PORTABLE PHOTOPLETHYSMOGRAPHY
SYSTEM FOR BIOMEDICAL RESEARCH

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We analyze ways to improve photoplethysmography instrumentation. We propose a 5-channel portable photoplethysmography system based on a notebook personal computer (PC), making it possible to digitize and analyze pulse curves for humans and animals using interactive dialog PC software under both stationary and field conditions for scientific and industrial purposes.

The change in peripheral blood circulation and the change in vascular tone in normal and pathological states of the organism is of great theoretical and practical value in biomedical research for diagnostics of cardiovascular diseases. The photoplethysmography method, based on recording and analyzing pulse curves, is an important instrumental method for studying human and animal cardiovascular systems [1].

Based on analysis of ways to improve photoplethysmography instrumentation, below we propose a 5-channel system making it possible to expand the possibilities for biomedical research on the cardiovascular system of biological objects.

Photoplethysmography is a noninvasive method for studying congestion in living tissues of the organism, based on recording oscillations in the optical density of the tissues due to operation of the heart, respiration, and the action of various physiological factors in the living organism. The operating principle of the photoplethysmograph involves irradiating the tissues with a source of radiation (most often infrared (IR)) followed by a photodetector registering the portion of this radiation reflected by or passing through the tissue. The changes in optical density of the living tissue (the photoplethysmograms) are due to pulsations of the blood in the peripheral vessels of the biological object. The light intensity reflected or scattered by the tissue under study depends on the amount of blood contained in it. Since the absorption coefficient for absorption of IR radiation by the blood is significantly higher than the absorption coefficient for absorption by the tissue, only changes in the blood volume within the tissues are recorded by photoplethysmographs; and scattering of the radiation occurs mainly as a result of its reflection from the surface of erythrocytes. The photoplethysmogram is obtained by filtering out the constant (d.c.) component of the optical density of the tissue and the slow variations in congestion (cutoff frequency about 0.2–0.25 Hz). The recorded pulse curves reflect the rhythmic activity of the heart. The upper limit of the pass band for the amplifier channel is generally 40–50 Hz when recording photoplethysmograms for humans or large animals. By analyzing the informative amplitude vs. time parameters of the pulse curve and its first and second derivatives (such as the maximum amplitude, the rise rate of the leading edge, etc.), we calculate the basic hemodynamic indices characterizing the state of the cardiovascular system. Additional diagnostic information may be extracted from analysis of the frequency spectrum of the pulse curve. Recording and studying the slow variations in congestion also gives important information about the functioning of the systems of the organism (cardiovascular, respiratory, nervous, etc.).

Advantages of the photoplethysmography method include the fact that the measurement instrumentation on which this method is based makes it possible to obtain high sensitivity, linear calibration characteristics, high temperature stability of the measurement results, the capability of recording both the a.c. component of the pulse signal due to the operation of the heart as well as the d.c. component, depending on the average level of congestion in the tissues. Along with high-quality metrological characteristics, this instrument also has good service characteristics, such as small external dimensions and low power consumption of the probes, the capability of operating under 100% humidity conditions and in strong electromagnetic fields, no electrode contacts with the living tissue and hence also no electrical effects on the biological object under study, simple steril-
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Diagnosis: healthy  
Y = 165, X = 3474  
Y = 160, X = 3828

Fig. 1. Hard copy of the display on the monitor screen of the PC with recorded photoplethysmograms of an examined subject, with comments.

ization and convenient attachment of probes so there is little effect on the blood supply to the tissues, which is especially important during prolonged monitoring of the physiological state of the biological object (contactless data recovery is also possible).

At the same time, this method has a number of disadvantages: the sensitivity to motion artefacts; the effect of external light sources; the dependence of the probe signal on the state of the skin.

There are three ways to improve the metrological characteristics of photoplethysmographs:
using instrumental methods, by improving the circuitry of the measurement channel;
using mathematical software to process the measurement data on computers;
improving the probe design.

The first method presumes the use of microcircuitry, placing the buffer preamps as close as possible to the photosensors, and using amplifiers with modulation/demodulation of the signal.

The second method involves digitizing the photoplethysmographic data, which allows for further processing using special-purpose microprocessors or general-purpose personal computers. Then we can use all the algorithmic software developed earlier for analysis of digital measurement signals [3,4] for processing the photoplethysmograms.

Now let us consider the basic ways to improve the probes. The effect of external illumination and line noise is considerably reduced by going from a d.c. power supply for the radiation source of the probe to a pulsed power supply with a frequency of a few kilohertz, followed by selective amplification of the amplitude-modulated (proportional to the congestion in the tissues) light flux converted by the photodetector [5,6].

Adding an additional photodetector to the probe makes it possible to stabilize the light flux of the radiation source, and also to tune out artefacts connected with the state of the skin surface of the biological object [7–9].

The quality of the recorded photoplethysmogram mainly depends on the way the probe is adjusted (pressure, point of attachment, misalignment, etc.). In particular, when the probe is pressed very hard against the skin, the amplitude of the recorded pulse curve considerably decreases and its individual sections are smoothed out. To reduce the errors depending on the force of such pressure, we use probes with metered pressure on the tissue, with a spring-controlled section of the probe on which an optocouple is attached, or we use contactless signal recovery from the photodetector. This is important when there are pathological changes on the surface of the tissue under study (burns, trophic ulcers, etc.).