IJIAET International Journal of Innovative Analyses and Emerging Technology

| e-ISSN: 2792-4025 | http://openaccessjournals.eu | Volume: 3 Issue: 9

Development of a System for Monitoring the Functional Parameters of the Heart Using a Smartphone

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Introduction

The detection, diagnosis and treatment of many human diseases based on changes in heart rate have a long history. Even today, heart rate measurement and continuous monitoring is becoming important not only for patients with various heart diseases, but also for healthy people. That's why mobile apps, web apps, and smart watches that detect heart rate are being widely produced around the world. They are being developed day by day to be more and more comfortable, light, cheap and even stylish. They also have many additional features, such as counting heart rate, measuring body temperature and blood oxygen saturation, calculating calories burned, measuring the distance traveled, displaying the location, saving data and sending it to the desired device (phone, tablet, computer, server etc.) supports capabilities such as transmission and even calling an ambulance if necessary. In addition, monitoring systems with different capabilities are being developed for those involved in sports activities of various directions, and their capabilities are being improved more and more.

It should be noted that many developed human heart monitoring systems in the telecommunications market are primarily intended for business purposes. Also, the level of accuracy of the monitoring systems is limited due to the fact that the monitoring systems are focused on the low cost of detecting, calculating and monitoring the received signals.

The main part

FPG is an optical method used to determine changes in blood volume in the peripheral blood circulation through the skin using a pulse oximeter. It is considered a method of obtaining information about changes in the cardiovascular system using optical signals without harming the skin, and special applications based on this method are widely used worldwide in mobile devices, smart watches, gadgets and special devices, and are becoming very popular due to their ease of use. Using the FPG method, it is possible to calculate and monitor a number of physiological parameters such as heart rate, respiration rate, and tissue aging, as well as some changes in blood vessels and heart [2]. It is also possible to assess cardiovascular diseases such as hypertension and atherosclerosis with the help of signals received by special medical equipment based on the FPG method, and even get important information about the stiffness and elasticity of arteries. FPG sensors can also be used to record changes in the amount of blood circulation in small blood vessels of human tissues.

Researchers demonstrated that the FPG method can be used to study blood volume in 1936 by two research groups (Molitor and Knyazuk of the Maersk Therapeutic Research Institute (MTITI) and New Jersey and Ganzlik of the Stanford University School of Medicine) independently measuring changes in blood volume flowing from the ears of rabbits. started Later, MTITI researchers demonstrated in a scientific experiment that it is possible to analyze the blood flowing from the blood vessels of a human finger using FPG sensors based on light reflection. In 1937, the use of the FPG method in humans was first performed by the scientist of the Department of Physiology of St. Louis University Medical School, Alrik Hertzman. In 1940, Hertzman and Dillon, researchers from the Department of Physiology, divided current into alternating (AC) and direct (DC) components and observed zomotor activity using a separate electronic amplifier for each of them. As a result of the experiments, Gertsman found that the error in the FPG technique is that the poor contact between the sensors and the skin has a strong impact on the signal quality. But pressing the sensor against the skin with too much pressure proved to be ineffective. Also, the scientists discovered during their research that the sensors should be stationary over the area under investigation, any movement or displacement could lead to errors. The results of the observations and researches led to the development of the sensor devices that are widely used today.

In recent decades, with the increasing demand for small-volume, high-accuracy, low-cost, and easy-to-use technologies that provide information about the cardiovascular system without disturbing the integrity of the skin, photoplethysmography has been extensively researched. Advances in optoelectronics and clinical devices have contributed significantly to the development of FPG. Today, a lot of scientific work is being carried out to further improve the FPG method, reduce noise, and analyze the received signals. The FPG method is being widely used in the analysis of heart activity, in the detection of heart diseases, in the correct diagnosis of diseases, and in the study of biosignals for other purposes.

During each cardiac cycle, the blood pumped by the heart through the veins is distributed throughout the human body, and during each cardiac cycle, the volume of blood flowing through the body has a different volume. Therefore, the process of detecting the heartbeat by absorption of a light signal into a vessel is not uniform: it is directly proportional to the volume of blood, that is, more volume causes more blood to be absorbed, or vice versa (Fig. 2.1). So, the change of absorption intensity over time corresponds to the heartbeat rhythm. Also, light absorption varies depending on the blood composition: more or less light can be absorbed depending on the amount of light-absorbing substances (glucose, oxygen, etc.) in the blood. The process of determining cardiac activity with FPG can be done in two ways:

1. The FPG method is a method based on light absorption, if the sensors record the part of the light beam that has passed through the tissue.
2. Or if the sensors record the part of the light beam reflected from the tissue, then the FPG method is a method based on light reflection.

