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Method of Photoplethysmography Diagnostics of Domesticated Animals Cardiovascular Diseases

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Abstract

At present time the standard procedure to diagnose cardiovascular diseases (CVD) of domesticated animals (dogs) is electrocardiography (ECG) monitoring at animal clinic. Sadly, results, obtained that way, are often mistaken because of stressful state of the animal, caused by medical manipulations [1]. The usage of photoplethysmography (PPG) method can become a good substitute for CVD monitoring. Main advantages of PPG, in compare with ECG, are single probe placement (on the ear or tailset), no need of gel electrodes and capability of measuring actual CVS parameters without need of special medical training or laboratory conditions. It is one of non-invasive methods for measuring the amount of the blood volume changes inside the blood vessels, applicable for cardio activity estimation by calculating heart rate variability. In most cases, PPG monitoring devises are small, easy to place and can monitor different physiological parameters of the animal, such as heart rate, pulse wave characteristics, blood oxygen saturation, etc.

Keywords Cardiovascular diseases; Health monitoring systems; Photoplethysmography; Pulse wave; Remote diagnostics

Abbreviations

PPG: Photoplethysmography; CVD: Cardiovascular Diseases; LED: Light-Emitting Diode; CVS: Cardiovascular System; ECG: Electrocardiography

Ethic Statement

All experiments with the dogs were carried out in strict accordance with the directive of the Ministry of Health and Social Development of the Russian Federation dated 23 August 2010 #708n "On approval of the laboratory practices". The protocol was approved by the Committee on the Ethics of Animal Experiments of the Immanuel Kant Baltic Federal University (Order Number: 347-12).

Introduction

PPG-based sensors for physiological parameters measurements becomes progressively more popular in human medicine [2], but still yet to be used for CVS monitoring of animals. The principle behind PPG sensors is optical detection of blood volume changes in the microvascular bed of the tissue [3]. The sensor system consists of a light source and a detector, with red or infrared light-emitting diodes (LEDs) commonly used as the light source. PPG sensor detects the changes in intensity of transmitted or reflected light. The changes in light intensity are associated with small variations in blood perfusion of the tissue and provide information on the cardiovascular system; in particular, the pulse rate and pulse wave [4].

The principle behind PPG is the fact that light travelling though biological tissue can be absorbed by different substances, including pigments in the skin, bone, and arterial and venous blood. Most changes in blood flow occur mainly in the arteries and arterioles [5]. Arteries contain more blood volume during the systolic phase of the cardiac cycle than during the diastolic phase. PPG sensors optically detect changes in the blood flow volume (i.e., changes in the detected light intensity) in the microvascular bed of tissue via reflection from or transmission through the tissue [6].

Photoplethysmogram, obtained by optical methods, has the following groups of characteristics:

1. Amplitude, associated with anacrotic and dicrotic cardial periods. Despite the fact of relativity nature of that parameters, its dynamics gives valuable data about vascular reaction process during some short-term affecting factor.

2. Periodic, that represents data about cardiac cycle rate and heartbeat rate, correlation and time of systole, diastole and its phases. That data has absolute values and can be compared with respective reference values. In this group such parameters like time delay between anacrotic and diacrotic phases of the pulse wave, its period, pulse wave rising edge index, systole phase filling time, duration of systolic and diastolic phases and heart rate are measured.

3. Statistic, showing the variability of amplitude and heart beat rate during long periods of time (minutes).

4. Calculated parameters based on previous data values. This group consists of: dicrotic wave index, representing the position of dicrotic peak relatively to anacrotic peak; anacrotic to dicrotic periods ratio.

Calculation of the aforementioned parameters allows to diagnose both instant body responses to environmental physical factors and to detect hemodynamics changes during long periods of time, that way estimating the CVS state in a whole.

