offers advantages in telemedicine as it compares between previous methods, and improves them by suggesting a new method that solves some previous problems, and gives extra development to this aspect in Telemedicine.
1 Theoretical REVIEW OF THE BIOENGINEERING SYSTEM

1.1 Introduction on the problem

Monitoring the heart performance has always been a matter of interest for how important it can get to tell about people health condition. The detecting of the HR, HRV, and RR is sufficient to detect a lot of heart performance and a patient health. Nevertheless, measuring those parameters had been somewhat disturbing for people with all the connecting wires and probes for monitoring especially for hours in the hospital where people need to stay connected to these uncomfortable tools in the hospitals. Nowadays, researches are developing contactless modes of monitoring these parameters with more comfortable ways. Although, there are a lot of difficulties and problems face the new development, this paper offers some solutions to overcome some of these difficulties. It presents three different algorithms for detecting Heart Rate (HR), Breathing Rate (BR), and Heart variability as well using contactless methods which have been previously studied, but has a lot of cons need to be solved and pros need to be developed. For example, the previous methods focused on recording videos in the ambient light in an indoor environment [1], which is not sufficient when recording the parameters during exercises in the outdoor environments. Thus, this paper helps to solve and develop some problem of previous work to develop recording heart factors to help estimating the performance of the heart during many activities, such as doing sports, sleeping, eating, watching a video, playing games, chatting, also for babies and newborns in hospitals, or when they are alone in a room. We accomplished prototypes of two methods, one is made by MIT in USA, which depends on magnifying little movements of the head not seen by naked eyes [2], and the other one depends on the variation of the skin color of the face taking from selected ROI (Region Of Interest) [3]. Then comparing results from these two methods with the heart rate estimated from an Oximeter. Eventually, proposing a new algorithm that can solve problems from the previous methods to increase the quality of the system.
Our paper solves a very important matter. As only one paper written before suggested that all the previous studies were taken indoors, and it suggested a method giving the ability to take the measurements outdoor with reducing the brightness effects [4]. Our study presents the same method but applies it before the magnifying of the variation of the pixel.

1.2 Previous work in the same field

For each heart beat blood circulation, the blood going throw the vessels creates color variation in facial skin. Therefore, it is possible to extract HR from the color variation of the facial skin. The first contactless monitoring system was created in 1995 [5]. They used camera images in order to extract physiological parameters using color variation of the skin, but their approaches did not report measureable results; they reported only a graph of heartbeats and also failed to show any correlation with reference ECG signals. Further progress was made in with another method, which was introduced for the measurement of computer user’s emotional state using the thermal image from a thermal camera in 2005 [6]. The experiment was applied on 12 people and the authors found some interesting relation between stress and blood flow, as stress is correlated with increased blood flow in the frontal vessel of the forehead. Later in 200 [7] . shows that RR (Respiratory Rate), HR and HRV are possible to extract simultaneously using a camera. They captured images of a part of the subject’s skin and then the changes in the average image brightness of the region of interest (ROI) are measured for a short time. They used MATLAB custom functions for filtering and spectral analysis. Finally, they could extract HR and HRV for a certain period of time. Later the contactless measurements of heart pulse had been developed based on the analysis of thermal images using FFT algorithm [8]. They showed that the temperature of the vessel is modulated by pulsatile blood flow is directed at recovering the frequency of the component signal with the highest energy content. After processing, the thermal image signal can yield quantitative information about blood flow velocity, respiratory function etc. The noncontact methods using camera further improved to a system capable of capturing
two PPG (Photoplethysmogram) signals simultaneously at two different wavelengths using non-contact system [9]. Ten test people participated in this experiment where both camera and PPG sensors were used for data collection. Their proposed system extracted oxygen saturation (SpO2) successfully but the efficiency is not compared. Additionally, they showed that the system was capable of obtaining good quality PPG signals from deep tissue. Another successful attempt was done using digital cameras to extract heart rate and respiratory rate from facial video recorded in ambient light from 30 seconds to a few minutes, which is a major flaw to apply in real time applications [10]. Noncontact based method for physiological parameters extraction has been further improved in recent years. A novel method was presented in 2009 [11], which is able to get the parameters of a person heart by putting his finger in front of a mobile camera. More and more development took place in 2011 to enhance the recording of heart parameters using a finger in front of a camera. Later in the same year, a method has been developed to extract underlying source signal from R, G, and B channels using a webcam [12], it took place in the indoor environment and recorded breathing rate from finger sensor and chest belt spontaneously. The problem with these studies, is that they took place only in indoor environment, and not in the real time without showing how much time it needs to give the results. Later in 2012, MIT developed a new method of detecting the heart parameters using camera, by detecting the head motion in accordance to the blood circulation [2]. In 2013, a method was approached to estimate HRV from an eye tracker [13]. In 2014 a non-contact method to detect the psychological mood of the drivers was developed [14]. The most successful method for non-contact method to extract psychological states by webcam camera was made in 2015. They developed an algorithm to get HR, HRV using a normal camera with 90% accuracy. Further development has been made later in 2016 by studying three channels affection to extract heart parameters in lab environment [15]. All of these previous study was taken in a lab environment with the ambient light. In 2017, a more advanced method was developed to enhance these methods to be able to record in the outdoor environment using a LAB transformation [16].
1.3 The goal of the project

The method depends on analysis the frames of video taken from a webcam connected to the Laptop in order to measure and monitor breathing rate, heart rate, and heart rate variability according to the analysis of region of the face. These regions are detected depending on analysis of the corresponds of the facial areas to the absorption of the three main colors in order to detect the Regions of Interest ROIs such as forehead, which is the one of the highly responded areas in the face to the color variation. Another developed part of the project depends on mood detection to determine some kind of changes in the HR and the HRV for people. By processing the data, information of the patient’s mood and health can be detected. Using specific methods of computational intelligence, and mathematical algorithms to apply three methods for detecting these features. In addition to compare with a reliable device to detect which of these methods are more reliable and more efficient in different environments.

The goals of the biomedical research are as follows:

- The goal of the research is to get the most accurate method of all to detect and monitor breathing and heart rate according to facial analysis of specific area, to use it to detect the patient mood and health.
- To design the bioengineering system: which is getting the more advanced and accurate method of all other methods being compared with each other and with a more reliable method in real time which includes all of the bioengineering system components the receiving, processing, analyzing, control, and the decision-making by the physician.
- To generate new methods to solve the problem: which includes several algorithms and mathematical methods to form the analytical and the control units, the algorithms generated in this papers are reliable enough and developed from previous methods.
- To compare between methods differ in the way of processing data in order to get the best efficient way.
- The study of the stability: the aim is to make the system stability as higher as possible by trying to consider all the external factors of the system.

- To describe the elements that affect the methodological system: study the changes of the parameters reaction of the changes on mood changes on different people.

1.4 Objects and the subjects of the project

1.4.1 The objects of the research

The heart rate, the breathing rate and the mood of the people under experience are very important parameters telling facts about human health. It turns out that, the face is the ideal place to detect these parameters [17], because the skin is thinner than other parts of the body and we can recognize the blood circulation in the blood vessels as they are closer to the surface. The goal is to define these characteristic of the person to keep showing, and monitoring his/her health in different activities. In addition, when these parameters are processed according to mathematical algorithms and methods, they may be stored in a memory unit to be able to check late, or may be sent to a physician to monitor health. When a fit person, such as an athlete, exercises the pulse rate and breathing rate levels rise, the heart rate of the human speeds up to pump extra food and oxygen to the muscles [18]. Breathing speeds up to get more oxygen and to get rid of more carbon dioxide. Thus, can vary from person to another, and it is defiantly so important to monitor these parameters. In addition, these characteristic can also change with the mood. For example, Decreased cardiac vagal function is linked with increased cardiac mortality and depression is associated with decreased heart rate variability [19].

1.4.2 The subject of the research

To study all of the previous factors, in order to estimate the health condition of the person under examination. Studying these factors can be accomplished in different situations and states of the human under examination, it can be done during different activities, such as running, sleeping, eating, watching a movie, etc. In
addition, it could be done to estimate people reactions in different situation, such as watching a movie or an advertisement. It also applicable in hospitals as much as telemedicine, as it reduces efforts.

1.5 The background information

As it well known, HR, RR, and HRV are very important health status information [20]. The frequency measurement is used in many medical or sport applications like stress tests or life treating situation prediction, as it is described above. Next, we come through all the definition of these parameters.

1.5.1 Heart Rate and Heart Rate Variability

HR is defined as the rate of occurrence of cardiac beats in a specific period of time, usually expressed in beats per minute (bpm) [21].

See Table 1.1 for parameters of healthy people in different ages.

Table 1.1– The general values of heart rate for healthy people

<table>
<thead>
<tr>
<th>Pulse rate by age span</th>
<th>Heart rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 month</td>
<td>120–160</td>
</tr>
<tr>
<td>1–12 months</td>
<td>80–140</td>
</tr>
<tr>
<td>12 months–2 years</td>
<td>80–130</td>
</tr>
<tr>
<td>2–6 years</td>
<td>75–120</td>
</tr>
<tr>
<td>6–12 years</td>
<td>75–110</td>
</tr>
<tr>
<td>More than 12 years</td>
<td>60–100</td>
</tr>
</tbody>
</table>

Pros of measuring HR: Easy to measure, Can measure during exercise, no need for extreme accuracy to use it, great gauge of cardiovascular exertion during exercise, and vast numbers of devices and wearables of varying quality/accuracy exist.

Cons: Limited to mainly measuring cardiovascular activity, at rest, heart rate is a vague indicator of internal activity at best and inconsistent at worst, Vast numbers of devices and wearables of varying quality/accuracy exist.
While the heart rate is all about the average beats per minute, the temporal variation between sequences of consecutive heart beat intervals is defined as heart rate variability (HRV). It measures the changes in time (or variability) between successive heartbeats. It can be defined by the time gap between heartbeats that varies as a person breathes in and out. The time between beats is measured in milliseconds (MS) and is called an “R-R interval” or “inter-beat interval (IBI) see Figure 1.1 for further details. On a normal ECG reading, the standard upwards deflection of a QRS complex is at the peak of the R wave. The duration between two R neighbors are defined as the R–R interval, N–N (normal–normal) intervals. [22]. For R-R interval declaration see Figure 1.1

![Figure 1.1](image)

**Figure 1.1** – R-R intervals between adjacent QRS complexes in normal sinus heart signal

The HRV can be measured by many different methods [20], in time and frequency domain. While the simplest method is time domain measuring. With this method, the heart rate can be detected at any point in time or the intervals between successive normal complexes are determined. Whereas, the HRV indicates the nonlinear dynamics in the measurements. In a continuous electrocardiographic (ECG) record, each QRS complex is detected [23]. Simple time–domain variables that can be calculated include the mean NN interval, the mean heart rate, the difference between the longest and shortest NN interval. For illustrations of how the R-R interval deferens between each other see Figure 1.2. Other time–domain measurements that can be used are variations in instantaneous heart rate secondary to respiration.
These parameters are influenced by many different factors, such as gender, age, physiological and psychological condition, drug interferences.

