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Light-guided Dynamic Phantom to Mimic Microvascular for Biomedical Applications

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Abstract: we presented a dynamic phantom to mimic vascular changes in human body. The photoplethysmogram was simulated and validated on a multispectral imaging system. The phantom has promising applications to standardize biomedical technologies.

1. Introduction

Biomedical imaging plays a crucial role in modern clinical analysis, providing visualisations of body tissue. It enables non-invasive or minimum invasive diagnosis and offers real-time surgical guidance [1,2]. Optical phantoms are designed to mimic the optical properties of biological tissues. They are essential tools to simulate light distribution in tissues, validate the performance of optical imaging systems, and characterise optical spectroscopy [3]. With the development of portable and wearable health monitoring devices, there is a growing need for dynamic phantoms which can change the optical properties to mimic dynamic changes in the oxy- and deoxyhaemoglobin concentration in tissue. Some researchers developed liquid dynamic phantoms using blood components to mimic various oxygen saturation in blood [4]. However, human blood brings ethical considerations and limits the stability and shelf life of the phantoms. Besides, using an oxygen pump increases the complexity of the experimental setup. One approach to overcome these disadvantages is to insert a liquid-crystal display (LCD) layer into the solid tissue simulating phantom, which allows rapid changes in attenuation by applying different voltages to the LCD [5]. The performance of these phantoms is largely influenced by the scattering properties of the top layer phantoms since the attenuation of LCD is angular dependent. The geometry of the phantom design cannot simulate complex structures like vascular. In this work, we implemented a novel light guide-based dynamic phantom to overcome the abovementioned challenges. The phantom was characterised by 4 wavelengths. A photoplethysmography signal of a healthy person was generated by the dynamic phantom and tested by the camera. This dynamic phantom can be a helpful tool for calibrating and validating near-infrared spectroscopy devices.

2. Material and methods

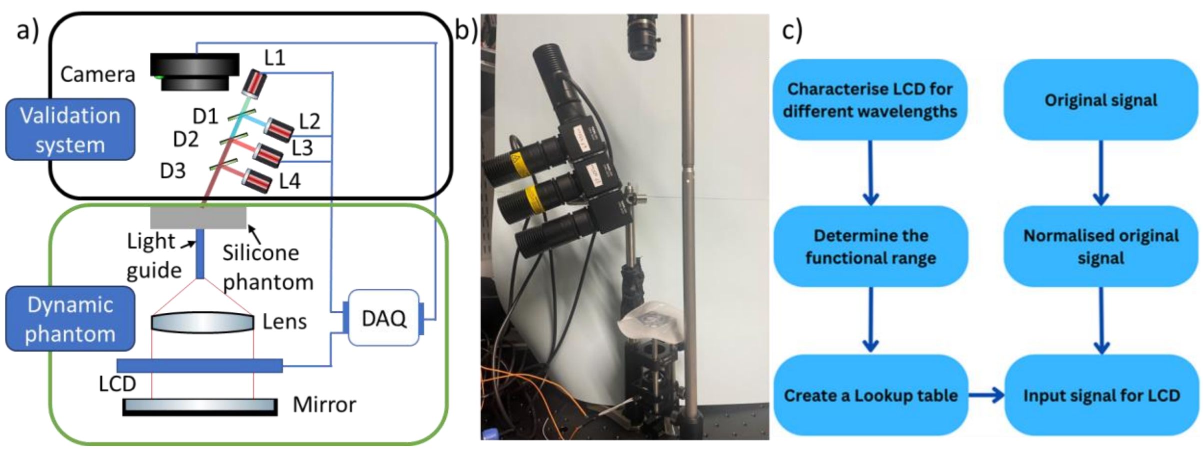

Fig.1. a) The schematic layout of the dynamic phantom and the validation system. L1: 530 nm (M530L4, Thorlabs), L2: 455 nm (M455L4, Thorlabs), L3: 660 nm (M660L4, Thorlabs), L4: 940 nm (M940L4, Thorlabs), D1: 490 nm longpass dichroic mirror (DMLP490R, Thorlabs), D2: 605 nm shortpass dichroic mirror (DMSP605R, Thorlabs). D3: 805 nm shortpass dichroic mirror (DMSP805R). b) The photo of the setup. c) The flowchart of generating input signal for the dynamic phantom.