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Materials and Methods

The interaction of light with biological tissue can be quite complex and may involve scattering, absorption and/or reflection [5]. Within the visible region, the dominant absorption peak corresponded to the blue region of the visible spectrum, followed by the green-yellow region (between 500 and 600 nm) corresponding to red blood cells. The shorter wavelengths of light are strongly absorbed by melanin. Water absorbs light in the ultraviolet and longer IR spectrum; but, red and near-IR light pass with ease. So, IR wavelengths have been used as a light source in PPG sensors.

Blood absorbs more light than the surrounding tissue. Therefore, a reduction in the amount of blood is detected as an increase in the intensity of the detected light. The wavelength and distance between the light source and photo detector (PD) determine the penetration depth of the light [7].

The wearable PPG has two modes-transmission and reflectance as shown in Figure 1. In transmission mode, the light transmitted through the medium is detected by a PD opposite the LED source, while in reflectance mode, the PD detects light that is back-scattered or reflected from tissue, bone and blood vessels (Figure 2).

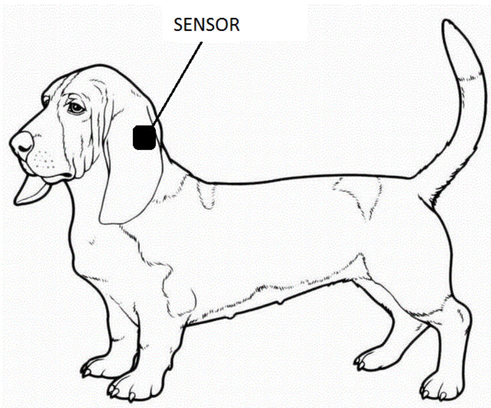

Figure 1: PPG sensor location on the body of the dog.

Transmission-mode PPG is affected by motion artifacts and pressure disturbances. Any movement of the dog, such as physical activity, may lead to motion artifacts that corrupt the PPG signal and limit the measurement accuracy of physiological parameters. Pressure disturbances acting on the probe, such as the contact force between the PPG sensor and measurement site can deform the arterial geometry by compression. Thus, in the reflected PPG signal, the amplitude may be influenced by the pressure exerted on the skin.

On the contrary, reflectance mode is capable of obtaining a relatively good signal. To be effective, the sensor must be located on the body at a site where transmitted light can be readily detected, for example, on the earlobe (Figure 1). Movement artifacts distortions can be mitigated by careful selection of sensor placement and signal post processing.

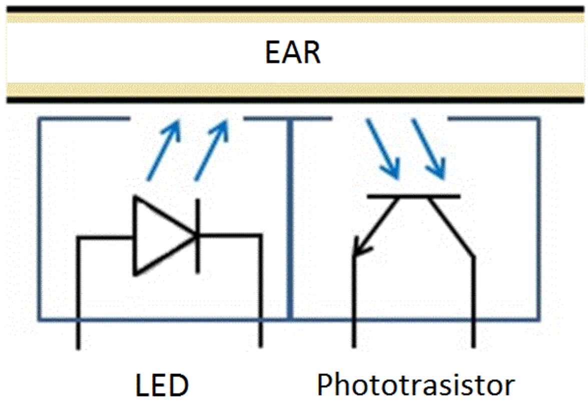

Figure 2: Light-emitting diode and photodetector placement for reflectance-mode photoplethysmography.

Results and Discussion

Intensity of light, being dissipated by the measuring site tissue, reflects the quantity of blood in tissue in real time, monitoring quantitative and qualitative dynamics of consequential changes of blood volume in measuring site during each cardiac cycle all the time of the measurement [5].

Pulse wave consists of 2 parts, representing anacrotic and dicrotic phases, respectively (Figure 3).

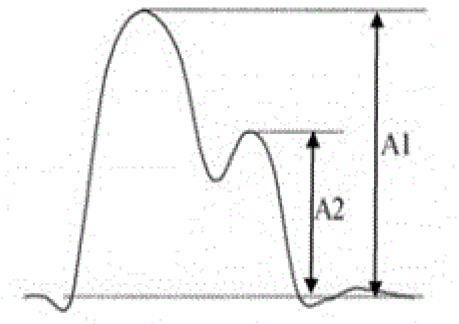

Figure 3: Photoplethysmogram of the pulse wave.