In our method, the most obvious part of the section, which can be recognized by looking at the output signal appearing on the screen, is the R part. Hence, we can easily detect the R-R interval, by calculating the intervals for the entire signal, then taking the mean see equation (1.1) and the standard deviation of the R-R intervals (1.2)

\[ M = \frac{\sum_{i=0}^{n} I}{n} \]  \hspace{2cm} (1.1)

Whereas, M is the mean value of the R-R intervals, I is an R-R interval which differs over time. n is the number of the intervals are taken.

\[ SD = \sqrt{\frac{\sum_{i=0}^{n} (I - M)}{n}} \]  \hspace{2cm} (1.2)

Where SD is the standard deviation of the sample, I is the R-R interval at one moment, M is the mean value of the sample, and n is the number of the samples.

Next we illustrate the difference in the R-R peaks that are shown in our output signal in the PPG to obtain the HRV Figure 1.3.
This signal is taken from our system to show the obtained PPG in real experiment, and it illustrates the R peaks and the intervals between two neighbor peaks.

1.5.2 Indications of heart rate variability

Heart rate variability (HRV) has been a relatively new method for studying the effects of stress on human body. Research evidence increasingly links high HRV to good health and a high level of fitness [17], whilst decreased HRV is linked to stress, fatigue and even burnout. The variability should be high in the normal physiological state of an individual and should only erode with age or progression of the disease.

Measurement of HRV for use in monitoring training and recovery involves analysis of the heart’s beat-to-beat variation. By accurately measuring the time interval between heartbeats, the detected variation can be used to measure the psychological and physiological stress and fatigue on the body during training.

Generally, a low HR indicates rest, while a high HR corresponds with exercise or exertion. Generally, a low HRV (or less variability in the heart beats) indicates that the body is under stress from exercise, psychological events, or other internal or external stressors [20]. Higher HRV (or greater variability between heart beats) usually means that the body has a strong ability to tolerate stress or is strongly recovering from prior accumulated stress.

HRV is actually an umbrella term for many different calculations and analysis methods [23] Since HRV focuses on the imperceptible changes between each heartbeat (in milliseconds), it is much more complex and requires higher degrees of accuracy than heart rate. However, thanks to recent technology improvements, consumer grade heart monitors and smartphone apps can do all of the measurement work and neatly present the insights needed for decision making. [24]

Pros of Heart Rate Variability: HRV can be used as a daily check-in with the body to determine its readiness to tolerate stress on a given day. In this regard, HRV is commonly used to optimize and individualize training programs based on a
person’s’ readiness or recovery state. Also, HRV can be used to determine how various lifestyle choices affect health and performance by trending HRV and the correlated events over time.

Cons: Difficult to measure during exercise or while moving (though unnecessary usually), and accuracy requirements limit the use of some trendy wearable HR monitors.

1.5.3 Respiratory Rate

A person's respiratory rate is detected by the mean value of the number of breaths taken by a human per minute. The normal respiration rate for an adult is estimated between 12 to 20 breaths per minute at rest. A respiration rate under 12 or over 25 breaths per minute while resting is considered abnormal. [25]

The RR differs accordingly with the heart rate and mood. In addition, it can increase over 30-60 Bpm (Breath per minute) in cases of intensive exercises. See Table 1.2 to get some information about normal RR in different ages.

Table 1.2 – Normal RR for different ages

<table>
<thead>
<tr>
<th>Respiratory rate by age span</th>
<th>Breathing rate (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 12 months</td>
<td>30–60</td>
</tr>
<tr>
<td>Toddler 1–3 years</td>
<td>20–40</td>
</tr>
<tr>
<td>Preschooler 4–5 years</td>
<td>22–34</td>
</tr>
<tr>
<td>School age 6–12 years</td>
<td>18–30</td>
</tr>
<tr>
<td>Adults</td>
<td>12–16</td>
</tr>
</tbody>
</table>

These value help to understand the predicted filtration of the system, in order to concentrate to get the normal signal for the human parameters.

1.5.4 The principle of detecting the changes in color

There is growing interest in extracting the heart rate without contact, starting from the fact that the skin color changes accompanied with the cardiac cycle, especially in the face area, this can lead to the ability to extract information about cardiac activity from recording normal videos with using only a webcam [26]. In
addition to measuring heart rate, the method can be used to extract breathing rate as well. Hence, other features can be estimated such as heart rate variability and mood state of a person. The cyclical movement of blood from the heart to the head via the abdominal aorta and the carotid arteries Figure 1.4 causes the changes of the face color especially in some region that will be declared later in this paper. Our algorithm detects pulse from this changing and extract the information about the cardiac. The two methods described in this paper, suggest two principle of extracting signals from the face, the first one includes the skin changes upon a slightly changes of the movement by the moment produced by the Carotid Artery as blood flows through [2]. The heart pumps the blood through the artery, which gives a small movement unseen by a naked eye, and the reflection of the muscles of the head returns the head as a reaction of this action made by pumping blood. These mini movements synchronized with the bumps of the blood, can be detected after amplifying and filtering frames sequence of a recorded video. This approach tracks feature points on a person’s head ROI (Region Of Interest), filter their spectrum by a temporal frequency band of interest, and extracts an average pulse rate from this signal by examining its frequency spectrum and obtain precise beat locations with a simple peak detection algorithm. The human head with the artery, which causes the movement in the head, are illustrated in Figure 1.4
The second approach depends on color variations of the skin of the human [27]. As well known, the human skin reflects and absorbs radiation. A human has 4 to 6 liters of blood of which 52 % to 62 % is plasma. The remaining 38 % to 48 % are different blood cells with the largest part of them being red blood cells. The plasma is mostly transparent so the majority of the absorption of the blood stems from the red blood cells. The function of the red blood cells is to carry oxygen. To do this each cell contains a vast amount of the protein hemoglobin Hb which can bond oxygen molecules. When blood is flowing from the heart to the body, it contains oxygenated hemoglobin \( \text{Hb}_{O_2} \) and when it flows back to the heart, it contains deoxygenated hemoglobin Hb. See Figure 1.5 which has been taken from has been made using data found in. It shows that both Hb and \( \text{Hb}_{O_2} \) have absorption peaks between 530 nm and 590 nm which corresponds to green and yellow colors [28]. It works because each heartbeat increases the volume of blood in the user’s vessels. Blood’s hemoglobin absorbs light, which decreases the light reflected by the skin [26].

![Figure 1.5 – Absorption spectra of oxygenated and deoxygenated hemoglobin](image)

Hence, it is absorption of some wavelength radiation changes according to the amount of blood passing through the blood vessels. This fact indicates that the thinner the skin, the more variation of absorption of radiation, and the mini changes of color of the skin can be resulted of the cardiac pulses. Since these cardiac pulse results to subtle color changes of a skin, a pulsatile signal which can be described as
photoplethysmographic (PPG) signal, which can be measured through recording facial video using a digital camera. The base of this method is to reveal temporal variations in frame sequences of each pixel value, which are difficult or impossible to see with the naked eye, and display them in order to measure the important parameters. Using this method, we are able to visualize the flow of blood as it fills the face and also to amplify and reveal small variations.

Those two methods are run in the real time to show the signal, and calculate the parameters instantly, and presents on the screen.

1.5.5 Color transformation of an image, Light, with two color channels

LAB referees to the color space consists of a lighting component L and two color components A and B [26]. The two components A, and B make the color of the image after deleting the lightness. The A channel makes the red and the green channels of RGB images, and all the colors that they produce by mixing them together with different proportion. Where the red channel is the A+ and the green channel is the A-. The B consists of the other colors where the B- is the blue and the B+ is the yellow. These components A, and B indicate the amount of the color in the photo. For the component A positive values indicate amounts of red and negative values indicate amounts of green, and similarly for the B component yellow is positive and blue is negative. Lightness, which is the central axis in ranges from black at 0 to white at 1. In this research, we use the A component obtained from this method, after eliminating the lightness component from the frames. This can cause to the ability to work in indoor and outdoor environments unlike the previous researches, which took place in indoor environment with ambient light. For illustrating the Lightning component with A, B channels see Figure 1.6
In addition, this transformation can reduce the noise from the light source, as brightness can be separated from the color component. It has other pros that the green and red colors are both combined in the same channel (A). While all the color changes happen in between these colors, we can conclude the changes easily by studying only component A.

### 1.5.6 Ideal band-passing filter

The filter is used by the MIT and included in the MATLAB toolbox. The ideal band passing works on the concept of the Laplacian–Pyramid where the original image is convolved with a Gaussian kernel. The resulting image is a low pass filtered version of the original image. The cut-off frequency can be controlled using different parameters. The Laplacian is then computed as the difference between the original image and the low pass filtered image. This process is continued to obtain a set of band-pass filtered images. Thus, the Laplacian pyramid is a set of band pass filters, and it is optional to use different cutoff frequencies as the task demands. This concept builds the ideal–band passing which is used to obtain the PPG signal in the second and third methods. [29]

### 1.5.7 Peak Detection in the signal

This method depends on finding the local maximum in the signal. It returns a vector with the local maxima (peaks) of the input signal vector. A local peak is a data sample that is either larger than its two neighboring samples or is equal to Inf.
Non-Inf signal endpoints are excluded. In our study, we use this method as our output signal is built with only one variable changes with time, as it showed like a one variable function at the end of the process. The purpose of applying this method is to find the peaks of the PPG signal in order to detect HR and RR as well. [30]

1.6 Conclusion

A brief introduction is made through this chapter of the earlier start of the field of our study. The previous studies have faced some problems with working in different environments and most of them only focused on the color-based methods, while few others focused on motion-based method two. Hence, our goal of this study is to compare, discuss, and combine different features to overcome the problem of the previous studies. A general reviews of different concepts is given to introduce the work and build the complete model of each method correctly to be able to study and conclude fairly. Many concepts on measurements, detections, tracking, filtration, and calculations are introduced in this chapter to make the study and analysis in the upcoming chapters easier to be understood. We used some approved methods, suitable for our study and environment to build up our three methods in the next chapters. Furthermore, we considered to illustrate very step in a convenient easy way to the user and the reader.
2 MODELING AND DESIGNING THE GENERAL METHOD FOR OUR BIOENGINEERING SYSTEM

2.1 The structure of the biomedical system

The purpose of this biomedical system is to construct the signal from the face of the patient and store it in the registration unit in the device; (in our case a portable laptop) it could be any smart device like a phone. This method is applied in a laptop, and then the signal is stored in the registration unit in the laptop, in order to be analyzed by MATLAB, the analyzing unit that contains all the algorithms and mathematical methods to extract the right signals using all filters and equations, which will be illustrated in the this Chapter. Then displaying the signal on the screen of the Laptop to show how much the heart rate and breathing rate are. The physician may be in future as a neural network, which will work to constructs the mood and the possibilities for some health problems, which could happen with the person. The neural network work as a human in the principle of fuzzy logic to make a decision about the patient health state. In case any of the patient health threats, the system shows on the screen of the device to inform the patient to go to the doctor. The Figure 2.1 shows the structure of our device.
Figure 2.1 – The structure of our BES

The building of the diagram for the BES helps to understand the internal units, which this system is made of, and it also helps in understanding how the system work.