Infrared, red and blue light-emitting diodes are usually used for devices based on such methods. But since infrared and red rays are absorbed a lot in skin tissues, they cannot reach the blood vessels well, and the accuracy of the obtained results may decrease. Therefore, the use of blue or green light in the FPG method increases the accuracy of the result.

Vascular changes in the human body can be detected from several points, for example, the shoulder, chest, fingers, wrist and other points according to the methods proposed by the manufacturers. Figure 2.1 shows the process of determining the functional changes of the cardiovascular system depending on the changes in blood flow in the finger.

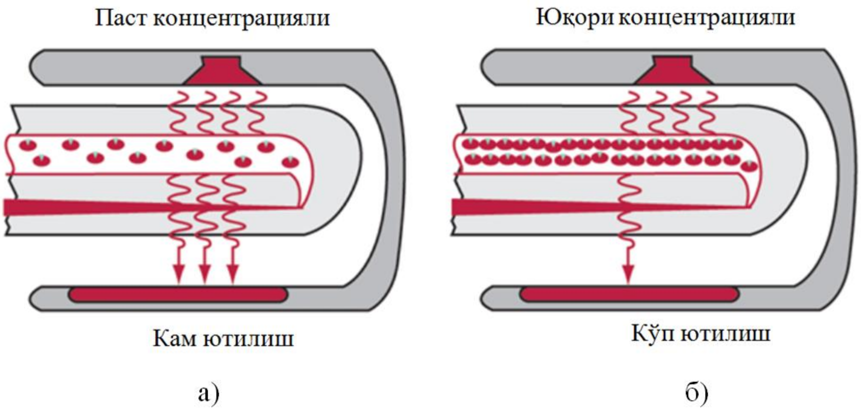

Figure 2.1. Principle of operation of pulse oximeter. Changes in light absorption depending on the change in blood flow volume: a) low absorption corresponding to low volume, b) high absorption corresponding to high volume

Typically, in a light emitting diode, signals are generated using a modulated electrical signal and the effects of interference from low-frequency noise in the signal are reduced to the desired level. Modern FPG sensors use low-cost semiconductor technologies: LEDs and corresponding photodetectors. Typically, these LEDs and photodetectors operate in the red or near-infrared wavelength range. Bebster provides basic information about optical sensors used for FPG and pulse oximeters in his review article [4]. The correct choice of light source is very important in the fabrication of FPG sensors and in the processing of biosignals using FPG sensors during the study of cardiac activity (Burke and Whelan, 1986, Lindberg and Oberg, 1991; Ugnel and Oberg, 1995). LED technologies convert electrical energy into light energy and have a very narrow frequency band (typically 50 µm). LED technology is small, the service life is very long (>105 hours), the maximum value of the spectrum shifts by a very small amount during a large temperature change. The average intensity of LED technologies should be kept constant, that is, kept at the lowest minimum value. Because this is the only way to effectively prevent overheating and injury of local skin tissue. At the same time, the correct choice of photodetector is also an important task (Weinman and Fine, 1972, Fine and Weinman, 1973). Since the photodetector converts light energy into electrical energy, it is very important that its spectral characteristics match that of the light source.

It is worth noting that since FPG sensors reflect functional changes of the cardiovascular system based on optical signals, they also record ambient light, which means they have a very high noise level. That is why special noise reduction filters have been developed in devices based on the FPG method. Figure 2.2 below illustrates the process of signal processing in the FPG method.

During their research, Dorlas and Nijbur found that the volume of blood pumped by the heart in one minute is directly proportional to the systolic amplitude of blood vessel expansion. They also proved that it is more convenient to determine the heart rate by the systolic amplitude than by the pulse arrival time for the assessment of chronic blood pressure. Since each heartbeat causes a different volume of blood to circulate throughout the body, the FPG signal takes on a pulsatile physiological pattern that represents the synchronous changes of the heart. In this case, next to the main vibrations, we can see small fluctuations, which are low-frequency vibrations caused by breathing, thermoregulation, the nature of skin tissues, and other factors.

