Optimising Smartphone Camera Parameters for Reliable Photoplethysmography

Mateusz Soliński[1,2,3], Edward Okoekpen[2], Venla Koivunen[4], Bartosz Pietyra[3], and Mikolaj Basza[1,5]

[1]Computational Physics Laboratory, Tampere University, Tampere, Finland
[2]School of Biomedical Engineering and Imaging Sciences, King's College London, London, U.K.
[3]OpenPPG, Warsaw, Poland
[4]Faculty of Medicine and Health Technology, Tampere University, Tampere, Finland
[5]1st Department of Cardiology, Medical University of Warsaw, Warsaw, Poland

Abstract

Photoplethysmography (PPG) using a smartphone camera provides a low-cost and accessible method for measuring fingertip pulse waveforms. However, the effects of camera acquisition settings and pixel-selection strategy on PPG performance remain insufficiently understood. We systematically investigated how these factors influence smartphone PPG quality. Ten camera presets combining different ISO sensitivity, exposure time, focus, and white-balance settings were evaluated with five pixel-selection strategies: Corner, Spread, Grid, Random, and Threshold5%, yielding 50 configurations per participant. One-minute PPG recordings were acquired using an iPhone 13 mini and the OpenPPG application from 43 healthy participants (18 females; 27.3 ± 5.1 years; Fitzpatrick skin types I–V), with ECG as reference. After quality-based exclusions, 1,628 recordings were analysed. Performance was assessed using absolute heart-rate error ($|\Delta HR|$), PSD-based SNR (SNR_{PSD}), and ensemble-based morphological SNR (SNR_{ens}). Grid showed the best overall performance, yielding the lowest mean $|\Delta HR|$ (2.73 bpm), highest SNR_{PSD} (5.48 dB), and highest SNR_{ens} (7.71 dB). The best configuration achieved a mean $|\Delta HR|$ of 1.22 bpm. Mixed-effects modelling showed that higher ISO was consistently associated with lower HR error and higher values of both SNR measures, while longer exposure was associated with higher SNR_{ens}. These findings demonstrate that acquisition configuration can influence PPG performance on the evaluated smartphone and should be considered part of the measurement protocol.

1. Introduction

Smartphone-based photoplethysmography (PPG) enables physiological measurements using the built-in camera and flash, providing a widely accessible platform for cardiovascular monitoring [1]. When a fingertip covers the camera, pulsatile changes in light absorption associated with peripheral blood-volume variations can be reconstructed as a PPG waveform.

The quality of the recorded signal depends on multiple factors. While considerable attention has been devoted to signal processing, motion artefacts, and other external sources of variability, the camera sensor's acquisition settings have received less systematic attention.

Camera parameters such as ISO sensitivity, exposure time, focus, and white balance directly influence the recorded optical signal, and differences in device settings have previously been shown to affect PPG measurements [2]. Moreover, the strategy used to select and aggregate image pixels may influence waveform quality because illumination and pulsatile information are not uniformly distributed across the camera image [3, 4].

In this study, we systematically evaluate the effects of camera settings and pixel-selection strategies on smartphone fingertip PPG. We compare multiple acquisition configurations using HR agreement with ECG and signal-quality measures to identify configurations providing more reliable PPG measurements.

2. Methods

2.1. Study design

We recruited healthy adult volunteers without self-reported cardiovascular disease. All participants provided informed consent, and the study was registered through the Research Ethics Minimal Risk Self-Registration at King's College London (MRA-24/25-51403).

We evaluated 10 camera presets combining different values of ISO sensitivity, exposure time, focus, and white balance. We selected presets 2–10 using a Taguchi L9 orthogonal array, while preset 1 represented the automatic

Table 1. Camera preset configurations used for smartphone PPG acquisition. Preset 1 corresponds to the automatic camera mode, while presets 2–10 were defined using fixed parameter combinations.

Preset	ISO	Exposure [s]	Focus	WB [K]
1	auto	auto	auto	auto
2	100	0.0083	0.0	3000
3	100	0.0100	0.5	4500
4	100	0.0333	1.0	6000
5	400	0.0083	1.0	4500
6	400	0.0100	0.0	6000
7	400	0.0333	0.5	3000
8	250	0.0083	0.5	6000
9	250	0.0100	1.0	3000
10	250	0.0333	0.0	4500

camera configuration. We evaluated five pixel-selection strategies simultaneously for each preset: Corner (a fixed 10×10-pixel patch), Spread (five spatially distributed four-pixel regions), Grid (nine distributed four-pixel regions), Threshold5% (the brightest 5% of pixels in each frame), and Random (randomly sampled pixel patches), as illustrated in Fig. **??**. Thus, each participant underwent 10 measurements, with five PPG signals reconstructed from each recording.