2.2 The control loop

Our system is assumed a closed loop as much as possible. The internal and the external factors interact between each other in a kind of controlled way. We have an object that is represented by the face of the person, and the purpose is to construct the feature of the patient face, ROI that is considered as the forehead area, since it is estimated to give, very good and constant results as the skin color changes spontaneously during the heartbeats. The purpose of the system is, first to detect and track the face of the patient with a method called Viola-Jones detection (explained in this chapter 2) algorithm and a trained classification model for detection, process
which will be illustrated later in the upcoming chapters. See the internal and the external factors in Table 2.1

Table 2.1 – This table illustrates the internal and external component of the BES

<table>
<thead>
<tr>
<th>The internal factors</th>
<th>The camera resolution</th>
<th>The process speed</th>
<th>The camera speed</th>
<th>The reliability of the algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>The external factors</td>
<td>The noise from environment</td>
<td>The user experience</td>
<td>The movement of the face</td>
<td></td>
</tr>
</tbody>
</table>

The second step is to catch the forehead area to apply the algorithm of detecting the heart pulse, which also will be illustrated in the next chapters. The role of the control unit is to control the flow of the signals and the date, and to control the relation between the internal and external factors of the system. The external factors in here is presented by the noise, which comes from the little movement of the patient face, the noises of the camera, and the noise of the lights in the place where this study takes place. The speed of the processor, and the speed of the camera, are internal factors that can be controlled. See Table 2.1 for internal and external factors. These factors detect the system reliability and stationarity. In this method, we tried to get the best reliability by detecting these factors to get as more reliability as possible. After detecting these factors, the control unit controls the processing unit, which tries to reduce the noise in the real time method. The when the noise is high, the adaptive filter works to reduce the amount of noise in the signal in a way called the feedback process. A closed loop in the system is illustrated in Figure 2.2
There are similar control loops as shown in Figure 2.2 for all the section of the biomedical system, which are all controlled by the general control unit in the micro-processor inside the computer. In order to represent the system with accurate presentation and the attempt to cover all of the external and internal factors.

2.3 The planned level of development in this thesis

In this thesis, the efforts are being executed to develop the system with the methodological level, software, and metrological assurance. In order to estimate the most reliable methods for studying a biological object (a person), measuring biomedical indicators, and processing and analyzing of biomedical information, to make the accurate medical decision. The previous algorithms were focusing on different parameters and methods of processing, which will be explained later in the next chapter. The developed algorithm gives more accurate and useful way for telemedicine and home examination, as it can be useful any time, and any situation. The tracking algorithm in this system gives it a higher reliability and possibility to be used in any situation. In addition, in this biomedical system we provide a set of data used to ensure the unity and the required accuracy of measurement to ensure checking and testing of a bioengineering system, presented in the control unit.

2.4 The data acquisition technic

The test set-up was designed in a way to eliminate most of the interfering environmental influences, as we wanted to find the relation between the heart rate and the information extracted from video-data. The participants were placed right in
front of a webcam (Logitech HD 1080 p, 24 Bit RGB, 8 Bit per channel) and color-videos were recorded with a length of couple of seconds at 15 frames per second (fps), and a resolution of 640x480 pixels. The participation is asked to sit at a distance of about 0.5 m from the webcam with indirect sunlight as the only source of illumination indirect ambient light. The setting consisted of two phases, in the first phase the program just recognizes the participant face. In the second phase, the program starts taking video recordings of the participant face to calculate the heart rate [31]. The position of the participant is illustrated in the Figure 2.3

![Figure 2.3](image)

Figure 2.3 – To illustrate the position for the participant

The data acquisition take the first step with the system interface with the human as some criteria needs to be accomplished in order to start the program when the data acquisition starts. It is a very important step as it needs to be accurate for receiving accurate measures

### 2.5 Voila and John method for face detection

Face recognition has received a huge attention from researchers especially in bioengineering [32]. It uses several methods such as, pattern recognition, computer vision communities, and machine learning and computer graphics communities. This started by trying to mimic the people ability to recognize the face of the human.

Frontal-view face detection systems, automated face detection was achieved using an algorithm based on image invariants by MATLAB program with an algorithm called Viola-Jones detection algorithm and a trained classification model for detection. Automated frontal view face recognition was realized using Viola-
Jones detection algorithm and a trained classification model for detection. See Figure 2.4 to illustrate the steps are used to get the output.

Figure 2.4 – Plot representing of face recognition system

To extract the face we need to process one frame by one. To detect the face we need to teach the program to catch a face like shape in one frame [33], then put test if this shape has an eyes, mouth, and nose by setting references points on the face that match our frame (scan the image with a mask which best presents the face shape. After that, scan the face shape rectangle with masks best represent the eyes, nose, mouth of human face) after detecting the shape of the head we need to put it into a ROI shape (rectangle, square), then detect the other features of the face. The program adjust itself to changes by testing the ROI continuously, then set new points to adjust the changes that could happen if the person moves a little bit. Results are shown in Figure 2.5 to illustrate the application in our method.
Figure 2.5 – The face recognition in our method applied in real time, a) obtained from the system before detecting the face, b) after detecting the face's features.

The application of this method in our system shows that the algorithms detects the features of the face then it detects the existence of the face which helps to understand better how this algorithm works by showing the results.

2.5.1 Mathematical explanation of Voila and John algorithm

The algorithm is based on calculating a number of Haar-like features very fast using the integral image [34]. The basic principle is to give a mask with already given values of each point pi. This value is the sum of all the pixels in the respective rectangle in the 3×3 grid. Thresholding points in a circle with regard to the center point, p0, find the Haar feature of p0. The equation (2.1) and Figure 2.6 describe the formula of 8 bits frame.

\[ p_0 > p_1, p_0 > p_2, \ldots \ldots \ldots p_0 > p_8 \]  \hspace{1cm} (2.1)

Where \( p_0 \) is the value of the pixel in the center of the mask, \( p_0, \ldots, p_8 \) are the neighbor pixels.
Figure 2.6 – Local binary pattern (LBP)

The rectangle’s shown in the Figure 2.6 has dimensions \((s_x; s_y) \) \(s_x = s_y = 2\), (it also could be non square). This can be calculated in the image after obtaining the integral image which can be produced by the integral of all the pixels value of the image. The new pixel value will be the sum of the current value of the pixel and the value of the neighbor pixel \((i-1)\). Hence, for any \(s_x; \ s_y\) the so called integral image \(I\) is introduced. For an image \(X\), \(I\) is defined as in the next equation (2.2)

\[
ii_{k,l} = \sum_{i=1}^{k} \sum_{j=1}^{l} x_{i,j} 
\]  

(2.2)

Where \(ii\) is the integral image, \(x\) is the real image, \(k, l\) are the size parameters, and the \(i, j\) are the parameters of the pixel location. \(X\), is the image, and \(I\) is the integrated image

where \(x_{i,j}\) and \(ii_{k,l}\) denote pixels in \(X\) and \(I\), respectively. This can be calculated very efficient and recursively, under proper edge conditions, by the equation (2.3)

\[
ii(i,j) = ii(i - 1, j) + ii(i, j - 1) + x(i, j) 
\]  

(2.3)

Where the \(ii(i-1,j)\) is the value of the integral image in the left neighbor of the current value of the image, \(ii(i,j-1)\) is the integral image value of the bottom neighbor and \(x(i,j)\).
The integral image makes it possible to calculate the sum of any rectangle in the image, by looking at only 4 values in the integral image. The calculation of an $3\times3$ Haar feature is possible with only 16 lookups.

In MATLAB, the 9 rectangles of the mask are configured by a $3\times3$ grid located somewhere in this image. The sum of all the pixels in each rectangle is calculated using the integral image, and thresholded with regard to the rectangle in the middle in order to calculate the feature. The algorithm uses a moving window over the entire image. First, faces are detected at the smallest allowed scale. If a region does not contain a face, the window moves a few pixels to the right, and iteratively covers the whole image. After the entire image has been searched, the size of the window is multiplied by a factor and the image is searched with the larger moving window and so on. Using a large dataset and boosting, a strong classifier can be created, like a cascaded classifier. It consists of 20 stages, where each stage contains from 3 to 10 Features. Dependent on the outcome of each feature, a positive or negative number is assigned. The sum of these numbers are compared with a threshold specific to the current stage, to determine whether the stage has failed. If a stage fails, the window does not contain a face, and the system stops the operation, with showing error message. However, if all 20 stages are passed, a face has been detected in that area.

For tracking faces generally, Viola-Jones algorithm is employed for face detecting in PPG method in real time in our method. The PPG method is used to extract the changing of the color in the image. It helps to detect the heart beats. It produces the raw signal before filtration. The goal of this process is to detect and trace the face in order to obtain the perfect area. Three region of interest (ROIs) are being tested in our method, the lips, the forehead and the chicks represented later in the next paragraph.

**2.6 The region of interests and the face detection**

The next step is detecting the region of interest, which here is resembled by the forehead area [35]. As well known, the most sensitive area to color variations
during heartbeats is mouth area, since it has a lot of blood capillaries and thin skin. Nevertheless, we chose the forehead as it is less sensitive to noise and slightly affected by the expressions of people, while speaking and laughing. The program automatically detects the ROI by giving it some order about the size of the face and how features should be located (as previously described). It also tests this result with its own knowledge about feature detecting to give results that are more accurate. Then a study accomplished to test the perfect channel that gives the best shape of the signal. The red blood cells are known with the absorption of the green color, which makes the green channel changes in color, hence, it gives the best results. Refer to the intensities in the color in color maps of the same face taken for three channels Figure 2.7

![image a](image a) ![image b](image b) ![image c](image c)

Figure 2.7 – Three different color map analysis of three channels, a) represents the Red channel, b) represents the Green channel, c) represents the Blue channel.

We did these tests to obtain the suitable ROI which we should focus on in this method, there are three popular ROI that people focus on in these kind of researches, which give the more responses to the changing colors during the heart beats, these regions are shown in the color maps of the face Figure 2.7. From the figure, we can see that the region of red color gives the intense response, which helps to track the PPG, the forehead, the mouth, and the chicks with nose. A lot of studies focused on chicks and forehead, while fewer focused on mouth, because it needs to be controlled by the person under experiment Figure 2.8 shows different signals obtained from the mouth area. In this study, we took all of the three main ROI and extract the PPG signal to see the best response.
From the Figure 2.7 we can see that the best respond is in the forehead region as it gives the maximum, the green channel and the red channel are more accurate when measuring the absorption of the light by the blood in the faces region. Our study focuses on these two channel and compare them to A channel in the LAB transformation of the image as it combined these two channels and gives better results.

![Figure 2.7](image)

Figure 2.7 – Comparing different results obtained from all three channels in the face area

Although, the skin of the human lips is very thin and contains a lot of blood capillaries which help in detecting the higher response comparing between different regions of the face. Still, taking the lips as ROI can also results for a lot of errors and noise. The obtained signals from the three ROI, R,G,B channels are illustrated in Figure 2.9

![Figure 2.8](image)

Figure 2.8 – Comparing different results obtained from all three channels in the mouth area

Although, the skin of the human lips is very thin and contains a lot of blood capillaries which help in detecting the higher response comparing between different regions of the face. Still, taking the lips as ROI can also results for a lot of errors and noise. The obtained signals from the three ROI, R,G,B channels are illustrated in Figure 2.9
Figure 2.9 – Three different output signals taken from three ROIs in our system based on color variation, a) shows the signal when ROI is mouth area, b) shows the signal when ROI is the forehead area, c) shows the signal when ROI is the chicks’ nose area.

