Smart Combination of PPG Signal and IR Camera: A Multi-Parameter Device for Vital Signs Monitoring

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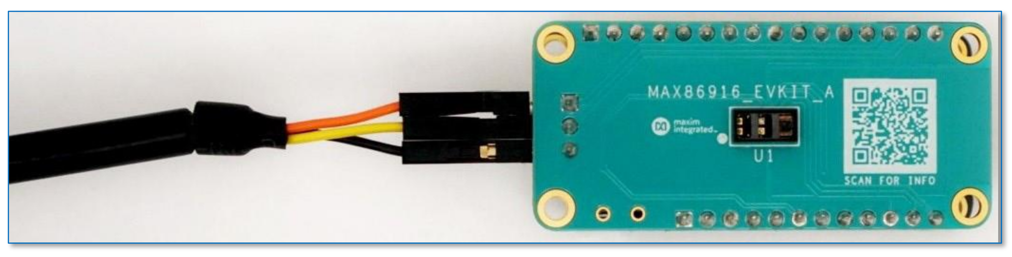
VITAL SIGNS MONITORING

In recent years, significant advances in digital health made possible to provide more personalized and timely care, and health systems to become more efficient. With this study, we propose a multi-parameter device, at a prototypal level, which represents a convenient and efficient solution in order to accurately monitor health and collect vital data: it is able to return blood pressure values, heart rate, blood oxygen saturation levels and body temperature, relying only on two different sensors, multi-wavelength photoplethysmography and thermal camera, combined with AI algorithms.
Actually, the accuracy, robustness, and generalizability of single-wavelength PPG sensing are sensitive to biological factors as well as sensor setup and placement: since different wavelengths interact with the skin differently, we used multiwavelength PPG to improve the precision of the outcome and contribute to motion artifact removal. Furthermore, the developed machine learning algorithms gain accuracy and robustness by involving both temporal and spectral features, extracted from the PPG signal only, which undergoes an accurate procedure for motion artifacts, with no need for calibration. The contact-less camera system can be easily integrated within a device for vital signs monitoring. In fact, contact-based temperature monitoring techniques can be uncomfortable, and cameras have been used to track specific body parts of interest as non-contact approaches based on optical sensors.

The device used for the prediction of heart rate, the degree of blood hemoglobin oxygenation and blood pressure, is the “MAX86916 EV System Board” with “MAX86916 GUI”. [1] The MAX86916 is a multi-wavelength optical module: it consists of four LEDs, with four different wavelength, which are infrared (930-955 nm), red (655-663 nm), green (520-535 nm) and blue (455-466 nm), and a photodiode.



HEART RATE MONITORING

To calculate the heart rate (HR), a single wavelength was used, specifically infrared light (950 nm). The HR is calculated as the time interval between one peak and the next, also called “RR Interval”.
The heart rate, expressed in beats per minute (bpm), is calculated as the average of the RR intervals divided by 60 seconds.

$$HR = \frac{mean(RR\ Interval)}{60}$$

BLOOD OXYGEN SATURATION (SpO_2) MONITORING

For the SpO2 evaluation, the system requires a combined use of signals related to two different wavelengths: red light and infrared light.
After performing artifact reduction, it is possible to calculate the root mean square (RMS) for both red and infrared components:

$$RED = \sqrt[2]{\frac{\sum_{n=1}^{N} smooth\_red(n)^2}{N}}$$

$$IR = \sqrt[2]{\frac{\sum_{n=1}^{N} smooth\_ir(n)^2}{N}}$$

It is possible to calculate the ratio R as:

$$R = \frac{RED}{IR}$$

The value of the SpO_2 can be estimated as:

$$SpO_2 = K_1 R^2 + K_2 R + K_3$$

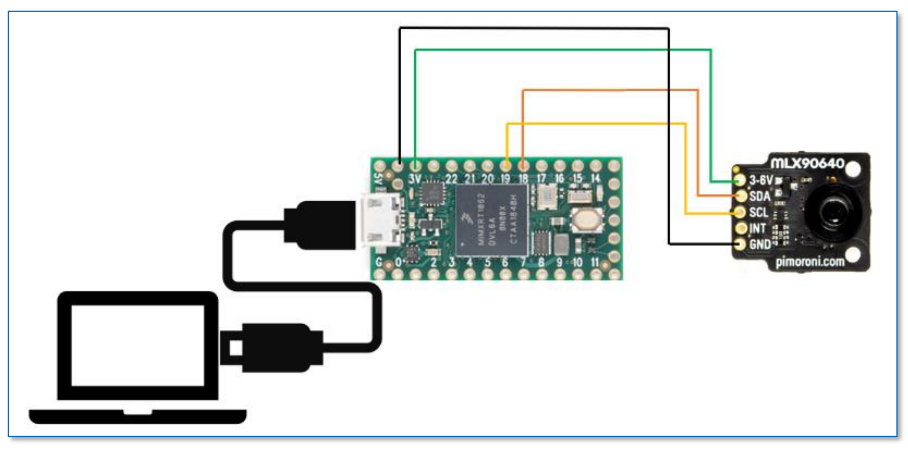
where K_1, K_2, K_3 are calibration coefficients, experimentally acquired from the literature.

