OpenPPG: Research Mobile App for PPG Waveform Acquisition using Smartphone Camera with Raw Data Access

Mateusz Soliński[1,3], Mikołaj Basza[2,3], Bartosz Pietyra[3], Marta Szkwyra[4]

[1] Department of Engineering and School of Biomedical Engineering & Imaging Sciences, King's College London, London, UK
[2] Medical University of Silesia in Katowice, Poland
[3] OpenPPG, Warsaw, Poland
[4] SRT Studio, Warsaw, Poland

Abstract

Photoplethysmography (PPG) is gaining importance in cardiovascular and digital health research due to its simple acquisition from consumer devices, including smartwatches, pulse oximeters, and even smartphone cameras. Beyond heart rate (HR) and peripheral oxygen saturation (SpO_2), it has demonstrated clinical value in atrial fibrillation detection, with research expanding to hypertension, diabetes, and heart failure. Despite robust evidence for smartphone camera–based PPG acquisition, its utilisation remains limited, mainly due to restricted access to raw waveforms among the current software providers. To address this gap, we developed OpenPPG, a free, research-oriented iOS application designed for high-quality PPG acquisition via the smartphone camera. The application captures brightness fluctuations in separate RGB channels to create a real-time pulse waveform. It enables event marking, clinical metadata annotation, and configurable preprocessing. Users can export raw or filtered PPG and built-in accelerometer signals, signal-quality assessment, and derived HR and HRV features. All outputs are available in CSV format with unrestricted access to individual RGB channels. By providing transparent, reproducible, and cost-free access to high-quality PPG data, OpenPPG supports innovation in signal processing, machine learning, and the development of digital biomarkers.

1. Introduction

Photoplethysmography (PPG) is increasingly used in cardiovascular and digital health research due to its simplicity, low cost, and integration in consumer devices (smartwatches, pulse oximeters, smartphones). While traditionally applied to heart rate (HR) and oxygen saturation (SpO_2), the PPG waveform also reflects vascular properties, autonomic function, and cardiometabolic status [1]. Its clinical utility is established in atrial fibrillation detection [2], and growing evidence supports applications in hypertension, diabetes, and heart failure [3, 4].

Despite the growing potential of PPG, key barriers for robust research remain. Most commercially available tools and devices do not provide access to raw data, hindering transparency in how signals are pre-processed and analysed. These restrictions are typically due to the protection of companies' intellectual property. However, the research using PPG on academic, non-commercial fields requires open, standardised, and reproducible access to raw data and transparent signal acquisition pipelines.

About a year ago, we encountered a similar problem: a lack of available wearable measurement tools and easy access to the raw PPG signal for research related to its morphology analysis in cardiovascular patients. Although a few vendors offer research devices with raw data access (e.g., Shimmer, Dublin, Ireland; PLUX Biosignals, Lisbon, Portugal), we found no smartphone app that would provide access to the raw camera signal. The available software only allows access to highly processed data, mainly HR or its variability (HRV). To address this unmet need, we developed OpenPPG, a free, research-oriented iOS application (app) enabling high-quality PPG acquisition using the smartphone camera [1]. It provides simultaneous access to raw and filtered pulse waveforms for each RGB channel and combined brightness, includes real-time signal quality indices, supports event annotation with custom clinical metadata, data from the built-in accelerometer, and exports in standard formats for downstream analysis. OpenPPG provides transparent and reproducible access to high-quality PPG signals, enabling advances in cardiovascular signal analysis, machine learning, and digital biomarker discovery. This article outlines the rationale, design, and key functionalities of the app.

[1] https://openppg.app/

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2. App design and methods

2.1. App design and workflow

The signal acquisition within the OpenPPG application follows a standardised workflow designed to optimise data quality, computational efficiency and reproducibility. The smartphone camera and torch are automatically activated at the beginning of each recording, with the fingertip placed over the lens to provide stable illumination and consistent contact. The application continuously displays the PPG waveform together with a real-time signal quality index (SQI). The overview of different application screens is showed in Figure 1.

The subject is instructed to maintain stable contact between the skin and the mobile camera and pressure throughout the measurement (typically a fingertip that covers either the selected camera lens or the torch; the lens can be switched before the measurement using a button on the main screen). In case of unstable recordings, adjustment of pressure or switching the active lens can improve quality. Once a stable waveform and “good” SQI label are achieved, a systolic peak detection algorithm is initiated. Event markers can be added in real time to annotate specific conditions (e.g. stimulus, medication administration) by double-tapping on the screen. Upon completion, recordings can be reviewed as raw or filtered signals in the Summary section. Basic metadata, such as ID, age and gender, can be entered in predefined, customisable forms (in Settings). All data are then stored in the application history and may be exported in CSV format. The user can choose the list of data to export, including signals from separate RGB channels, raw or filtered PPG signal, built-in accelerometer data, quality index, and metadata.