The second most important region for detecting the PPG is the forehead as it gives high response and less noise and errors. The other reason of choosing this ROI is that our system records the parameters of different activities and different moods, which sometimes require the person to speak and move mouth.
2.7 Positive feedback and negative feedback

A positive feedback loop causes a self-amplifying cycle where a physiological change leads to even greater change in the same direction. A negative feedback loop is a process in which the body senses a change, and activates mechanisms to reverse that change [36].

In this system, the open loop we have is the relationship between the mood changes and the heart rate and breathing rate parameters. [37] See Table 2.2

Table 2.2 – Mood relationships with the HR and RR

<table>
<thead>
<tr>
<th>Mood</th>
<th>Heart Rate</th>
<th>Breathing Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depressed mood</td>
<td>high-frequency heart rate</td>
<td>high-frequency heart rate</td>
</tr>
<tr>
<td>Happy mood</td>
<td>Low-frequency heart rate</td>
<td>Low breathing Rate</td>
</tr>
<tr>
<td>Fear</td>
<td>high-frequency heart rate</td>
<td>high-frequency breathing rate</td>
</tr>
<tr>
<td>Angry</td>
<td>high-frequency heart rate</td>
<td>high-frequency breathing rate</td>
</tr>
</tbody>
</table>

This an internal open loop which one parameters affect the other parameter, the positive feedback is between the heart and the breathing rate. Emotions such as anger and hostility ramp up your "fight or flight” response. When that happens, stress hormones, including adrenaline and cortisol, speed up heart rate and breathing. Which makes this like a control loop inside the parameters of our biomedical system.

The negative feedback is in the control unit in our BES, which affects the work of the adaptive filter, when the noise is too high; the adaptive filter reduces the signal in order to maintain the best results on the screen. See Figure 2.10
The system detects the noise in the output signal, in case it is too high in comparison with the previous data, the adaptive filter eliminate the noise as much as it should be suitable for the signal in general, this helps to obtain a cleared signal as much as possible.

2.8 Classification of the bioengineering system

Our Bioengineering system is designed on the base of improving the method for non-contact monitoring of selected biomedical signals, evaluation of breathing and heart rate using recorded video frames, and verification of the obtained results. This base is accomplished for the informational and methodological support level of the BES. In attempt to develop the method to get more accurate and easier way. The classification of our system on the base of the previous information is Training apparatus of interactive type of BES. See Figure 2.11 for general classification of the BESs and Figure 2.12 for classification of our system.
2.9 Conclusion

In this chapter, we started by studying the main design of our BES, considering all the external and internal factors that affect the loops in our BES. Furthermore, we proceeded by studying the main algorithm, which each method should follow in a convenient order considering all the factors of each method. However, some of the methods can change the order slightly as it affected by other factors. In addition, we described the main methods used in designing our systems by studying them applicably and mathematically. The chapter studies the control loops inside the system, the mathematical support, gives explanation on the data acquisition technic in this system, the clearly explanation of the face detection
algorithm, and its mathematical support. Finally, we studied the positive and negative loops inside the system and give the classification of our bioengineering system to prepare every necessary explanation for the next chapter.
3 ANALYZING THE MAIN METHODS AND THE PRACTICAL SUPPORT OF OUR BIOENGINEERING SYSTEM

3.1 Massachusetts Institute of Technology method of detecting movement of the head to obtain heart rate

Based on techniques to reveal invisible signals in videos [2], Eulerian video magnification, MIT was able to magnify the human skin color variations invisibly to the human eye with each heartbeat. These variations can take place in motion and colors of the human skin low amplitude to obtain the signal of the heart. In this method, they use a combination of spatial and temporal processing of videos can magnify variations that reveal important details of the human face.

3.1.1 The basic approach of the method

The method works on Eulerian video magnification for revealing subtle changes in the world [2]. It detects the color values at each pixel in a frame of the video, and amplifies the changes considering the next frame in the video with an already known band-path of the desired frequency. For example, they took a selected area of the human face and used the frequency of the human heart rate range then amplified the signal, this reveals the variation of color as blood flows through the face. Furthermore, it can be applied in different situations, such as showing the breathing of the baby by focusing this method to be applied at the baby chest. This method can be used to both the color changes and the motion changes as well. In this paper, we explain mathematical part of this method, which relies on a linear approximation related to the brightness constancy assumption used in optical flow formulations. After that, applying a derivative. This leads to a multiscale approach to magnify motion without feature tracking or motion estimation.

3.1.2 Frames processing

MIT approach combines spatial and temporal processing to emphasize subtle temporal changes in a video [2]. The process is illustrated in Figure 3.1.
Firstly, they decomposed the video sequence into different spatial frequency bands. These bands might be magnified differently because (a) they might exhibit different signal-to-noise ratios or (b) in case of the bands contain frequencies that aren’t hold in the frequency band of the linear approximation in the motion magnification does not hold. Then they can reduce the amplification for these bands to reduce the artifacts. When the goal of spatial processing is simply to increase temporal signal-to-noise ratio. In the general case, a Laplacian pyramid is computed, then applying temporal processing on each band. For extracting the heart rate of a human face, they selected frequencies within 0.4-4Hz, corresponding to 24-240 beats per minute. When they want to extract the pulse rate, they can use a narrow band around that value. The temporal processing is uniform for all spatial levels, and for all pixels within each level. Then they multiplied the extracted band-pass signal by a magnification factor. This factor is already specified. Next, they added the magnified signal to the original one and collapse the spatial pyramid to obtain the final output. This filtering is performed uniformly over the pixels.

**3.1.3 Principle of motion magnification**

The system first decomposes the input video sequence into different spatial frequency bands, and applies the same temporal filter to all bands. The filtered spatial bands are then amplified by a given factor, added back to the original signal,
and collapsed to generate the output video. The choice of temporal filter and amplification factors can be tuned to support different applications [2].

### 3.1.4 Mathematical explanation

Let’s use the 1D signal to explain the relationships of the motion magnification and temporal filtration. This technic can be generalized for 2D signals too, but to simplify the equations better to use 1D signal [2]. The processed image can be presented by the equation Error! Reference source not found.

\[
I(x, t) = f(x + \delta(t))
\]  

(3.1)

Assuming that \(I(x; t)\) is the image intensity at position \(x\) and time \(t\), and the translational motion, which is related to time, which is different intensities with respect to a displacement function \(\delta(t)\).

The goal of motion magnification is to synthesize the signal, when \(I(x, 0) = f(x)\) we can conclude the equation Error! Reference source not found.

\[
\hat{I}(x, t) = f(x + (1 + \alpha)\delta(t))
\]  

(3.2)

Where \(\alpha\) is the amplification factor.

They assumed that since we can represent the image intensity mathematically, like a first order Taylor series, such as illustrated in the equation (3.3)

\[
I(x, t) \approx f(x) + \delta(t) \frac{df(x)}{dx}
\]  

(3.3)

Where \(\frac{df(x)}{dx}\) is the derivative of the main signal.

In here we have the frames mathematically represented with changing of intensity throughout time, now we have to apply the band-pass filter to get the right
frequency of the changes happening because of the heart beats. See the equation (3.4) for band-pass filter.

\[ B(x, t) = \delta(t) \frac{\partial f(x)}{\partial x} \]  

(3.4)

Let \( B(x, t) \) be the result of applying a broadband temporal band-pass filter to \( I(x, t) \) at every position \( x \).

Then we need to amplify that signal by \( \alpha \) and add it back to \( I(x, t) \). Adding the amplification signal is illustrated in the equation (3.5)

\[ I(x, t) = I(x, t) + \alpha B(x + t) \]  

(3.5)

Combining of the equations (3.3), (3.4), and (3.5) we have the equation result in shown in (3.6)

\[ \tilde{I}(x, t) \approx f(x) + (1 + \alpha) \delta(t) \frac{\partial f(x)}{\partial x} \]  

(3.6)

Assuming the first-order Taylor expansion holds for the amplified larger perturbation, \( (1 + \alpha)\delta(t) \), we can relate the amplification of the temporally band-pass signal to motion magnification. The processed output is simply in (3.7)

\[ \tilde{I}(x, t) \approx f(x + (1 + \alpha)\delta(t)) \]  

(3.7)

This shows that the processing magnifies motions—the spatial displacement \( \delta(t) \) of the local image \( f(x) \) at time \( t \), has been amplified to a magnitude of \( (1 + \alpha) \).

This effect is demonstrated here on a 1D signal, but equally applies to 2D.

For completeness, let us return to the more general case where \( \delta(t) \) is not entirely within the passband of the temporal filter.
In this case, let $\delta_k(t)$, indexed by $k$, represent the different temporal spectral components of $\delta(t)$. Each $\delta_k(t)$ will be attenuated by the temporal filtering by a factor, then $B(x, t)$ is shown in (3.8)

$$B(x, t) = \sum_k \gamma_k \delta_k(t) \frac{df(x)}{dx}$$ \hspace{1cm} (3.8)

Where $k$. This results in a band-passed signal, $\gamma_k = k\delta$, resulting in a motion magnified output.

The result is as would be expected for a linear analysis: the modulation of the spectral components of the motion signal becomes the modulation factor in the motion amplification factor, $k$, for each temporal sub-band, $\delta_k$, of the motion signal.

### 3.1.5 Application of the method

Using MATLAB code on laptop, and taking the video frames for couple of seconds using a Logitech HD 1080 p camera 640 * 480 videos at 15 frames per second. We were able to apply this method to extract the parameters of the heart from the face of the people who contributed in this study. Then we made a program that can show the changes in the heart signal in front of the person on the screen in the real time. Starting by detecting the face and tracking it by inserting the Viola and John method, then using Eulerian method of magnifying the subtle changes in the ROI in the face as previously explained. To process an input video by Eulerian video magnification, there are four steps: (1) select a band-pass filter; (2) select an amplification factor; (3) select a spatial frequency cutoff (specified by spatial wavelength); and (4) select the form of the attenuation. The frequency band of interest can be chosen automatically in some cases, and using the ideal band passing, we can acquire the signal and get rid of the noise, then the program show the signal on the screen and gives the parameters. Figure 3.2 shows an example made by MIT to illustrate the use of the method to magnify small motions.
Figure 3.2— Eulerian video magnification used to amplify subtle motions of blood vessels arising from blood flow

In this example of the MIT motion-based method, the video frames which are seen in Figure 3.2, were magnified using their method. They tuned the temporal filter to a frequency band that includes the heart rate—0.88 Hz (53 bpm)—and set the amplification factor to $\alpha = 10$. To reduce motion magnification of irrelevant objects, they applied a user-given mask to amplify the area near the wrist only. They were able to magnify the motion of the ulnar and radial arteries as they can barely be seen in the input video, but is significantly more noticeable in the motion-magnified output video.

