Use of circular polarization in imaging photoplethysmography

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Imaging photoplethysmography (iPPG) is a very promising method for evaluating hemodynamic parameters *in vivo*, especially for visualizing and quantifying changes in organ perfusion during surgical operations [1,2]. An important element of the iPPG optical system is polarization filtering, usually implemented by means of two crossed linear polarizers. One of these polarizers is installed after the illuminator and serves to illuminate the organ under study with incoherent linearly polarized light. Another polarizer is attached to the camera lens. Its transmission axis is adjusted to be orthogonal with that of the first polarizer. Since red blood cells (RBC) are highly anisotropic, after interacting with them, the light acquires elliptical polarization. Such polarization filtration reduces the effect of both skin specular reflections and motion artefacts on the detected iPPG signal, thereby increasing the signal-to-noise ratio [3]. However, such a scheme has a practical disadvantage due to the need to adjust the polarization filter, which is not always feasible in an operating room.

Here we propose to implement polarization filtering using only one optical element, namely a circular polarizer combined with a linear one. Such type of polarizing filters is widely used in photography to reduce specular reflections and is known as a CPL-filter. In our iPPG module, eight or more light-emitting diodes (LED) are positioned around the camera lens to ensure proper illumination of the organ under study. The CPL filter covers both the lens and all LEDs in such a way that the light emitted by the LEDs first hits the side of the CPL filter with a linear polarizer. In such a configuration, the subject's skin is illuminated by circularly polarized light, the polarization of which remains circular after specular reflection from the skin, but with the opposite rotation, thereby preventing the reflected beam from passing through the CPL-filter and reaching the sensor of the camera. On the contrary, after interacting with RBCs, the light becomes elliptically polarized and passes through the CPL-filter. Therefore, CPL-filter provides filtering of specular reflections in a similar way, as a pair of crossed linear polarizers does. The advantages of using CPL filters in iPPG systems are: (i) no adjustment is needed, and (ii) easy integration into small-aperture optical systems, such as endoscopic and laparoscopic [4].

We have carried out a comparative study of polarization filtration provided by crossed linear polarizing filters and CPL filters when visualizing and quantifying perfusion distribution in subject's forearm. It was found that both schemes provide an increase in the signal-to-noise ratio of the iPPG signal compared to using nonpolarized light: by 36% and 44% for cross-polarized and CPL filtering, respectively.

In addition, the contrast factor (ratio of transmitted-to-suppressed light intensity) provided by CPL-filter is greater (1900 : 1) or at least not worse that contrast provided by the cross-polarized filtering (1550 : 1). Thus, the CPL-filter is not inferior to the cross-polarization filters in efficiency, its usage in iPPG systems is more advantageous, while parameters of CPL filter (thickness, light transmission, resistance to high temperature, supporting a coverage both light source and camera) open the possibility its application for polarization filtering of the photoplethysmographic signal in the iPPG laparoscopic systems [4].

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[1] O.V. Mamontov, A.V. Shcherbinin, R.V. Romashko, A.A. Kamshilin, Intraoperative imaging of cortical blood flow by camera-based photoplethysmography at green light, Applied Sciences, vol. 10, p. 6192, (2020).

[2] A.A. Kamshilin, V.V. Zaytsev, A.A. Lodygin, V.A. Kashchenko, Imaging photoplethysmography as an easy-to-use tool for monitoring changes in tissue blood perfusion during abdominal surgery, Scientific Reports, vol. 12, p. 1143, (2022).

[3] I.S. Sidorov, M.A. Volynsky, A.A. Kamshilin, Influence of polarization filtration on the information readout from pulsating blood vessels, Biomedical Optics Express, vol. 7, pp. 2469–2474, (2016).

[4] V.A. Kashchenko, A.V. Lodygin, K.Y. Krasnoselsky, V.V. Zaytsev, A.A. Kamshilin, Intra-abdominal laparoscopic assessment of organs perfusion using imaging photoplethysmography, Surgical Endoscopy, vol. 37, pp. 8919–8929, (2023).