2.2. Data acquisition

We recorded fingertip PPG signals using an iPhone 13 mini and a dedicated version of the OpenPPG application [5]. We used the upper-right rear camera lens, as viewed from the back of the device, for all measurements. Camera frames were acquired at 100 Hz with exposure times of 0.0083 and 0.0100 s, and at 33 Hz with an exposure time of 0.0333 s. A Polar H10 chest-strap sensor via the HeartFM mobile application [6] provided the simultaneous single-lead ECG reference.

Participants remained seated and held the smartphone in the right hand with the index finger covering the camera and flash. We obtained ten simultaneous one-minute PPG and ECG recordings from each participant. We randomised the order of camera presets and applied all five pixel-selection strategies simultaneously within each recording.

2.3. Data processing

We exported raw PPG signals, inter-beat intervals (IBIs), and signal-quality flags from OpenPPG. We performed beat detection using the MSPTDfast algorithm. We retained recordings when at least 50% of their duration ($\geq$ 30 s) was classified as good quality. Signals reconstructed using the Random strategy were excluded because this method systematically produced poor-quality waveforms.

We calculated PPG-derived heart rate (HR) from the detected IBIs and compared it with the ECG reference. HR-estimation error was quantified as the absolute difference between mean PPG and reference HR, $|\Delta HR| = |HR_{\mathrm{ECG}} - HR_{\mathrm{PPG}}|$.

We also assessed signal quality using two complementary signal-to-noise ratio (SNR) measures. SNR_{PSD} quantified spectral concentration around the ECG-derived cardiac frequency and its second harmonic within 0.7–4.0 Hz. SNR_{ens} quantified beat-to-beat morphological consistency by comparing individual pulse waveforms with a median ensemble template.

2.4. Statistical analysis

Performance was summarised for each camera-preset and pixel-selection combination using $|\Delta HR|$, SNR_{PSD}, and SNR_{ens}. We used linear mixed-effects models to assess the independent effects of ISO, exposure time, focus, white balance, and pixel-selection strategy while accounting for repeated measurements within participants. We included Participant ID as a random intercept, and adjusted models for age, sex, Fitzpatrick skin-tone group, reference HR, and measurement order. Because $|\Delta HR|$ was right-skewed, we log-transformed it before modelling. We excluded the random pixel-selection strategy because of its consistently poor signal quality.

3. Results

3.1. Study population and signal inclusion

A total of 43 healthy participants were included in the analysis (18 females, 42%; age 27.3 ± 5.1 years). Fitzpatrick skin types ranged from I to V. From the 2,150 reconstructed one-minute PPG signals, 430 signals obtained using the Random pixel-selection strategy and 92 additional low-quality signals were excluded, resulting in 1,628 signals available for analysis.

3.2. Performance across acquisition configurations

Performance differed across both camera presets and pixel-selection strategies (Fig. X). Averaged across pixel-selection strategies, the lowest HR errors were observed for Presets 1, 7, 6, and 4 (3.07–3.32 bpm), whereas Presets 2 and 3 produced the largest errors (8.31 and 7.84 bpm). Grid showed the best overall performance across pixel-selection strategies, with the lowest mean $|\Delta HR|$ (2.73 bpm), highest SNR_{PSD} (5.48 dB), and highest SNR_{ens} (7.71 dB). At the individual configuration level, Preset 6