Choosing the filtration method is essential in this algorithm, the MIT algorithm can use the Eulerian video magnification for both, getting the motion or the color changing in the video frames. For example, for motion magnification, a filter with a broad passband is used, to detect the movements, which is unable to detect by naked eyes.

There are another method to track and magnify motions that is called, Lagrangian Processing. Lagrangian approaches explicitly track motions, while this one can be used for complementary motion domains. Lagrangian approaches, work better to enhance motions of fine point features and support larger amplification factors, but in this method we used Eulerian method from MIT cause it is better suited to smoother structures and small amplifications. It does not assume particular types of motions. In addition, the Lagrangian method is more sensitive to increases in spatial noise, while the Eulerian error is hardly affected by it. [2]
3.2 The second method depends on color variations without magnification

The goal of this method is to estimation the resting heart rate that measures heart beats for people, and it can be an important indicator of the health. This method is also taken in the ambient light in the indoor environment, to record the signal from the heart of the person in front of the camera. It depends also in the variation of the skin color in the face to detect the blood flow inside the vessels of the face under the skin [38–43]

3.2.1 Basic approach of this method

For color amplification of blood flow, our objective was to detect the color change as the blood flows through the face. A narrow passband produces a more noise-free result. We use band-pass filters for color changes detections, since they have passbands with sharp cutoff frequencies. Then we analyze the signal to extract the PPG. Estimation of the heart rate and breathing frequency from changing the skin color in the ROI such as mouth, forehead, or chicks and nose, as has been illustrated above. The analysis of the color changes depends only on the frames taking from the camera, without magnifying the changes in the skin color [44, 45]. This method had taken place in several studies performed on estimation parameters from faces [15].

3.2.2 Frame processing

The frames processing includes the analysis of the spectral components of this video frames. The analysis mainly starts by detecting and tracking the face using the detection method in MATLAB (Viola and John algorithm) as previously described. The detection of the face followed by the choosing of the region of interest (ROI) which is in our study the forehead (previously explained). After that, the program processes each frame simply by applying the mean detection on all the pixels in the ROI, to convert the 2D signal into 1D signal, which is easier to process. The system works for couple of seconds with a video sequence using the same camera (Logitech HD 1080 p). These mean values of the forehead ROI are used as an input signal for
analysis of spectral components in frequency ranges of breathing and heart rate. Results obtained by the non-contact camera sensor should be compared with the heart rate recorded by an oximeter sensor.

### 3.2.3 Mathematical analysis

The main noise elements are the external factors, which have to be removed before the signal is used for next data processing like heart rate frequency determination. The mean values of the frames are taken in the ROI area for different frames in time, the plot of this signal is shown in real time while the patient is looking at the screen.

The mean value is calculated with the equation (3.9)

\[
m(t) = \frac{\sum_{x=x_1}^{N_1} \sum_{y=y_1}^{M_1} \bar{I}(x_1: x_2, y_1: y_2, t)}{N_1 \times M_1}
\] (3.9)

Where the \(m(t)\) is the mean value at a specific moment \(t\). \(x_1, y_1, x_2, y_2\) are the limitations of the ROI of the image. \(N_1, M_1\) are the size of the ROI.

After getting the signal, and before applying the method for calculating the number of the peaks in the signal to obtain the heart rate, we applied a band-pass filter to reduce the noise and extract only the signal, which refers the heart rate. The main purpose of the filter is to isolate the signal as much as possible to extract the heart bits and the breathing signal from the row signal. The filter applied in this study is a Butter, with a cut down frequency as 1Hz, and cut-up frequency as 1.66 Hz. Shown in Figure 3.3
The other filter is applied for breathing rate; the filter is applied to the signal to extract the breathing peaks before counting the peaks in the processed signal. The breathing rate for human is in between [12 and 18 per minute]. The filter is also designed as Butterworth Figure 3.4

The peak detection: After filtration, the maximum values are the values, which correspond to the filter the most. Hence, we can calculate the maximum peaks to obtain both the heart rate and the breathing rate.

3.2.4 Application of the method

The program starts the camera automatically by MATLAB using image acquisition toolbox then, it saves continues photo by (15) frames/second. The photos then are processed immediately to obtain the signal in a real time process and in the memory buffer to make them ready to be processing in the workspace see Figure 3.5
Figure 3.5 – Processing frames in real time

The data saved is a video file, which records continuously for thirty seconds the face of the person stands still against the camera. It will detect the changes in the color of the skin, which is unnoticeable by a human eye. The data is a video frame ready to move to the second step of processing.

After taking into consideration, the previous steps, spectral analysis of the red, green and blue mean image values in the forehead area indicated that the first dominant frequency components are approximately 0.34 Hz (representing a breathing rate of about 20.5 breaths per minute). The second dominant frequency of about (ex. 1.23 Hz) (with the highest peak in the green component) represents a heart rate of about (ex. 74 bpm) for this example. The estimation of the breathing rate. The analysis of the signal after filtration indicates a better signal with the PPG appearing clearly and ready to extract this information more precisely, the band-pass filters which were applied, represent the HR and RR range of a normal healthy adult with extra values of possible unhealthy rates. See Figure 3.6 for output signal.
The scientific results of the project are to detect whether the heart rate or breathing rate are normal or not, which also helps to determine the mood of the person, in order to extract the probability of detecting some diagnosis.

### 3.3 The third algorithm

In this algorithm, we combine between some characteristics both of the previous algorithms to get more efficient and more accurate one. We use advantages recorded in both algorithms as previously discussed to obtain the most accurate algorithm from all, taking into consideration, the other advantages that could be added to this one, not existed in other two algorithms. At first, as the other ones, we apply Viola and Johns method to detect and track the face. As we concluded before, the MIT algorithm depends on magnifying the changes in the motion of the face, which are unable to be seen from human naked eye. In this method, we take the color-based magnifying of the face. The magnifying is based on getting calculating the pixel value in each frame; detect the changes and magnifying them. In this method, we magnify the changes in the ROI only after detecting the face, and apply this to detect respiratory rate too in the chest. After making the changes, we detect the ROI which we process. The ROI, in this method is the same (Forehead). In this way, we secure that the magnification of the color variations focused on the face in general, not only the region of interest, in order to reduce the noise in the signal. Then after focusing on the forehead area, we convert the image from the RGB image...
to the LAB image. (Lab image is previously discussed in the previous chapters). This conversation helps in reducing the noises from the light source, all of the studies before, were taken in the ambient lights indoor. Whereas, our method can be applied indoor and outdoor as it focuses on the A channel, not on the brightness component of the image. Why component A? The component A includes the green channel and the red channel of the image, which have the maximum response of the color variation, in response of the blood flow under the skin by each heart bump, as previously described. Finally, taken the mean value of the pixels values in this area in order to get PPG signal.

3.3.1 Mathematical Support

The attempt at first is to magnify the signal by studying each pixel value and comparing it with the next value of the same pixel, and the multiply the changes with a magnification factor in order to get the changes magnified for detecting better signal. Let assume that the whole image is a 2D signal consists of the sum of all pixels values as follows in the equation Error! Reference source not found.

\[
IM(t) = [I_1(x_1,y_1,t), I_2(x_2,y_2,t), I_3(x_3,y_3,t), .... , I_i(x_i,y_i, t)]
\]

(3.10)

\[
IM(t) \text{ is the frame in a moment of study, } I_i(x_i,y_i, t) \text{ is the pixel value in the same moment.}
\]

The image pixels value changes in time; hence, the image value in general changes in time as illustrated in (3.11)

\[
I(x,y,t) = (f(x,y) + \delta(t))
\]

(3.11)

\[
I(x,y,t) \text{ the pixel value in the moment of study, } f(x,y) \text{ is the value before changing, } \delta(t) \text{ is the little change that happens over time as shown in (3.12)}
\]
\[ B(x, y, t) = \delta(t) \frac{df(x)}{dx} \frac{df(y)}{dy} \] (3.12)

Let \( B(x, y, t) \) be the band-path filter of the image. \( \frac{df(\theta)}{dy} \) is the derivative of the signal.

After applying the band-path filter, we get the changes in the desirable frequencies for detecting the signal, the resulted image after filtering and applying the magnification factor is as follows in (3.13)

\[ \tilde{I}(x, y, t) = I(x, y, t) + \alpha B(x + 1, y + 1) \] (3.13)

\( \tilde{I}(x, y, t) \) is the value after applying the filter, \( \alpha \) is the amplification factor which could be detect by the user.

After applying the amplification factor the equation looks like this the equation in Error! Reference source not found.

\[ \tilde{I}(x, y, t) \approx f(x, y) + (1 + \alpha) \delta(t) \frac{df(x)}{dx} \frac{df(y)}{dy} \] (3.14)

We can conclude that we can multiply the changes in the image with an amplification factor and add it to the previous value of the photo is the time \((t-1)\).

Then cropping the ROI from the face and apply the mean frame to the ROI from the image after being processed

\[ mean(t) = \sum_{x=x1}^{N1} \sum_{y=y1}^{M1} \tilde{I}(x1:x2, y1:y2, t) \] (3.15)

We can see here that the mean value changes in time to give the PPG signal, which goes as the heart pumps blood throw the face.

**3.3.2 Application of the method**

Applying this method in MATLAB, and taking the video frames for couple of sec using Logitech HD 1080 p camera \(640 \times 480\) videos at 15 frames per second,
using the same steps as the MIT for amplification of the changes in the video. To extract the heart signal, but modulate it to apply in the real time. After detecting the face and tracking it by using the Viola and John method, then Eulerian method of magnifying the subtle changes in the ROI in the face as previously explained. After that, this method has advantages of deleting the effect of the brightness from the image by converting it to the LAB image, which allows the program to record the heart parameters by only detecting changes in the two channels, red and green, which has the high responses in accordance to the changes of color in face. Then, applying the suitable filter (Ideal Band Passing) to detect the range of the frequencies suitable for the heart and breathing rates applying the mean to the selected ROI channel (A) which in turns reduces the noise of the signal and gives the PPG final signal. Finally detect the peaks using detecting peaks algorithms to extract HR, HRV, and RR. See Figure 3.7 for illustrating the method diagram.

![Diagram](image)

Figure 3.7 – Diagram illustrates the steps of the third method

The program calculates the HR, by counting the peaks in the PPG signals, and the HRV, by extracting the variations in time between two followed R signals (R-R Intervals), then giving the mean and the STD of these values to the user. The program shows the signal and parameters on the screen in real time see Figure 3.8
Figure 3.8 – Results obtaining by the third advanced algorithm

The in system also provides the units for each parameter to provide the complete information needed for the user; also, it provides a description of the method on the screen in front of the person.

3.4 Metrological support

Metrological assurance: a set of knowledge and data used to ensure the unity and required accuracy of measurement in the developed bioengineering system, ensure checking and testing of a bioengineering system, a system of standards and measures, means of checking and testing of measuring channels [46].