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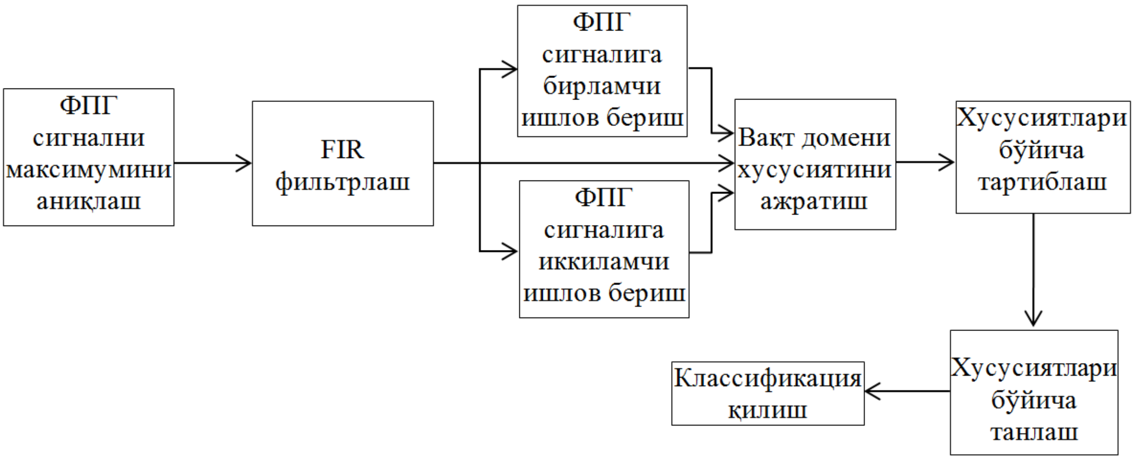

Figure 2.2. FPG signal processing.

The FPG pulse is usually divided into two parts: an increasing anachronic phase at the edge of the pulse and a decreasing catacrotic phase at the edge of the pulse. The FPG signal consists of systolic (systolic), diastolic (diastolic) and external wave phases. As can be seen from Figure 2.3 below, the dicrotic notch occurs in the catacrotic phase with healthy arteries, and the systolic amplitude (x) is indicative of pulsatile changes in arterial blood flow around the measurement site. Systolic amplitude depends on the volume of pumped blood.

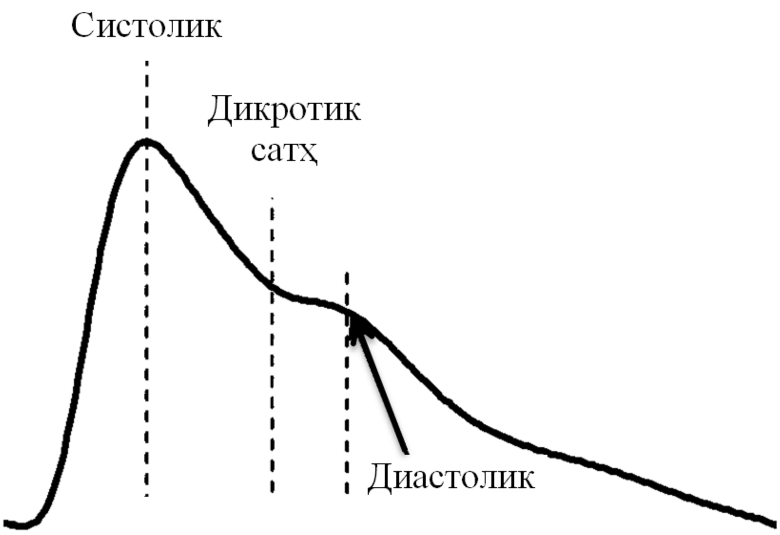

Figure 2.3. Overview of the FPG signal

At the same time, based on the FPG method, it is possible to calculate the number of heartbeats, determine blood pressure and find out other symptoms of diseases. However, the FPG method has the following disadvantages:

- The structure of the system based on the FPG method will have a very complex appearance. This requires additional time and additional equipment to calculate the required parameter;
- Since the devices are based on neural networks or fuzzy systems, they require special skills from the researcher (the filtering itself consists of several stages, the topology of the neural network is very complex, etc.) or it is required to coordinate certain variable parameters (for example, the color of the human skin absorption intensity changes depending on);

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- Compatibility with some devices is not up to the mark, for example, due to extreme cold or wind, the data provided by the sensors working with the FPG device or the device support may be incorrect.

Conclusion

In this research work, the capabilities of devices and systems developed by the world's leading scientific research institutions and manufacturers for the purpose of monitoring cardiovascular functional changes were studied and analyzed. The models, operation process, types and services provided by these systems were discussed and compared and analyzed. In the research work, the following practical issues were resolved during the analysis of hardware and software tools processing ECG and FPG signals:

1. Information about various parameters of cardio-signals and their characteristics were given.
2. The capabilities of software and hardware used in cardio-signals were analyzed.
3. Application areas and models of ECG signal processing application packages, analytical software tools, hardware and software tools used in ECG signal filtering were developed.
4. Algorithms of ECG signal processing have been widely developed.

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