Optical Characterization of Oximeters and Development Kits for Photoplethysmography

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Photoplethysmography (PPG) is a non-invasive method used to diagnose parameters associated with optical blood analysis. Equipment such as an oximeter utilizes this method to diagnose oxygen saturation. The present work aims to analyze and characterize devices for PPG and understand their operating principles through quantitative experimental tests. The conclusion of this study is expected to obtain information about the technical and constructive aspects of the optical system of some PPG devices.
Keywords: Photoplethysmography. Optics. Characterization. Devices.

Photoplethysmography (PPG) stands as a non-invasive technique utilized to discern variations in capillary and arterial blood volume by exploiting the interaction of light with human tissue, as highlighted in studies by Rochmanto and colleagues (2017) [1], and Tamura and colleagues (2014) [2]. The typical PPG signal comprises an alternating current (AC) component and a direct current (DC) component, from which vital information such as oxygen saturation and hemoglobin levels can be extracted. Total hemoglobin consists of four components: oxyhemoglobin, deoxyhemoglobin, methemoglobin, and carboxyhemoglobin, with their spectral curves well-defined and referenced in the works of Yoon and Jeon (2005) [3] for hematological component analysis.

An oximeter is a non-invasive sensor that employs the PPG method to measure oxygen saturation. This device relies on optical transmission principles, wherein the emitting source and the signal acquisition sensor are positioned on opposite surfaces. Light-emitting diodes (LEDs) in the red and infrared range typically serve as the emitting source. At the same time, the signal acquisition sensor is commonly a photodiode sensitive to the same wavelength range as the transmitted light.

Currently, pulse oximeters employ optical reflection techniques, where both the emitting source and the signal acquisition sensor are situated on the same surface. The acquisition sensor typically consists of a photodiode similar to those utilized in transmission oximeters. In addition to utilizing LEDs emitting in the red and infrared ranges, these pulse oximeters may incorporate a green LED.

Moreover, for studying purposes without a need for medical validation, development-kits can be used to analyze PPG signals. These kits generally employ reflection-based devices with optical configurations like pulse oximeters. The ensuing tests aim to analyze and characterize several PPG devices while comprehending their operational principles. For this purpose, two development kits were selected for testing: one manufactured by AMS and the other by Analog Devices, alongside a pulse oximeter produced by Multilaser.

Materials and Methods

The optical characterization of the devices involved conducting two quantitative experimental tests: acquiring the spectral curve of the LEDs and surveying the optical emission signal over time.

The devices under characterization included the development kits AS7057_EVK_UG001039

Received on 22 January 2024; revised 6 May 2024.
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J Bioeng. Tech. Health 2024;7(2):117-120

from AMS and the EVAL-ADPD4100Z-PPG from Analog Devices, which utilize the reflection principle, and the HC261 oximeter from Multilaser, which operates on the transmission principle. Figure 1 illustrates an enlarged image of the optical components of these devices. For the first test, the experimental setup comprised an optical fiber from Ocean Optics, an AvaSpec-2048 spectrometer from Avantes, and the AvaSoft8 acquisition software. The light sources analyzed were the LEDs integrated into the devices.

The experimental setup for the second test consisted of employing an Ocean Optics optical fiber connected to a Thorlabs SM05PD2A silicon photodiode, a Thorlabs AMP 120 trans-impedance amplifier, and a Tektronix oscilloscope, model TDS1001B. Figure 2 depicts the experimental acquisition system for the first and second tests.

Results and Discussion

Figure 3 depicts a graph illustrating one of the spectral curve measurements acquired for the infrared LED from the AMS development kit. This graph facilitates the determination of the wavelength of the emission peak. Table 1 summarizes the measured peaks across the devices for each LED (green, red, or infrared).

Figure 4 is the PPG optical signal from the AMS development kit analyzed on the oscilloscope. It is possible to extract information such as pulse width and emission frequency of the light signal through this signal. This information was not found in the datasheets of these components. Table 2 describes the results obtained for all devices analyzed in this study.

Figure 1. Enlarged image of the LED and sensor area of the AS7057_EVK_UG001039 kit (A) and, the EVAL-ADPD4100Z-PPG Kit (B) and the HC261 Oximeter (C).