The results obtained from our BES is compared to same results on the same people obtained by each other and by other reliable devices to calculate heart rate and breathing rate for the same person. The results are shown in Figure 3.9
3.5 The sustainability:

Sustainability is measured by assessing performance of Biomedical Engineering System [47]. One method for measuring the sustainability of our new system is to assess against existing best practices. In our bioengineering system, the main points for enhancing sustainability is to calculate heart rate and breathing rate with our system, and using the manual way on the wrist to test the accuracy of our method meanwhile recording. We counted pulses for 15 samples in different states, during counting breathing and heart rates, the system was counting in three different methods the same parameters with extra parameter HRV. The system shows very good results as seen later on.

3.6 Comparison of the methods

To hold the comparison correctly between all the methods, we took two steps to decide about the best way. Shown as followed.

Figure 3.9 – Showing differences between two methods, a) obtained from MIT motion-based method, b) obtained from the third method

The figure also shows the third method gives instance signal better than the one provided with the MIT signal which is an advantage to the study.
3.6.1 Comparing between two methods of magnifying video from motion-based magnification and color-based magnification

To compare between methods first we need to compare between magnifications. The Figure 3.10 shows two videos of the same face taken by different methods of magnification.

![Video a](image1.png) ![Video b](image2.png)

Figure 3.10 – Shows two frames from a video recorded for the same person and processed by Eulerian magnification method, a) for color-based magnification, b) motion-based magnification

The magnification of the subtle variation of the face can be accomplished upon two methods, color variation, and motion variation. The changes can be done by applying different derivatives on the frames of the video then count the differences, magnify it and apply filtration to the results, this will make the changes appear to the naked eye. The color variation can be estimated by applying narrow filtration, while the motion variations need wider filtration.

We recorded two videos of the same person and made the magnification of this video for each frame. The results can be seen in the Figure 3.10. We concluded from watching both of the videos that the difference between the two methods is obvious in this example. The magnification based on color variations illustrates the heartbeats and breathing rate in the results video, better than the method based on motion itself. Thus, can be explained by the narrow filtration, which detects the small
changes of the face better than the wider filtration applied to the other method to estimate motion variation.

We evaluated our methods of comparing the color variation amplification with the motion variation amplification by taking two different videos of one person is contributed in this study. By making the processing of the same video once by magnifying color changes and other by magnifying, the motion changes and then show the results of the both methods to compare. It shows that the color variations are more accurate and more sensitive to the filtration than the motion changes are.

The purpose of this experiment is to see by eyes the changes of the motion after processing the video with two methods of magnification, and to make a prior decision on which of these methods gives better results.

3.6.2 The compare between the three methods, and statistics analysis

There are some advantages and disadvantages for all the three methods. Thus, the first method has a lot of noise and inaccuracy in detecting some parameters and signal; despite of, the calculations were made in the same method as the two other algorithms. Whereas, the main problem of the MIT method, is a need to pre-identify the cutoff frequency of the band-pass by the user, as the user writes the suitable frequencies for his own parameters and let the system detect the correct frequency. This can lead to many errors, and the person may not be able to identify these parameters before the study takes place. The second problem of this method is that the study should take place in the indoor environments, not taking into consideration doing the experiments in the outdoor environments, which are required by people who do sports in the fresh air, for example. The third problem is that the motion magnification can detect the heart rate, but it is less sensitive to the filtration. The comparison section shows the differences between the two methods. Further, the third method combined the advantages taken from both other methods, and need more time than the first method but less than the second needs, still needs a lot of development.
To compare between these methods. The three methods recorded the parameters of the same person at the same place; the person was also connected to an oximeter in order to observe the reliable signal. These three methods gives all the same parameters at the same screen. See Figure 3.11–Figure 3.13 for results of the three methods.

Figure 3.11– Shows the results obtained by applying the first method based on color variations

Figure 3.12 – Shows the results obtained by applying the MIT method based on motion variation
In this study, different states samples were examined to compare between the two algorithms proposed in this paper. The person was sited in from on the Logitech webcam, looking directly to a screen in front of him/her, around 50 cm distance from the camera. The person could make slightly movements in front of the camera, and the system tracked the face to keep capturing the ROI. When the person was ready the system started to record his/her heart bits during around 40 seconds it changes between methods. Then the system drew the PPG on the screen in front of the person, showed HR, HRV, and RR. We further, took 15 samples in different mood states in our research to make sure that the comparison is fare enough and here are the results obtained from three results. The results taken were compared during measuring the heart rate by two systems with the results from a reliable device. See Table 3.1 for showing the results obtained from the three methods.
The results were taken in the indoor environment with the ambient light of the room, also the samples were taken when the person directly faces the camera sitting in the right distance from the camera.

Table 3.1– Results to compare between heart rate and breathing rates obtained by our BES and other devices

<table>
<thead>
<tr>
<th>State</th>
<th>Method on color</th>
<th>Method MIT</th>
<th>Developed method</th>
<th>Real</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Method</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>on color</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HR</td>
<td>HRV</td>
<td>HRV (STD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEAN</td>
<td>RR</td>
<td>HRV (STD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>states</td>
<td>HR</td>
<td>HRV</td>
<td>HRV (STD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEAN</td>
<td>RR</td>
<td>HRV (STD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>90</td>
<td>0.7</td>
<td>0.4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>76</td>
<td>1.19</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>74</td>
<td></td>
<td>76</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>74</td>
<td></td>
<td>74</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>81</td>
<td>0.5</td>
<td>0.33</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>83</td>
<td>1.29</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 happy</td>
<td>78</td>
<td>1.05</td>
<td>0.29</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>78</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 relaxed</td>
<td>74</td>
<td>0.6</td>
<td>0.4</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>64</td>
<td>1.04</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 medium exercise</td>
<td>69</td>
<td>0.9</td>
<td>0.43</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65</td>
<td>1.22</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 after intensive exercise 15 min</td>
<td>72</td>
<td>0.85</td>
<td>0.44</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68</td>
<td>1.3</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 relaxed</td>
<td>74</td>
<td>0.7</td>
<td>0.44</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65</td>
<td>1.06</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 nervous (m)</td>
<td>78</td>
<td>0.76</td>
<td>0.41</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td>1.12</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 intensive exercise</td>
<td>80</td>
<td>0.86</td>
<td>0.4</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>83</td>
<td>1.1</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stressed</td>
<td>76</td>
<td>0.75</td>
<td>0.45</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68</td>
<td>1.09</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sad</td>
<td>74</td>
<td>0.7</td>
<td>0.4</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>66</td>
<td>0.96</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sad</td>
<td>83</td>
<td>0.6</td>
<td>0.41</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td>1.05</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relaxed</td>
<td>75</td>
<td>0.8</td>
<td>0.44</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68</td>
<td>1.01</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relaxed</td>
<td>72</td>
<td>0.93</td>
<td>0.45</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>66</td>
<td>1.03</td>
<td>0.39</td>
</tr>
</tbody>
</table>

From the table before we can see that the developed method gives better accurateness and the results obtained are more closed to the actual parameters.
3.6.3 Analytical and statistical analysis of the results

From studying the errors in obtaining the results, by calculating the mean values of the results obtaining by our Bioengineering system, and with normal devices to calculate the heart rate and the pressure, we can conclude that the error is approximately Table 3.2

Table 3.2 – The study of the heart rate measurements errors of the three methods

<table>
<thead>
<tr>
<th>Errors</th>
<th>HR measurements</th>
<th>M. Color Change</th>
<th>M. MIT</th>
<th>M. Advanced</th>
<th>Real</th>
</tr>
</thead>
<tbody>
<tr>
<td>sample</td>
<td>Extra Info</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>normal</td>
<td>23.28767</td>
<td>4.109589</td>
<td>1.369863</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>different person</td>
<td>8.823529</td>
<td>8.823529</td>
<td>11.76471</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>exercising</td>
<td>3.571429</td>
<td>1.190476</td>
<td>1.190476</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Happy mood</td>
<td>1.298701</td>
<td>1.298701</td>
<td>5.194805</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>relaxed</td>
<td>12.12121</td>
<td>3.030303</td>
<td>1.515152</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>medium exercising</td>
<td>6.756757</td>
<td>12.16216</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>after intensive exercise 15 min</td>
<td>2.857143</td>
<td>2.857143</td>
<td>2.857143</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Chatting</td>
<td>12.12121</td>
<td>1.515152</td>
<td>4.545455</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>Nervous</td>
<td>12.12121</td>
<td>1.515152</td>
<td>4.545455</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>right after intensive exercise</td>
<td>9.090909</td>
<td>5.681818</td>
<td>4.545455</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>Stressed</td>
<td>2.702703</td>
<td>8.108108</td>
<td>4.054054</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>stressed sad</td>
<td>2.777778</td>
<td>8.333333</td>
<td>2.777778</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>stressed sad</td>
<td>5.063291</td>
<td>11.39241</td>
<td>3.797468</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>relaxed</td>
<td>11.9403</td>
<td>1.492537</td>
<td>1.492537</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>relaxed</td>
<td>10.76923</td>
<td>1.538462</td>
<td>3.076923</td>
<td>0</td>
</tr>
</tbody>
</table>

| MEAN% |                | 7.812124 | 5.213359 | 3.478788 | 0 |
| STD%  |                | 5.761241 | 3.817397 | 2.741313 | 0 |

In Table 3.2 study indicates that the minimum error occurs in taking the measurements from the third advanced method for HR with error range is approximately 3.4± 2.7%, whereas, MIT motion-based method shows error of
5.2±3.8%. Finally, the first method shows 7.8±5.7%. Hence, developing the third method giving more reliable measurements, and give the ability to take them in different conditions. For studying the RR errors see Table 3.3.