Figure 1. Signal measurement screen (central), Recording display and signal quality index (SQI) assessment screen (left), HRV parameters and subject ID+metadata screen (right).

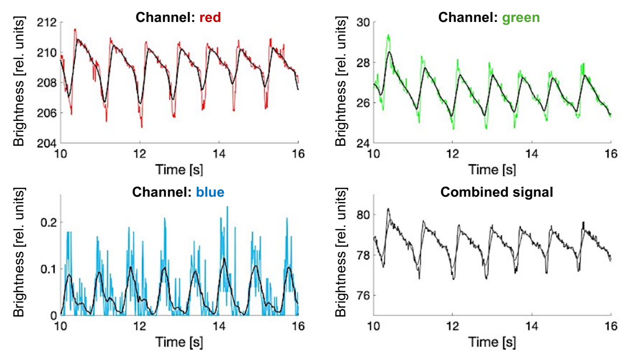

Figure 2. PPG signals from RGB channels and combined brightness (raw and filtered) recorded in a healthy 27-year-old female.

2.2. Signal acquisition

At each frame, the OpenPPG acquires brightness readings from the RGB (red, green, blue) channels using 20 pixels (2x2 pixel areas at 5 sites: in the centre and corners). It creates parallel raw signals for each channel separately, and one averaged signal consisting of the combined brightness from all channels – the main PPG signal obtained from the app (see Figure 2). The data are captured at a framing rate of 100 fps. Optional preprocessing includes a moving mean (w = 5), a 4th order Chebyshev II filter (0.25–12 Hz), and a 4th order Butterworth bandpass filter (0.25–12 Hz). Moreover, torch light intensity can be adjusted using a slider in the 'Recording Settings' section. The user can also decide which camera lens will be used before the measurement. Simultaneously, the movement signals are recorded using a built-in 3-axis accelerometer at the sampling frequency of 100 Hz and matched with PPG signals.

2.3. Signal qualty assessment

The signal quality of the PPG signal is evaluated using a modified version of the methods described in [5]. This method assesses the quality in 5-second moving windows with a hop size of 1 second. It consists of seven rules which evaluate the signals considering such features as: maximum absolute amplitude (rule 1), local amplitude maxima features (rule 2), number of threshold-crossings (rules 3 & 7), coherency in values between the first and second half of the window (rule 4), autocorrelation Features (rules 5 & 6). These rules are based on sets of threshold criteria (15 thresholds in total). The differences with the original version of the algorithm include analysing data with an overlap, as well as changes in definitions of some rules and threshold values to better fit with signals obtained from the app. The overlap provides practical, 1-second cadence signal-quality estimates. We also added post-processing that removes single-second "good" islands adjacent to bad-quality segments, improving the clarity and stability of the assessment.

We arbitrarily categorised the outputs of this method into three stages: bad quality (only rules 1 up to 3 are met), uncertain (1-6 rules met) and good (all rules are met), creating a signal quality index (SQI). The SQI is displayed to the user during measurement, enabling optimisation of finger placement and pressure on the camera lens, and is stored together with the raw and filtered signals for downstream analysis. The additional information about the signal quality comes from a built-in 3-axis accelerometer that can be exported together with SQI for every sample. An example of the recorded PPG and accelerometer signals during a finger movement is shown in Figure 3. The presented signal quality framework improves the reliability of data acquisition, which is particularly important in such sensitive measurement settings as the smartphone camera.

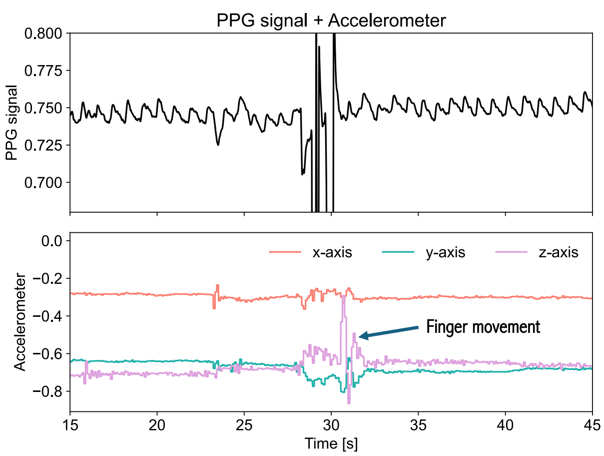

Figure 3. PPG signal and 3-axis accelerometer signals measured simultaneously. A finger movement occurred between 27 and 32 seconds, disrupting the PPG signal.