A B C

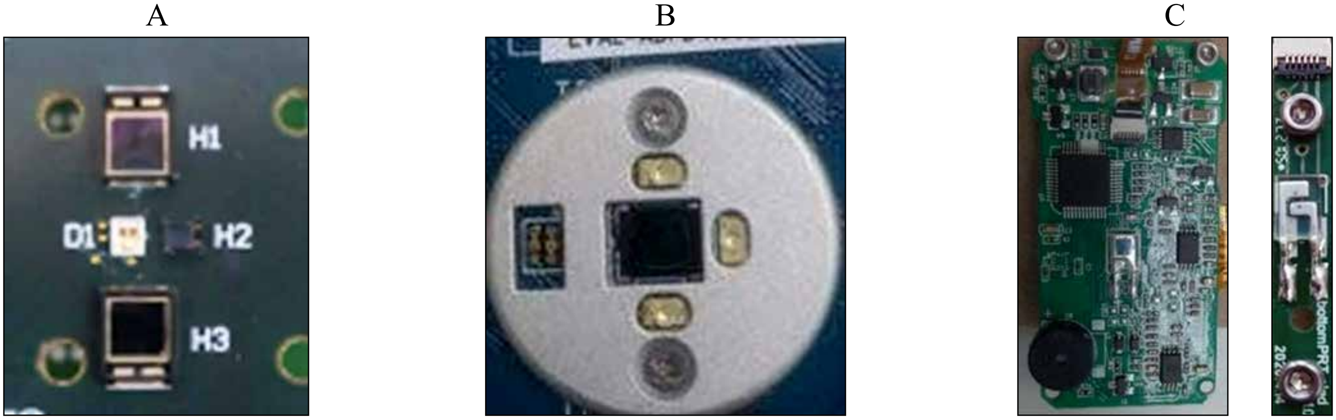
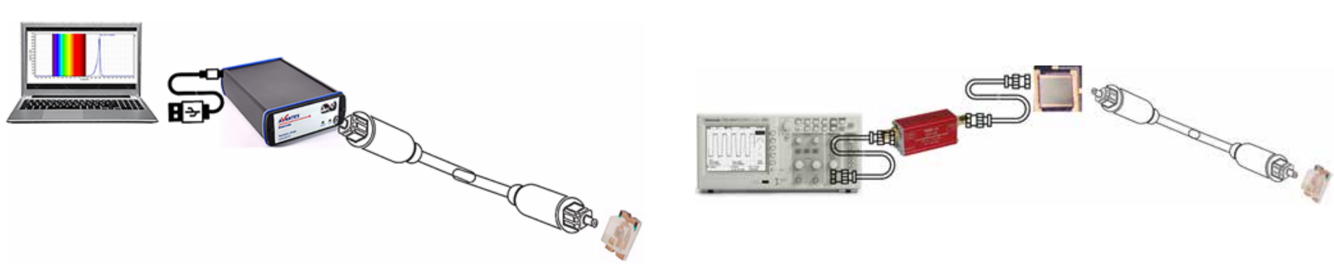


Figure 2. Experimental acquisition systems for spectral curve acquisition tests (A) and signal analysis optical (B).



A B

Figure 3. Spectral curve of the infrared LED.

