Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 86 (2017) 72 – 80

Physics Procedia

International Conference on Photonics of Nano- and Bio-Structures, PNBS-2015, 19-20 June 2015, Vladivostok, Russia and the International Conference on Photonics of Nano- and Micro-Structures, PNMS-2015, 7-11 September 2015, Tomsk, Russia

Origin of photoplethysmographic waveform at green light

Alexei A. Kamshilin*,Nikita B. Margaryants

Department of Computer Photonics and Videomatics, ITMO University, St. Petersburg, 197101, Russia

Abstract

In this article we analyze a number of observations obtained with the reflection-mode photoplethysmography (PPG), which can hardly be explained by commonly accepted model of the PPG-signal formation. It is shown that the physiologic model of light interaction with living tissue recently proposed by our group provides reasonable explanation of all observations. According to this model, it is pulsatile transmural pressure of the arteries, which compresses/decompresses the density of capillaries in the dermis, thus modulating the blood volume in the capillary bed, which in its turn modulates the power of remitted green light.

Peer-review under responsibility of the organizing committee of PNBS-2015 and PNMS-2015.

*Keywords:*photoplethysmography;blood pulsation imaging; amplitude distribution of blood pulsation

1. Introduction

The term “plethysmography” stems from two ancient Greek words “plethysmos” which means increase, and “grapho” which is the word for write. In medicine this term is commonly used to define process of determination and registration of blood volume changes in a live body. Hertzman was first who introduced in 1938 the term of photoplethysmography (PPG) to describe a non-invasive optical technique capable for transcutaneous registration of blood volume changes in the blood vessels (Hertzman(1938)). Underlying principle of PPG is the empirical observation that the light transmitted through (or reflected from) the living tissue obtains a modulation in time at the heartbeat frequency(Hertzman and Spealman(1937)). The

* Corresponding author. Tel.: +7-812-571-65-34
E-mail address: alexei.kamshilin@yandex.ru

Peer-review under responsibility of the organizing committee of PNBS-2015 and PNMS-2015.
doi:10.1016/j.phpro.2017.01.024

technique is very simple and cost efficient because it requires only two elements, a source of incoherent light (even natural illumination can be used) and a photoreceiver for implementation. Due to these advantages, an optical device for measurements of arterial blood oxygen saturation (pulse oximeter) was invented in 1972 by Takuo Aoyagi(Severinghaus and Honda (1987), Aoyaqi(2003)). Pulse oximeters became commercially available since 1983. Today these devices are adopted for carrying out the standard procedure of oxygen saturation estimation in numerous clinics worldwide. In addition, pulsatile variation of the signal in PPG sensors is commonly used for measuring the heart rate. Notably that the heart-rate estimations today can be provided by using ubiquitous smartphones (Jonathan and Leahy(2010)). Starting from the year 2000, when the first system of noncontact imaging photoplethysmography (iPPG) was proposed by (Wu et al.(2000)), there is rapid growth in the literature pertaining to PPG technique and its applications motivated by advances in technology of optoelectronic devices and digital signal processing. However, despite of the long history in PPG research, the detailed mechanism behind the phenomena of the light modulation caused by cardiovascular activity is still a matter of debate. Is it change of blood volume or blood pressure, which primarily affects the parameters of light?

In this paper we discuss existing models of light interaction with a biological tissue *in-vivo* drawing attention to recent experimental observations using iPPG systems, which are hardly explained in frames of the generally accepted model. Our opinion is that the recently proposed model(Kamshilin et al.(2015b)), which takes into account elastic deformation of the dermis by big blood vessels, more correctly describes the origin of light modulation.

2. Conventional model of PPG-waveform origin

2.1. Inverse relationship between blood volume and light intensity

In any PPG experiment, a biological tissue is illuminated by an incoherent light source, and the power of light either transmitted through or reflected from the tissue is measured by a photo-detector. Correspondingly, there are two modes of PPG systems: transmitting and reflectance(Nijboer et al.(1981)). In the transmitting mode of operation, the light source and photoreceiver are situated opposite each other with transilluminated vascular tissue between them. In the reflectance mode, the detector and light source are placed side by side to monitor the light remitted from the tissue. Basing on the experimental observations, the most of researchers is of the opinion that the light intensity registered by the photodetector is inversely related to the blood volume in the tissue (Hertzman (1938), Nieveen et al.(1956), Weinman et al.(1977), Roberts (1982), de Trefford and Lafferty (1984) Reisner et al.(2008)).This mechanism is not difficult to understand in the transmitting-mode PPG in the case of using near-infrared (NIR) light. Tissue is less opaque than the whole blood and, consequently less light goes through the transilluminated tissue and reaches the photodetector when the blood volume increases and vice versa. It is less obvious why the inverse relationship between remitted light power and blood volume should hold in the reflectance-mode PPG although experimental evidence seems to support this standpoint. In the latter mode, displacement of vessel wall may affect the light modulation (Weinman et al.(1977)). Moreover, it is not clear how efficient is light interaction with arterial blood in the reflection mode. Nevertheless, it was generally accepted that both modes of PPG measure blood volume variations in the vascular bed (Jago and Murray, (1988), Nitzan et al.(1998), Loukogeorgakis et al.(2002), Khanoka et al.(2004), Shelley et al.(2005)).Sometimes the PPG technology is even referenced to as pulse volume monitor(Kim et al. (1986), Murray and Foster (1996), Millasseau et al. (2006), Selvaraj et al.(2008), Cenini et al.(2010)).