2.4. Systolic peak detection and HRV

Systolic peaks (sp) and the beat onsets (on) are detected in real-time using the open-source MSPTDfast PPG beat detection algorithm [6]. This method is performed only in the segments of good quality to ensure the robustness of the detection. Systolic peak detection enables the calculation of real-time HR values and HRV parameters after the measurement. HRV outputs include the parameters in time domain: mean RR interval, standard deviation of RR intervals (SDNN), RMSSD, pNN20, pNN50, SDSD; frequency domain: power spectrum (VLF, LF, LFnu, HF, HFnu, LF/HF) and peak frequencies (VLFpeak, LFpeak, HFpeak) in the very low (VLF; 0.0033–0.04 Hz), low (LF; 0.04–0.15 Hz), and high (HF; 0.15–0.4 Hz) frequencies; and nonlinear indices such as Poincaré plot-derived parameters SD1 and SD2, sample and Shannon entropy. Some of the parameters require longer recordings (15-90 s) to be calculated and displayed in the measurement summary.

2.5. Patient data

After the measurement, the user can input patient data such as ID, age, gender, height, and weight in the predefined, customisable survey in the measurement overview. Additional fields can be created in Settings. This enables adjustable patient surveys tailored to researchers' needs. However, it is important not to enter any identifiable patient information and to keep measurements anonymous at the app level.

2.6. Measurement accuracy and quality

Measurement accuracy and signal quality were initially evaluated in an internal study involving 30-second resting-state recordings obtained from the left index finger of five healthy volunteers (three men and two women, aged 26–65 years, HR range 78-99 BPM, Fitzpatrick skin type I-III). PPG signals were acquired using the OpenPPG and compared with a medical-grade ECG sensor (Kardia Mobile, USA). Heart rate derived from OpenPPG demonstrated a mean absolute error of 0.78 ± 0.58 BPM and RMSE 0.93 ± 1.05 BPM when compared with ECG for iPhone 15 and MAE 0.76 ± 0.41 BPM and RMSE 0.85 ± 0.41 BPM for iPhone 11. Across all recordings, the mean signal quality index (SQI) was 90,2% for iPhone 15 and 85,2% for iPhone 11.

3. Discussion

The feasibility and accuracy of smartphone camera–based photoplethysmography for heart rate estimation have already been demonstrated in multiple validation studies. A meta-analysis of 14 investigations showed that smartphone applications using the built-in camera to derive PPG signals provided good agreement with reference methods for resting heart rate measurements in adults [7]. Several commercially available smartphone applications have demonstrated the feasibility of PPG-based heart rate and rhythm monitoring. For instance, FibriCheck (Qompium, Belgium), a CE-marked and FDA-cleared application, has been validated for atrial fibrillation screening using the smartphone camera [8]. Similarly, early solutions such as Instant Heart Rate (Azumio, USA) showed that camera-based PPG could reliably estimate heart rate in controlled conditions [9]. Collectively, these studies prove the readiness of the mobile-phone PPG technology for implementation in clinical settings. The OpenPPG application may be a useful tool to provide such research.

OpenPPG is the first mobile application to offer broad access to the data-acquisition pipeline, including export of raw light intensity from separate RGB channels; raw or filtered (three filters) PPG signals; torch light intensity; lens switching; and categorisation by SQI. These features address the lack of customisable, transparent data-collection systems, giving users full control over measurement settings. Our solution may foster further research on signal-measurement optimisation (e.g., combining signals from RGB channels or varying torch intensities).

The initial validation of HR estimation indicates robust signal acquisition in the app. We plan a larger study in a more diverse cohort to confirm the accuracy and reliability of HR and HRV indices. Despite many potential protocols, OpenPPG is likely most useful for short, frequent measurements (up to several minutes). It is well-suited to studies monitoring rapid, movement-free responses to interventions (e.g., mental stressors, fast-acting drugs, meditation and wellness techniques). It can also be used for cardiovascular screening and monitoring in clinical and home settings (downloadable via the iOS App Store). In summary, OpenPPG provides an accessible and flexible research tool for advancing both methodological studies and applied cardiovascular research.

The further improvements of the app would cover the optimisation of the signal acquisition by the most efficient pixel selection procedure, adding new parameters extracted from the waveforms (e.g. perfusion index), and development of the online infrastructure for additional (and optional) data storage.

4. Conclusions

We presented the main functionality and performance of the OpenPPG mobile application for pulse waveform acquisition using a mobile camera. By addressing the current limitations of closed commercial ecosystems, this approach provides researchers with unrestricted access to raw waveforms, thereby enhancing reproducibility and enabling independent validation. Establishing such open frameworks is essential not only to accelerate methodological innovation but also to facilitate the development and benchmarking of novel algorithms. We believe that creating free applications by researchers for researchers represents a valuable direction for advancing open, reproducible, and collaborative science.

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Address for correspondence:

Mateusz Soliński
King's College London, Strand, WC2R 2LS, London, UK
mateusz.solinski@kcl.ac.uk