Table 3.3 The RR error measurements taken from three methods

<table>
<thead>
<tr>
<th>Errors</th>
<th>RR Measurements</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>sample</td>
<td>Extra Info</td>
<td>M. Color Change</td>
<td>M. MIT</td>
<td>M. Advanced</td>
<td>Real</td>
</tr>
<tr>
<td>1 normal</td>
<td>25</td>
<td>1.5625</td>
<td>1.875</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3 exercising</td>
<td>29.41176</td>
<td>5.882353</td>
<td>5.882353</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4 Happy mood</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5 relaxed</td>
<td>46.66667</td>
<td>20</td>
<td>13.33333</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6 medium exercising</td>
<td>29.41176</td>
<td>5.882353</td>
<td>5.882353</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7 after intensive exercise 15 min</td>
<td>25</td>
<td>12.5</td>
<td>12.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8 Chatting</td>
<td>37.5</td>
<td>12.5</td>
<td>12.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>9 Nervous</td>
<td>56.25</td>
<td>12.5</td>
<td>12.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10 right after intensive exercise</td>
<td>35</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>11 stressed</td>
<td>17.64706</td>
<td>5.882353</td>
<td>5.882353</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>12 stressed sad</td>
<td>20</td>
<td>6.666667</td>
<td>6.666667</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>13 stressed sad</td>
<td>5.882353</td>
<td>5.882353</td>
<td>5.882353</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>14 relaxed</td>
<td>23.07692</td>
<td>23.07692</td>
<td>15.38462</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>15 relaxed</td>
<td>66.66667</td>
<td>33.33333</td>
<td>16.66667</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>MEAN%</td>
<td>30.53666</td>
<td>11.83349</td>
<td>9.639692</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>STD%</td>
<td>16.91922</td>
<td>8.490988</td>
<td>4.353857</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

In Table 3.3 study indicates that the minimum error occurs in taking the measurements from the third advanced method for RR with mean error value is approximately 9.6±4.3%, whereas, MIT motion-based method shows error of 11.8±3.8%. Finally, the first method shows 30±5.7% error. Hence, developing the third method giving more reliable measurements, and give the ability to take them in different conditions.
3.6.4 Study of relation between heart parameters and mood changing

As well known, the heart attitude changes during different activities and different moods. Recent studies have shown an important relationship between HRV and mood states of a human. HRV was significantly associated with emotion detection by a study was made in 2012 [48]. Other studies has indicated that the HRV decreases as the stress of the person increase, high HRV means that the person doesn’t suffer much from stress and anxieties [49]. The researchers were able to indicate who suffer from stress and anxiety by studying HRV. They came out with a results that irregular heart rate indicates less stress. Whereas, positive feelings and relaxing indicates high HRV [50]. On the other hand, stress and anxiety with negative feelings stimulate the sympathetic (SNS) nervous system of people which increases the HR and RR, the state known as “fight or flight”, whereas the positive feelings and relaxing decrease the HR, and RR. On the other hand, during exercise HRV is reduced (shorter R-R intervals), while HR and RR are increased, not only are the intervals between R-R peaks shorter, they become more uniform (reduced R-R variability) [51]. Our study is aimed to take different cases and mood situation of 15 states for the same person, and the Table 3.4 shows that the HRV changes with the mood states as has been notified previously with the affection of sympathetic (SNS) and parasympathetic (PNS) nervous system.

A lot of studies took place to study these relationships, and they are very important to describe the health conditions. In this study, we took some samples of to cover some emotional and conditions of health like exercising, relaxing and different mood, emotions related to people in general. The purpose from this analysis is to compare between those methods and how do they correspond to the changes in heart and breathing parameters in accordance to the changes of the mood and health states.
Table 3.4 – HRV with different mood and physical states

<table>
<thead>
<tr>
<th>sample</th>
<th>Extra Info</th>
<th>M. Color Change</th>
<th>M. MIT</th>
<th>M. Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HRV Mean</td>
<td>HRV STD</td>
<td>HRV Mean</td>
<td>HRV STD</td>
</tr>
<tr>
<td>1</td>
<td>Chatting</td>
<td>0.7</td>
<td>0.4</td>
<td>1.19</td>
</tr>
<tr>
<td>3</td>
<td>exercising</td>
<td>0.5</td>
<td>0.33</td>
<td>1.29</td>
</tr>
<tr>
<td>4</td>
<td>happy</td>
<td>1.05</td>
<td>0.29</td>
<td>0.8</td>
</tr>
<tr>
<td>5</td>
<td>relaxed</td>
<td>0.6</td>
<td>0.4</td>
<td>1.04</td>
</tr>
<tr>
<td>6</td>
<td>medium exercise</td>
<td>0.9</td>
<td>0.43</td>
<td>1.22</td>
</tr>
<tr>
<td>7</td>
<td>after intensive exercise 15 min</td>
<td>0.85</td>
<td>0.44</td>
<td>1.3</td>
</tr>
<tr>
<td>8</td>
<td>relaxed</td>
<td>0.7</td>
<td>0.44</td>
<td>1.06</td>
</tr>
<tr>
<td>9</td>
<td>moderate nervous</td>
<td>0.76</td>
<td>0.41</td>
<td>1.12</td>
</tr>
<tr>
<td>10</td>
<td>intensive exercise</td>
<td>0.86</td>
<td>0.4</td>
<td>1.1</td>
</tr>
<tr>
<td>11</td>
<td>Stressed</td>
<td>0.75</td>
<td>0.45</td>
<td>1.09</td>
</tr>
<tr>
<td>12</td>
<td>sad</td>
<td>0.7</td>
<td>0.4</td>
<td>0.96</td>
</tr>
<tr>
<td>13</td>
<td>sad</td>
<td>0.6</td>
<td>0.41</td>
<td>1.05</td>
</tr>
<tr>
<td>14</td>
<td>relaxed</td>
<td>0.8</td>
<td>0.44</td>
<td>1.01</td>
</tr>
<tr>
<td>15</td>
<td>relaxed</td>
<td>0.93</td>
<td>0.45</td>
<td>1.03</td>
</tr>
</tbody>
</table>

After comparing between different methods of our study, we can conclude from studying the Figures 3.14–3.16 that the MIT-based method and advanced one are very likely to give the same results in HRV changes according to mood states. The diagrams show higher HRV in relaxed and positive mood, while decreased ones during negative mood and physical work. The first method indicates errors at the first four states as it requires to be going up not down, while the MIT-based method shows wrong measurement at the fourth point which represents the fifth states in the schedule. Hence, the advanced method shows approximately correct measurements.
The study of the heart rate and breathing rate shows that the heart rate and breathing rate increase with the exercises and start to decrease in a period after
exercising. They report the lowest level in the relaxing and happy mood, with slightly increase in the stress and negative mood. The study of the Figure 3.17 shows

![Diagram a](image1)

![Diagram b](image2)

Figure 3.17 – HR and RR values taken from color-based method, a) represents the HR changings with states, b) represents the RR changings with states

The first shows a lot of inaccuracy while reading the measurements in HR and RR. It shows that the HR and RR increase while the person is doing exercises and under stress and negative mood, whilst they decrease while relaxing and positive mood with an error of 7.8±5.7% in reading HR, and 30±5.7% in reading RR. While the MIT and the advanced method give better results and measurements on HR and RR with changing in accordance to mood status and less errors to show the results see the HR and RR diagram of motion-based method Figure 3.18

![Diagram c](image3)

![Diagram d](image4)

Figure 3.18 – HR and RR values taken from MIT-based method, c) represents the HR changings with states, d) represents the RR changings with states
Figure 3.18 shows that the HR and RR increases in the physical work and negative mood, while decreases in the relax and positive mood, the MIT- based results show more accuracy and are more relative to the real estimated results.

Finally, the advanced method gives better results comparing with the two other previous methods Figure 3.19, it can detect the changes with less error value 3.4±2.7% in reading HR, and 9.6±4.3% in reading RR, and better approximates the real estimated values. In addition, the real diagrams are illustrated in Figure 3.20

![Diagram e](image1.png)  ![Diagram f](image2.png)

**Figure 3.19** – HR and RR values taken from third advanced method, e) represents the HR changings with states, f) represents the RR changings with states

![Diagram g](image3.png)  ![Diagram h](image4.png)

**Figure 3.20** – Real estimated values. g) for HR measurements, h) for RR measurements

However, the analysis of these diagrams and these tables show that the third method gives results that are more accurate in general. Taking into account, that the MIT-motion based method gives very good results in comparison with the color-
based method, which needs to be improved by applying some features of the MIT method as illustrated in the third method to give better results.

3.7 Conclusion

At the beginning, the chapter explains the two main methods, giving the mathematical support for each method, and the application of each method in MATLAB environment. Furthermore, it gives some real examples of each one. Concluding the third method by enhancing the two other methods and combining steps from both of them to get more advantages. It also gives a wide explanation of the application of each method with the cons and pros. At the end of the chapter, we describe the analytical study giving results obtained from each method with different states. The goal of this study is comparing between these methods by collecting samples and comparing them to each other and giving measurements that are more reliable. The results of this study is that the third method gives results are more accurate, and it is able to accomplish the work faster. The MIT motion-based method gives good results, better that the color-based method. Finally, this chapter explains the relation between different heart parameters with mood changes by plotting several diagrams about these relationships. By making this entire conclusion, we were able to illustrate that the third method has made a significant improvement, taking into consideration the benefits from using other methods to obtain parameters.
4 SPECIAL SAFETY ASPECTS

4.1 Introduction into safety aspects for our system

The software safety is aimed at enhancing the software efficiency to accomplish the safety-critical functions (SCF). These safety aspects are part of the completely bioengineering system safety and need to follow the requirements of the international standard of the software design. The software must meet the requirements of the following IECs, ISOs. Such as, IEC 61508-3, ISO 9241-100, ISO 0941-110, ISO 0941-129, ISO 0941-143, ISO 0941-151. In addition, the software should be simple and integrated to meet the modern applications and qualifications of the modern applications [52 – 56]. Nevertheless, the hazard which the software is exposed, are several and the safety study should be made to cover all the potential hazards which may occur during working. Taking into consideration, that it is almost impossible to cover all the hazards during working, but the study needs to cover almost all the potential hazards which may cause errors, or lack of data flow, or even failure. As our experiment took place in the indoor environment, it is aimed at recording the data from a person sitting in front of the camera in the lab area, where the conditions can be almost controlled. Although, one algorithm of the software is developed to work in the outdoor environment, still the comparison of these three algorithms should take place in the indoor area to cover all the conditions of the two other algorithms.

4.2 The areas where the software is applied

As previously described, the algorithms, in general, work in the indoor environment where the ambient light can be controlled or at least considerable. The indoor recordings of the parameters took place for the entire samples in the indoor environment to cover all the requirements of the three methods in general, the person sat on a chair with approximately 0.5 meters of the camera in the room where the light is white and moderate [55] . Although, the third developed one is able to work in the outdoor environment, where the light is so hard to predict and control to make
suitable for other two methods that were supposed to work in the indoor environment. Hence, the software took place in the indoor environment in a lab room with normal temperature and white moderate light.

4.3 Temperature, humidity and atmospheric pressure ranges

The software of our BES has to run in specific environment in order for get the most efficient results, as all of the other software; it is affected by the temperature, humidity, and pressure of the place where the experiment is taken. Environmental effects of the indoor area, such as heat, cold, pressure, and humidity can affect the performance of a computer software, and even slowing down the speed of the software [57]. Therefore, we accomplished our experiments in the indoor environments, as it is more easy and flexible to be controlled by us. The experiment took place in the room where the range of the temperature is between 22–27° C in order to stay in the ideal working temperature range which should be 10–27° C. If the room is hot, then the laptop will be heated and the air would not be able to cool it down. Therefore, the software will accomplish its work slowly and which affects the results of the system by slowing down the speed of the data acquisition from the camera and leads to mistakes of recording data, which is an important step in the program and the first basic step to get the accurate results.

The second and semi-importance aspect is to control the humidity of the area where the data is being recorded and processed; it works hand by hand with the temperature to affect the work efficiency of the software. The dry air affect the laptop together with high temperature to cause static electricity and wrong discharge which in order causes the stull and freezing in the software. Meanwhile, the high humidity can cause water and short circuits, which in turn, result in stull or even shut down.

As a result, we managed to have the experiments in normal moderate conditions to secure the work efficiency of the software as much as possible. As previously described, the conditions can affect the software efficiency which may lead to an error while recording data, which is really essential step in the study, also, they can affect it while processing which may also lead to error in calculating the
parameters. Hence, the experiment took place in the lab area, considering the standard values of conditions in the lab following the American Standards of Physics and Medicine [25°C, 760 mmHg, 50% Humidity], we provided 25 °C, 1 atm, 56% Humidity.