Fig. 1.a) illustrates the schematic layout of the dynamic phantom together with the camera-based phantom validation system. For the phantom design, the light passed through the silicone-based tissue-mimicking phantom [6] was

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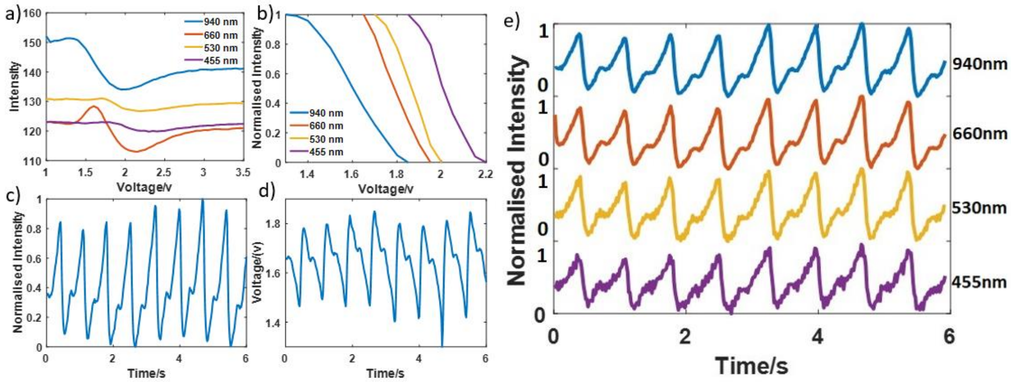

Fig.2 a) Phantom characterisation results in reflection mode. b) Rescaled signal from the dynamic phantom in the functional range. c) Rescaled PPG signal to be simulated. d) Input signal to modulate LCD for 940 nm. e) Normalised intensity measured by camera at 940 nm, 660 nm, 530 nm, and 455 nm.

collected by a 3 mm diameter polymer optical fibre (OMPF3000, The Optoelectronic Manufacturing Corporation (UK) Ltd.) and collimated by a condenser lens (ACL2520U, Thorlabs) to avoid the angular dependent performance of the LCD, then the light was modulated by a LCD (FOS-NIR (1100), LC-Tec Displays AB), after that the light was reflected to the surface of the phantom by a silver mirror (PF10-03-P01, Thorlabs). The phantom was characterised by 4 wavelengths: 455 nm, 530 nm, 660 nm, and 940 nm, covering both RGB and NIR ranges using an in-house illumination system. The system was validated by a monochrome camera (Flea3 FL3-U3-32S2M, FLIR) with a frame rate of 60 fps. The LCD, illumination system and camera were controlled by a NI DAQ (USB-6212, National Instrument). Fig. 1. b) shows the flowchart to generate the PPG signal. The phantom was characterised, and the functional range of the LCD of each wavelength was determined. Then a lookup table of voltage and attenuation was generated. A PPG signal of 6 seconds from a healthy person [7] was first rescaled to range 0-1 and then mapped to the lookup table to generate the modulation signal for LCD.

3. Results and discussion

Figure 2 presents the characterisation and validation results of the dynamic phantom. Fig. 2 a) shows that in a certain voltage range, the attenuation of the phantom was negatively correlated to the voltage, we defined that range as the functional range. The phantom responses were rescaled to range 0-1 and plotted in Fig. 2 b). Fig. 2 c) shows the rescaled target PPG signal, by mapping this signal to the phantom response in Fig. 2 b), the input signal for LCD was generated, which is shown in Fig. 2 d). Fig. e) shows the system validation results from the camera. The PPG signal can be reproduced by the dynamic phantom, while the noise is higher at 530 nm and 455 nm due to the weak response of LCD at these wavelengths. This dynamic phantom design can simulate different biological signals and has the potential to simulate vascular by arranging multiple light guides in the system.

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