First peak of the pulse wave concerned with systole period (A1). Amplitude value in anacrotic phase, also called pulse wave amplitude, corresponds to cardiac output blood volume. It gives indirect data about inotropic effect.

First peak of the pulse wave concerned with diastole period (A2). Dicrotic phase gives data about vascular tone.

The peak of pulse wave corresponds to maximum blood volume in the measurement site, and its opposite part represents minimum. Characteristics of the pulse wave depend of vascular wall rigidity, heart rate, volume of measurement site, blood vessel width. It is suggested, that rate and period of the pulse wave depends of cardio activity characteristics, so it is possible to estimate the health status of the dog.

After researching different PPG methods, the reflective method was chosen. This mode, comparing to transmission mode, seems to be optimal solution for animals, because there is no need to develop any gear for aligning the light source and detector, and calibrate the distance between light transmitter and receiver. Besides, the size of the transmission-type PPG device will be substantively bigger.

Different stages of signal processing are shown on Figure 4. PPG data was obtained during 1-month period and then averaged by key points. Selection consists of 500 measurements. Signal processing includes band pass filtering, squaring and derivation. Figure 4a shows reference ECG signal. Figure 4b shows initial PPG signal after hardware-software filtering. Characteristics of the signal then can be amplified by squaring. Figure 4c shows squared signal. Finally, derivation of the squared signal is calculated. End result shown on Figure 4d.

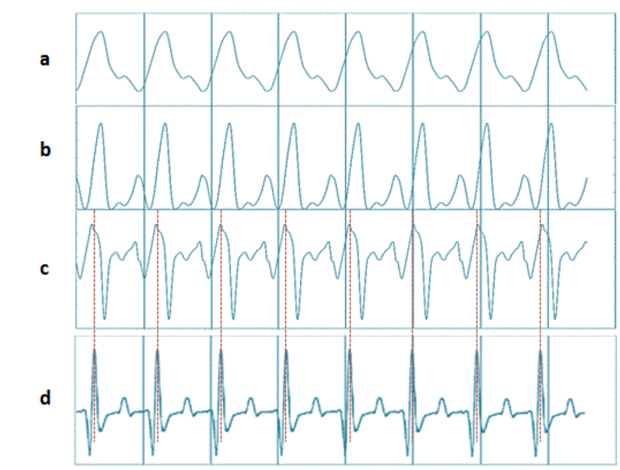

Figure 4: PPG signal processing. **Figure 4a:** Initial PPG signal. **Figure 4b:** Squared signal. **Figure 4c:** Derivation result. **Figure 4d:** Reference ECG signal.

Cardiac contraction (R-peak) of ECG signal does not correspond with the beginning of the blood pressure wave. The reason is that ECG R-peak reflects electric excitation of cardiac muscle. It takes a certain amount of time for the muscle to respond, develop enough pressure to open the aortal valve and actually form a pulse wave spreading along blood vessels. But, in most cases it is suitable to use R-peak as reference point for measuring time of pulse wave periphery arrival. The characteristic point of the PPG pulse wave is a moment when pulse wave reaches the earlobe. Therefore, Figure 4 illustrates the method of R-peak extraction from the PPG signal. Dashed lines indicate the moment of heart contractions, detected via ECG standard R–peak searching method. Dashed lines also show compliance of ECG R–peaks and pulse wave maximums of PPG derivation graph.

A solid correlation between PPG pulse-to-pulse interval and ECG peak-to-peak interval was shown. It proves the capability to use PPG signal for measuring CVS parameters as effective as ECG signal does, so PPG is suitable for diagnosis CVD of dogs. Developed PPG detector designed as a clip with LED and phototransistor. The clip was then positioned on dog's earlobe and output signal from phototransistor was processed and analyzed to obtain parameters required. Results of experiments confirm stability of measured signal and low level of movement artifacts distortions. There is a potential for future development of sensor design and signal-processing algorithm.

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