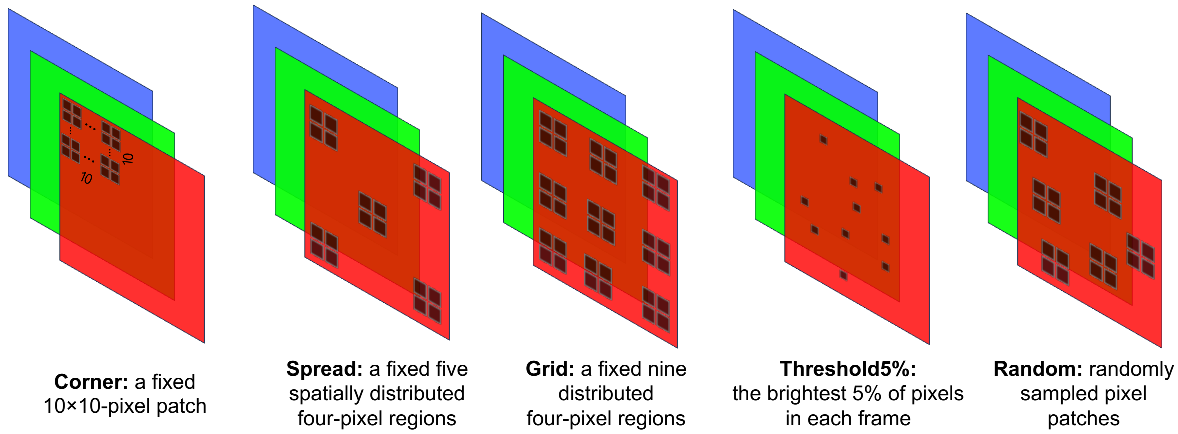

Figure 1. Illustration of five pixel selection method used in the study. The 'Random' method was excluded from the main results

Table 2. Performance across pixel-selection strategies, averaged over all camera presets. Values are mean ± SD.

Method	$\lvert\Delta HR\rvert$ [bpm]	SNR_{PSD} [dB]	SNR_{ens} [dB]
Corner	5.49 ± 8.56	5.27 ± 2.28	6.27 ± 2.47
Grid	2.73 ± 5.35	5.48 ± 2.29	7.71 ± 2.57
Spread	6.08 ± 9.63	5.17 ± 2.24	6.05 ± 2.39
Threshold5%	5.32 ± 9.34	5.29 ± 2.22	6.49 ± 2.51

+ Grid yielded the lowest $|\Delta HR|$ (1.22 bpm) and highest SNR_{ens} (8.12 dB), while Preset 10 + Grid yielded the highest SNR_{PSD} (5.78 dB).

3.3. Effects of camera parameters

Linear mixed-effects models confirmed that both camera parameters and pixel-selection strategy influenced PPG performance. Higher ISO was consistently associated with lower HR error ($\beta = -0.236$, $p < 0.001$), higher SNR_{PSD} ($\beta = 0.160$, $p = 0.001$), and higher SNR_{ens} ($\beta = 0.344$, $p < 0.001$).

Longer exposure time was associated with higher SNR_{ens} ($\beta = 0.378$, $p < 0.001$), but not significantly with HR error or SNR_{PSD}. Higher focus and white-balance levels were also associated with improved SNR_{ens}, while their effects on the other outcomes were less consistent.

Compared with Corner, Grid was associated with lower HR error ($\beta = -0.674$, $p < 0.001$), higher SNR_{PSD} ($\beta = 0.241$, $p = 0.033$), and higher SNR_{ens} ($\beta = 1.419$, $p < 0.001$). Spread was associated with lower SNR_{ens} ($\beta = -0.360$, $p = 0.002$), whereas Threshold5% showed no significant associations with any of the three outcomes.

Table 3. Performance across camera presets, averaged over pixel-selection strategies. Values are presented as mean ± SD.

Preset	$\lvert\Delta \mathrm{HR}\rvert$ [bpm]	$\mathrm{SNR_{PSD}}$ [dB]	$\mathrm{SNR_{ens}}$ [dB]
1	3.07 ± 5.94	5.48 ± 2.10	6.93 ± 2.53
2	8.31 ± 13.38	4.96 ± 1.83	5.54 ± 2.09
3	7.84 ± 12.61	5.22 ± 2.28	6.30 ± 2.58
4	3.32 ± 5.29	4.97 ± 2.49	7.05 ± 2.40
5	4.18 ± 8.24	5.20 ± 2.09	6.83 ± 2.39
6	3.20 ± 5.86	5.37 ± 2.51	6.87 ± 2.70
7	3.10 ± 3.84	5.47 ± 2.06	6.87 ± 2.27
8	6.21 ± 10.55	5.35 ± 2.40	6.61 ± 2.85
9	5.13 ± 9.19	5.50 ± 2.25	6.35 ± 2.27
10	4.71 ± 7.29	5.51 ± 2.53	6.96 ± 2.75

4. Discussion

This study demonstrates that camera acquisition settings and pixel-selection strategy can substantially influence fingertip PPG performance on the evaluated smartphone. The Grid strategy provided the most favourable overall performance, with lower HR error and higher spectral and morphological signal quality. Mixed-effects modelling further indicated that higher ISO was the camera parameter most consistently associated with improved performance across the three evaluated outcomes.