BLOOD PRESSURE MONITORING

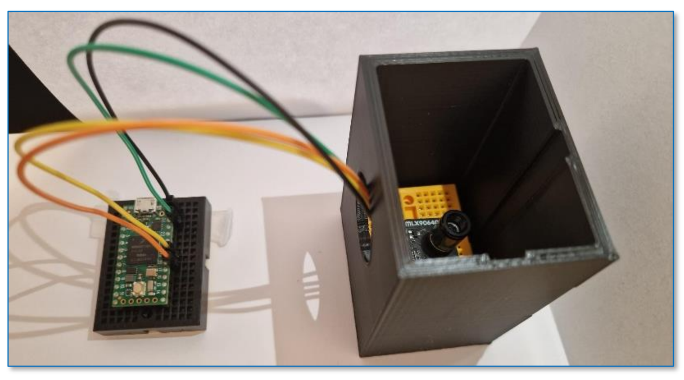
PPG signals are also used for cuff-less blood pressure prediction.
After accurate signal preprocessing which aims to remove motion artifacts and slow fluctuations, this system uses an algorithm based on feedforward artificial neural network (ANN) to estimate both systolic and diastolic blood pressure, using temporal and spectral features. [2]
The algorithm is first trained on the PPG-BP Database, given the large amount of data required, and then tested on the new dataset.
The performance of the algorithm is assessed by using the Mean Absolute Error (MAE), calculated as the average difference between the values predicted by the algorithm and the actual pressure values, measured with the sphygmomanometer.

TEMPERATURE MONITORING

The electronic system is based on the Teensy 4.0 microcontroller board and the MLX90640 thermal camera, an infrared (IR) imaging sensor that consists of a 32x24 pixel array that detects the infrared radiation emitted by the object's surface and converts it into an electrical signal. [3]



To conduct the measurement, a hollow parallelepiped-shaped support was created, inside which the thermal camera was inserted. The support was created using a 3D printer and made of plastic material, making it low-cost. The measurement protocol involves the simultaneous recording of temperature using the electronic system and a certified infrared thermoscan on the market, which serves as a reference device, with an accuracy of ±0.2°C. Specifically, the temperature is detected by placing the wrist on the support of the camera, and the reference value is measured on the same wrist using an IR thermometer.



RESULTS AND CONCLUSIONS

The performances are promising, with an average relative error of less than 5% for heart rate and blood saturation, and a Mean Absolute Error of 3.74 mmHg and 2.98 mmHg for systolic and diastolic pressure respectively. The MLX90640 thermal camera accurately measured patients body temperature in a non-invasive and continuous manner, with a maximum absolute error equal to 0.2 °C.

The work presented in this paper demonstrates how the single PPG signal allows one to easily monitor vital conditions in a continuous and non-invasive manner. Among the strengths of this method, it is possible to recognize: (1) the absence of calibration, which takes time and makes the algorithm not generalizable, (2) the only use of PPG signal for vital parameters, which does not require additional hardware and more expensive set-ups, (3) the non-contact approach for body temperature, which provides a better experience to patients with burn wounds or skin irritations and babies with limited attachment points. Among the limits, we can recognize that this method has been tested on healthy subjects only and the electronic device has been developed for an initial prototypal stage.

[1] D. Ray, T. Collins, S. Woolley, and P. Ponnapalli. “A Review of Wearable Multi-Wavelength Photoplethysmography”. IEEE Reviews in Biomedical Engineering, vol. 16, pp. 136–51, 2023. https://doi.org/10.1109/RBME.2021.3121476.
[2] Y. Kurylyak, F. Lamonaca, and D. Grimaldi, “A Neural Network-based method for continuous blood pressure estimation from a PPG signal”, in 2013 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Minneapolis, MN, USA: IEEE, May 2013, pp. 280–283.
[3] V. Pecoraro, D. Petri, G. Costantino, A. Squizzato, L. Moja, G. Virgili, and E. Lucenteforte, “The diagnostic accuracy of digital, infrared and mercury-in-glass thermometers in measuring body temperature: a systematic review and network meta-analysis”, Intern Emerg Med, vol. 16, no. 4, pp. 1071–1083, Jun. 2021.