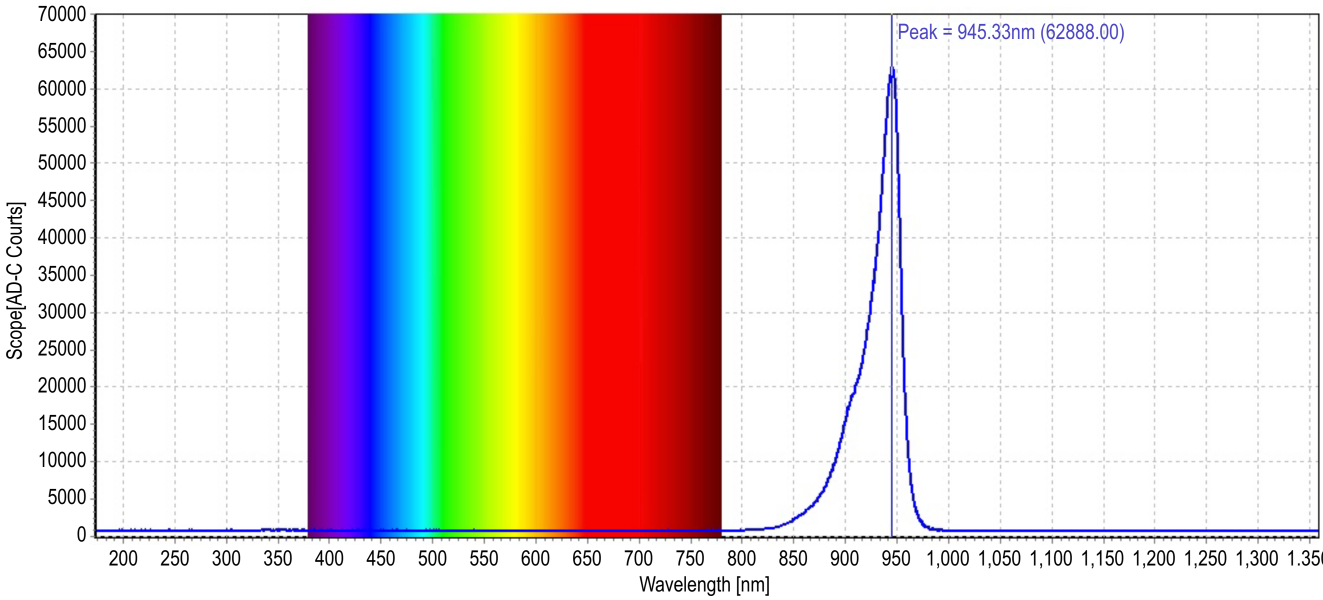


Table 1. Peak emission values of LEDs.

Device	Green LED		Red LED		Infrared LED	
	Measured	Datasheet	Measured	Datasheet	Measured	Datasheet
AS7057_EVK_UG001039	521 nm	526 nm	657nm	660nm	945nm	950nm
EVAL-ADPD4100Z-PPG	515 nm	520nm	660nm	640nm	938nm	940nm
Oximeter	x	x	659 nm	660 nm	889 nm	880 nm

Figure 4. PPG optical signal read on the oscilloscope.

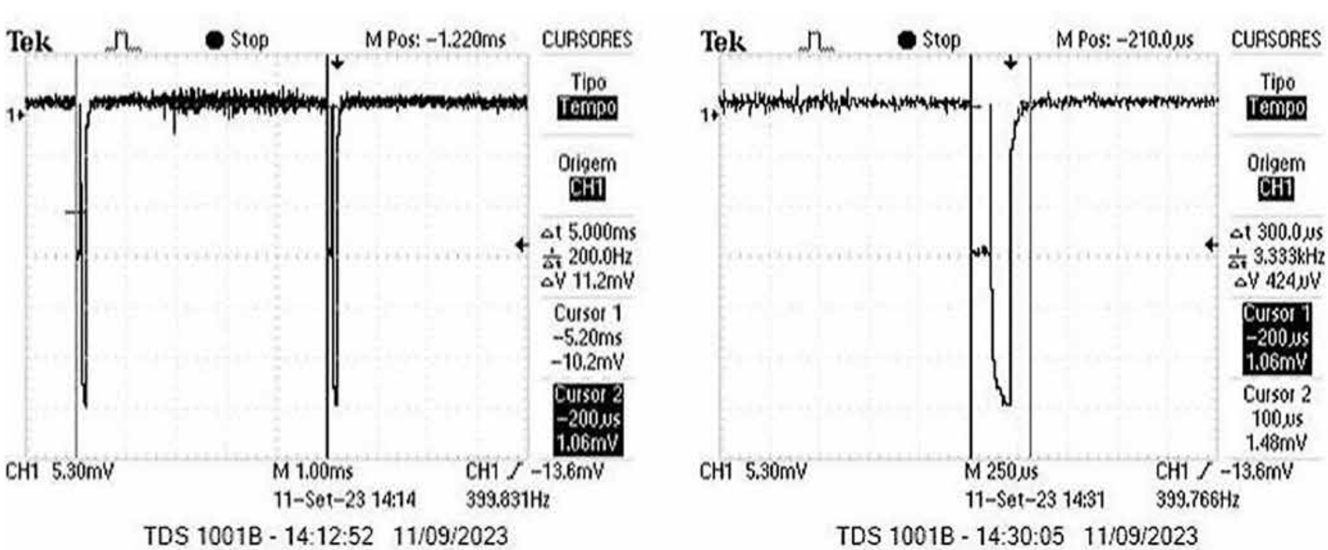


Table 2. Emission frequency and pulse width values of the device LEDs.

Device	Emission Frequency	Pulse Width
AS7057_EVK_UG001039	200 Hz	0.3 ms
EVAL-ADPD4100Z-PPG	300 Hz	4 us
Oximeter	100 Hz	1 ms

Conclusion

In addition to the red and infrared LEDs in all three analyzed devices, the reflection-based devices also incorporate green LEDs. Despite its lower skin penetration power, the green wavelength can be leveraged in the reflection model to extract information from capillary blood vessels.

Based on the results of the second test, it was observed that the LEDs do not emit light continuously. Instead, they are sequentially activated and exhibit well-defined emission frequencies. These frequencies vary across devices, reflecting their distinct diagnostic functions; for instance, the oximeter focuses on oxygen saturation (SPO2), while the kits encompass PPG analysis and diagnosis functions. The insights from these tests contribute significantly to understanding the structural aspects of the optical systems employed in these photoplethysmography devices, thereby enhancing their optical characterization.

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