The favourable performance of the Grid strategy may be related to its spatially distributed sampling of the image sensor. Sampling multiple regions may reduce the influence of local illumination inhomogeneities or artefacts and provide a more representative estimate of pulsatile intensity changes. However, because the evaluated strategies differed in both spatial distribution and number of sampled pixels, these effects cannot be attributed solely to spatial

Table 4. Top five preset–pixel-selection configurations for each performance metric. Values are presented as mean ± SD. Lower values indicate better performance for $|\Delta HR|$, whereas higher values indicate better performance for SNR_{PSD} and SNR_{ens}.

Rank	Preset	Pixel method	Performance
		$|\Delta \mathbf{HR}|$ **[bpm]**	
1	6	Grid	1.22 ± 2.39
2	4	Grid	1.34 ± 1.34
3	7	Grid	1.96 ± 2.29
4	1	Grid	2.09 ± 4.01
5	1	Corner	2.43 ± 4.89
		$\mathbf{SNR_{PSD}}$ **[dB]**	
1	10	Grid	5.78 ± 2.54
2	7	Grid	5.68 ± 2.13
3	9	Grid	5.63 ± 2.30
4	10	Threshold5%	5.58 ± 2.45
5	1	Grid	5.57 ± 2.11
		$\mathbf{SNR_{ens}}$ **[dB]**	
1	6	Grid	8.12 ± 2.83
2	1	Grid	8.02 ± 2.66
3	5	Grid	7.98 ± 2.41
4	4	Grid	7.93 ± 2.45
5	8	Grid	7.89 ± 3.05

sampling.

Camera settings also influenced PPG performance. Higher ISO was associated with lower HR error and higher values of both SNR measures, whereas longer exposure time was mainly associated with improved morphological signal quality. These findings indicate that camera parameters should be considered part of the PPG acquisition protocol rather than treated only as implementation details.

Importantly, the present analysis was performed using a single smartphone model. Smartphone cameras differ in sensor properties, optical geometry, and internal image-processing pipelines; therefore, the relative performance of the evaluated acquisition settings may not transfer directly to other devices. The present results should thus be interpreted as evidence that acquisition configuration can affect PPG performance, rather than as a universal recommendation for specific camera settings. Validation across additional smartphone models is required before device-independent acquisition guidelines can be established.

5. Conclusions

On the evaluated smartphone, camera acquisition settings and pixel-selection strategy substantially influenced fingertip PPG performance. Grid sampling showed the most favourable overall performance, while higher ISO was consistently associated with lower HR error and higher spectral and morphological signal quality. These findings support treating acquisition configuration as an integral part of smartphone PPG measurement protocols. However, specific settings should be validated for each device before being generalised across smartphone platforms.

Acknowledgments

E.O. was supported by the King's Undergraduate Research Fellowship (KURF), King's College London. M.S. was affiliated with the ERC-funded COSMOS and HEART.FM projects (grant nos. 788960 and 957532) and received a Sigrid Juselius Foundation scholarship at Tampere University (project no. 31800021). We thank Charles A. Picasso for developing the HeartFM app used for ECG extraction and Prof. Elaine Chew for providing access to the software.

References

[1] Sun Y, Thakor N. Photoplethysmography revisited: From contact to noncontact, from point to imaging. IEEE Transactions on Biomedical Engineering March 2016; 63(3):463–477. ISSN 1558-2531.

[2] Xuan Y, Barry C, Antipa N, Wang EJ. A calibration method for smartphone camera photophlethysmography. Frontiers in Digital Health November 2023;5. ISSN 2673-253X.

[3] Siddiqui SA, Zhang Y, Feng Z, Kos A. A pulse rate estimation algorithm using ppg and smartphone camera. Journal of Medical Systems April 2016;40(5). ISSN 1573-689X.

[4] Yao A, Chou Y, Yang L, Hu L, Liu J, Gu S. Research on heart rate extraction method based on mobile phone video. Medical Engineering amp Physics 2023;120(1):104051. ISSN 1873-4030.

[5] Solinski M, Basza M, Pietyra B, Szkwyra M. Openppg: Research mobile app for ppg waveform acquisition using smartphone camera with raw data access. In 2025 Computing in Cardiology Conference (CinC), volume 52 of CinC2025. Computing in Cardiology. ISSN 2325-887X, December 2025; .

[6] Chew E, Fyfe L, Picasso C, Lambiase P. Seeing music's effect on the heart. European Heart Journal October 2024; 45(41):4359–4363. ISSN 1522-9645.

Address for correspondence:

Mateusz Soliński
Computational Physics Laboratory, Tampere University
P.O. Box 600, FI-33014 Tampere, Finland
mateusz.solinski@tuni.fi