

Short-Wave Infrared based, remote vital parameter detection using pulsed illumination

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Abstract: The field of non-invasive vital parameter detection is rapidly growing, offering improved patient care and greater comfort by reducing invasive sensors and cables. Remote photoplethysmography (rPPG) is an optical method that measures blood-volume changes in tissue microvasculature. Similar to conventional PPG, which uses LEDs and a photodiode to detect transmitted light through a finger, rPPG instead measures reflected light from selected regions of interest. Using a Sony IMX990 InGaAs sensor and an LED array covering visible and short-wave infrared wavelengths, this work extends rPPG to a multispectral video system and demonstrates its initial effectiveness.

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I. Introduction

Non-invasive and non-contact vital parameter detection like remote photoplethysmography (rPPG) can significantly improve the comfort and therefore aide the recovery of patients. It can be used in hospitals, nursing homes, and home settings to help reduce staff workload and support independent living. In these environments, rPPG enables the detection of heart rate, blood oxygenation, and respiration rate—key indicators of a patient’s health status. Most rPPG methods do not yield results that would be sufficient to reliably use them in clinical settings but provide a first estimate of the current situation of the patient. For these methods, most RGB cameras can be used [1]. Short wave infrared (SWIR) imaging is widely used in food processing and quality control [2]. In medicine, it has gained increasing research interest but is not yet widely used in routine clinical practice. As many contact-based approaches use red and infrared LEDs for PPG measurements, expanding the usable spectrum from the visible into the infrared might greatly benefit rPPG methods compared to commonly used RGB cameras, by offering a wider range of selectable wavelength channels which might be more suitable for measuring deoxygenated and oxygenated hemoglobin. Also simultaneous analysis of hydration and imaging of lipids can be possible. The camera sensor used in this work, a Sony IMX990, built into a Lucid vision Atlas SWIR camera is sensitive up to a wavelength of 1700 nm but logs frames in single channel monochrome pixels. To differentiate different wavelengths, either filters or wavelength-specific illumination are necessary. In this work, a combination of pulsed illumination and precise timing of frames is shown as an efficient way to create a multispectral video and eventually derive vital parameters of a person in frame.

II. Material and methods

The system in development is comprised of two basic components. The camera with the LEDs in visible and

infrared light and the software to capture and analyze the frames.

II.I SWIR camera and illumination

The camera in use is an ATP013S-WC from the manufacturer Lucid vision labs. The camera is equipped with the Sony IMX990 InGaAs sensor which combines InGaAs photodiodes with silicon readout units through Cu-Cu bonding. The camera uses a GigE interface for transmitting configurations and data and additionally provides an eight-pin GPIO socket which can be used to send trigger pulses to the camera or monitor the current state of the exposure of a frame. In this work, this GPIO socket is connected to a microcontroller board which is in charge of timing the trigger pulses for the camera together with the trigger pulses for the LED bars, by using a sequential monolithic algorithm which takes into account the rise time of the LEDs before triggering a frame capture and then waits for the “ExposureActive” signal of the camera to return to its LOW-level before activating another LED bar for a new frame. The LED bars are arranged around the camera, as shown in Fig. 1, provide illumination in the wavelengths 465, 525, 625, 850, 1050, 1200, 1300, 1450, 1550 and 1650 nm and are able to supply their full power with a rise time of 11.5 μ s.



Figure 1: Explosion diagram of the combined camera and LED system.

Before a recording is taken, the desired wavelengths are chosen. While recording, a frame is captured with each of the chosen wavelengths as well as a non-illuminated frame. This is repeated periodically until a specified time has passed. Each frame is then transmitted via the GigE interface of the camera to the computer for further analysis.

II.II Processing algorithms

The saved and labeled images are loaded by a python script and opened in chronological order. Using the mediapipe face detection algorithm [3] one or multiple regions of interest (ROI) are selected. Each frame then has the average pixel value taken within the ROI and the value assigned to the corresponding wavelength. This way changes in the reflection of the illumination from the skin can be measured and displayed. Fig. 2 shows the measurement of two different ROIs. The top one being the right cheek of the subject and the bottom one being a part of the background to highlight the fluctuations, caused by biological processes.

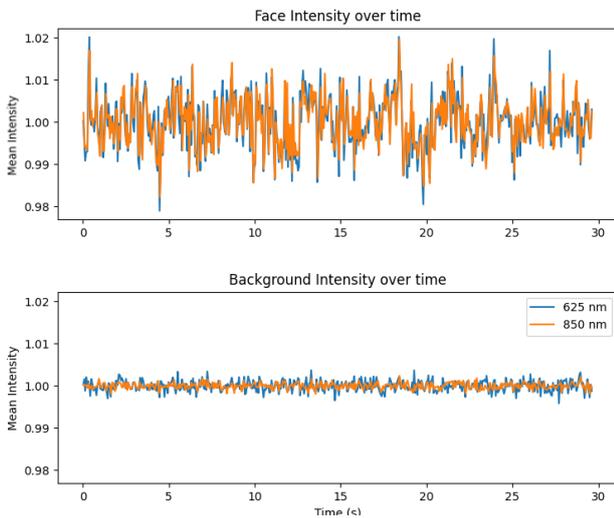


Figure 2: Explosion diagram of the combined camera and LED system.

By first separating the AC from the DC components, using a Savitzky-Golay filter with a window length of 31 data points and degree of 3, which outputs a variable base line adapting to changes in background illumination and subtle movements of the subject, and subsequently applying blind source separation (BSS) techniques [4] and fast fourier transforms (FFT) the heart rate of the subject can be detected. Through the ratio of ratios method applied to the signals at 625 nm and 850 nm, first estimates can be made for the SpO2 values as well. Equation (1) shows the calculation used for the R value, which gets input into an approximated calibration curve. To evaluate the system, a small group of five subjects has been chosen to be connected to an ECG monitor and a pulse oximeter while recordings of thirty seconds were taken of their face.

$$R = \frac{AC_{625\text{ nm}}/DC_{625\text{ nm}}}{AC_{850\text{ nm}}/DC_{850\text{ nm}}} \quad (1)$$

III. Results and discussion

Table 1 shows the results of the test measurements. Each value is the mean value of the measurement over 30 seconds. For measurements 1 and 2, the heart rate was at a nearly constant value (± 2) for the whole thirty second recording, while test subjects 3,4 and 5 had heart rates that decreased while the recording was taken. For all of the recordings the reference is the mean heart rate over the full 30 seconds. The RMSE is 3.47 bpm for this test group, while the accuracy of the reference measurement is described as ± 2 bpm.

Table 1: Predicted heart rate and SpO2 values and reference measurements..

Subject	Reference HR / bpm	Prediction HR / bpm	Reference SpO2 / %	Prediction SpO2 / %
1	75.3	74.8	98	95.8
2	50.6	50.5	99	93.6
3	67.1	62.5	99	97.8
4	65.28	60.5	99	94.5
5	72.5	68.5	99	96.3

Other rPPG methods yielded RMSE results close to 1.0 for the heart rate with only one known being under 1.0 bpm. [1] The approximated SpO2 values from table 1 are only a rough estimate as the system is not yet calibrated for this kind of measurement. State-of-the-art methods achieved RMSEs of 1.6. [5]

IV. Conclusions

This work demonstrates a proof of concept for a novel system using the IMX990 SWIR sensor with precisely timed illumination. Initial measurements show promising results for heart rate and SpO2 detection, though calibration of LED intensity and extinction coefficients is required. While promising, the setup must be refined to justify its current €20,000 cost, which may be reduced in the future through custom manufacturing and self-sourcing.

AUTHOR'S STATEMENT

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