### 4.4 Human system interaction

It is a very essential and important part of the software, it is described as a dialog between the human and the software, as it is the only thing can see by the person using the software. Following the requirements of the ISO 9241[52 – 55], the dialogue should be suitable for the task, self-descriptiveness, comfortable, and controllable. The user dealing with the software, shouldn’t see any additional unnecessary information which can be misleading and has no relation with the user. The interface dialogue should be really understandable and has no need for additional explanation. The software applies a very easy understandable interface to interact with the person in front of the laptop. The software presents GUI interface using MATLAB for input and output data. The window starts when the person starts the program giving him/her three choices to calculate the heart and breathing parameters. The window is self-explained, and super easy as it only tells the person stay still in front of the camera for limited time, then starts showing the heart beats in the axes near the video and writing the parameters when they are ready. The person gets to see his/her beats, the method is used, and his/her parameters.

The software is basically on comparing different algorithms of detecting HR, HRV, and RR for a user. Therefore, there is a need for ergonomic interface to interact with a person in a decent way. Without the interface, the user will not understand the results nor the purpose of the program, so we developed a GUI using MATLAB program to interact with a user, to record input and show output with the decent way.

The first interaction when the user starts the program is a controllable screen has three bottom for each method, which are named depending on each algorithm, the user sees two axes one says the video window, and the other shows the output
window. There is a table with the parameters on the same screen gives each parameter with its unit in two brackets.

The user starts the recording by choosing one of the method, and then the text box shows the name of the method with asking the user to stay still in front of the camera, and then shows the video on the video window, and start showing the signal on the window of the output in the real time. The user can watch his/her heart beat on the screen while recording the video. Finally, the calculated parameters on the table.

As previously explained, the interface is understandable need no explanation, as the buttons have sufficient explanations, and the text box provided further explanation. The interface is ergonomic, easy and uncomplicated and does not require unnecessary steps to ask the user to do before showing the results. The interface asks the user to do one step each recording.

The interface deals with the user in two ways, input data, and output data. As the input data is the video taken by the software when the user decides which method to start with. The video pops out and shows the recording of the human face and the text asks the person to not to move while recording the data. Finally, the output is shown on the screen in the real time when the user can see his/her heart beats. Immediately, the text shows that the signal is being recorded and the user can watch the signal in the real time, and the calculations of the parameters are shown on the screen with their names and units see Figure 4.1

The second important thing taken into consideration is the time of processing the signal, which is only couples of seconds to secure the comfort of the user. In addition, the interface can be controlled in case of any errors, it will stop the process and wait for the next order, or it can also stop by the user order to shut down the video. See the interface of the BES illustrated in Figure 4.1
Figure 4.1– Interface window of the system software

Hence, this shows that the interface of our BES is easy, understandable, controllable, and suitable for the task. Which meet the ISO 9241 requirements.

4.5 Capability of individualization

ISO 9421-129 [52] provides some requirements for individualization of the interface to make it more ergonomic. The capability to individualize needs to be built in response to the identification of user requirements. The individualization gives the software a wider application on a wider group of people. This allows the software to be applied not only on a group of general people, but also on individuals with special requirements. In our software, we took into consideration number of the requirements needed by ISO 9421-129 for individualization to be applied in our interface to make it more agronomic. The software interface is designed with a little amount of button written in a big font names with contradiction in color, to make it easier for a user to read before choosing especially for people who suffer from weakness in sight. In addition, the software provides additional description of each step at the top of the interface window to increase the understanding of the user for people with little backgrounds in these kinds of programs. The program is provided with error safety technics as when a button is mistakenly pressed or no faces encounter the camera, the programs stops and runs only after the demand of the user, concerning not giving any wrong parameters which can be a problem for some users.
4.6 Software design and development

This is an important section of programming, to choose the suitable programming language and support tools for writing the software. In order to meet the software requirement of the IEC 61508 [53] series. Firstly, the choose of the MATLAB comes from the wide support tools that it has for all the used equipment especially that we use the Logitech camera which has a special supporting tools in the programming languages that is provided by MATLAB. Furthermore, MATLAB gives an easy programming language used worldwide that can be understandable for millions of programmers around the world. In addition, it gives stainability that this language still being developed, and the software can be developed over the upcoming years. Finally, MATALAB gives an ergonomic interface to interact with user with different backgrounds.

As our system does not have a model of a device, we tried to meet the requirements of the IEC 61508 by answering the following questions of the software safety:

Does the code correctly implement the behavior of the device?

The system, basically, is developed to compare between different methods. These methods tries to implement the work of the ECG device, which records the heart electrical activities from the user to show the ECG signals. The main purpose of the ECG signal showing the signal is the detection of the heart rhythm, the size and functions of the chambers, detecting problems and diagnostics. Our main purpose of these functions is to concentrate on the heart rhythm. Hence, our software can implements the ECG device by showing the signal on the screen as the ECG device does, considering the difference between both signals where our system shows the PPG signal, while the ECG device shows the ECG signal. Taking into consideration, the ability to measure the HR, HRV, and RR from both signals, ECG, and PPG. In addition, both of signals are shown in the screen in front of the user in the real time and demonstrates the R peaks with each beats of the heart in front of the heart see Figure 4.2. The software succeeded to demonstrate the R peaks in the PPG signal in the real time in front of the user.
Figure 4.2 – PPG Signal output from the software

How convenient for realization of the task?

The study aims at comparing between three main methods that have been studied over many years. Each method represents a way of processing the video obtained by a webcam in order to get the correct parameters of the person health. Each one depends on a different way of processing, starting from the subtle variation of the face color to the subtle variation in motions of the head. Finally, to combine these two methods to get more advanced one with more additives. The purpose of this software is giving an agronomic way showing on the screen in front of the user with to allow comparison between these three methods with more reliable one such as oximeter. This software has been programmed with all the steps required to cover all of algorithm related to each method with has been studied and illustrated previously. The software gives each method by itself as full independent code includes all of the requirements to obtain the parameters. Giving an independent window with independent signal as output see Figure 4.3. Then, it shows the parameters obtained from each method to illustrate on the screen. This offers a way to compare between the three methods taking into consideration the more reliable method to get the best applicable efficient method from all. The main interface is illustrated in Figure 4.3
This software gives results then the user could use these result as data to make comparison using one of the analytical way to analyze these data. The analysis of this data shows that the best method is the advanced one as it shows more accurate parameters close enough to the real values obtained by the oximeter.

Therefore, the software correctly sufficiently accomplished the required purpose is asked to accomplished by giving the results of three method to the user. In this way, it works as the ECG device for the PPG signals giving accurate results to analyze.

Can the program work in conditions of real research activities?

The software is design to work at different environments with different conditions as it only need simple easy conditions to manage. Firstly, the software gives the user the ability to use various of webcam cameras connected to a computer of a laptop, the only thing is needed to know by the user, is the speed of recording the video (FPS). Once the user knows this parameter, he/she could easily write the parameter in the beginning of the code and run the program. These characteristics gives the software flexibility to work with different hardware. In the beginning of the study, we used another camera and then changed it for more quality. Secondly, the program can be run in different environment by taking into consideration the safety conditions, which have been described in the safety chapter before. The only condition that can be misleading is that the room needs to get sufficient moderate
light. A problem that has been solved in the third developed method where the light component has been erased from the process.

The program can work with repetitive cycle that the user can choose any method he/she would like to test at any time after opening the program. In addition, it is supplied by a safety code, in case the user mistakenly presses a wrong method, the user can easily press the correct method’s button again and the software will run the latest chosen button. Furthermore, the software is provided by another safety code, by closing the video window, all the process stops immediately and shows the signal at the same moment of the pressing and before, this advantage allows the user to concentrate on different points of the signal and gives additional safety option.

The software can be used in different activities for real researches such as hospitals and sports clubs to record the heart parameters of people in a contactless and more agronomic way to people being recorded. Furthermore, the software can work for any time wanted by the user as it is provided with an endless loop, and can accomplish repetitive studies in different environments.

4.7 Conclusion

This chapter studies the design requirements and the hazards that may the system may face during working which may affect its performance. To overcome these entire problems, we illustrated through this chapter that our system cover all the necessary requirements for working properly to give the best performance to get the best results since this software is super accurate, and the results can be affected easily. Furthermore, the requirements of the ISO and IEC for human reaction interface considering many requirements that help the system to be more efficient.
CONCLUSION

The methods described here form an alternative approach to biomedical data acquisition and analysis. Developing the abilities of different biosensors with possibilities of wireless data transmission increase the importance of remote data acquisition and signal analysis using computational intelligence and information engineering in the future to be used in Tele-Medicine application. This approach has a wide range of applications not only in biomedicine but also in engineering and robotics. In addition, holding a comparison between two main methods of this aspect of technology, it offers to make development of these methods. Further research will be devoted to algorithms for more precise data acquisition and processing to detect biomedical feature changes for correct diagnosis and for proposing further appropriate treatment. The important aspect about this study is that it compares between two well-known methods, MIT motion-based method, and color-based method, apply them equally and compare the results. Furthermore, it gives solutions of some problems that these methods face with extra improvement by mixing some of the advantages of both method to create more developed method that has the chance to be improved and applied in many areas in the future.

Advantages of using the system

The advantages of this research are very important to be applied in the telemedicine and give some development of the previous studies as follows

- Contactless: There is no need to attach any special device to the body.
- Non-invasive: Since the technology uses a standard webcam, the human body is not affected.
- Operation-free: Data is measured automatically.
- High accuracy: The technology is as accurate as a finger pulse monitor is.
- High speed: Heart rate can be measured fast.
- Continuous measurement: Simply remain in front of the camera
Future work

In order to improve performance a context specific classifier could be trained to extract more disease and mood changes by the BES. Training with examples specific to this application would allow user-defined performance targets to be set. In addition, the method could be improved to camera to be more efficiency detect the heart and breathing rate. Alternatively, face detection algorithms that use skin color and multi-component frameworks could be used to improve detection rates, and to detect different positions of the face in order to retrace the face while sleeping and doing sports. Furthermore, we can achieve additional goals in the future by adding neural networks or fuzzy logic after getting the signal. It will help the system to improve by comparing the results by itself and giving the best answer, with additional information about the health situation of the person being under testing. This system has a great flexibility to improve in the future to be more practical and reliable.
BIBLIOGRAPHY

1. Z. Wen Jun Jiang, "Real-time Quantifying Heart Beat Rate from Facial Video Recording on a Smart Phone using Kalman Filters".


3. Luis Felipe Jimenez, "EXTRACTING HEART RATE AND RESPIRATION RATE USING A CELL PHONE CAMERA".


38. Sungjun Kwon, Validation of heart rate extraction using video imaging, 2012.


41. Ming-Zher Poh1, Non-contact, automated cardiac pulse, 2010.
42. Rózanowski, "Robust Algorithm for Heart Rate (HR) Detection," Acoustic and Biomedical Engineering, 2010.
44. M. Baratchi, Measuring Hear Rate with Optical Sensor, 2014.
46. Udovichenko, Metrological support for measurement information systems and process control, 1996.
