On-Device Integrated PPG Quality Assessment and Sensor Disconnection/Saturation Detection System for IoT Health Monitoring

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Objectives

Develop on-device signal quality assessment (SQA) system for reducing false alarms and maximizing battery life of wearable devices.

- Exploring light weight signal processing schemes for discriminating noise-free PPG signals from motion artifact (MA) corrupted PPG and pulse-free noisy signals.
- Timely notifying sensor disconnection to users/physicians for necessary actions.
- Detecting signal saturation before extracting essential pulse parameters and clinical indexes.
- Demonstrating false alarm reduction and energy saving by discarding noisy signals.

Introduction

Photoplethysmography (PPG) is a simple and low-cost bio-optical sensing technique that is widely used in many pathological and non-pathological analysis applications.

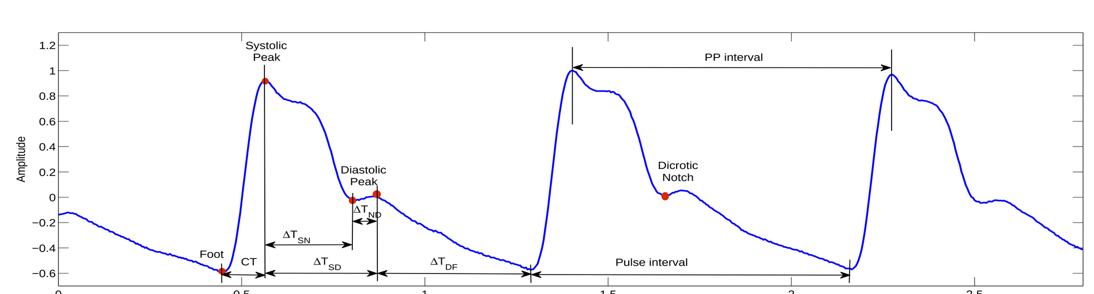

Figure: PPG signals with local waves and pulse parameters.

Key Challenges of Wearable PPG Monitoring Devices

- Ubiquitous, unobtrusive monitoring devices often produce false alarms.
- Battery power is wasted when corrupted signals are processed and/or transmitted.
- Inaccurate measurement of pulse parameters and clinical indexes under different physical activities.
- Frequent sensor disconnection and signal saturation under ambulatory PPG recordings.

Method

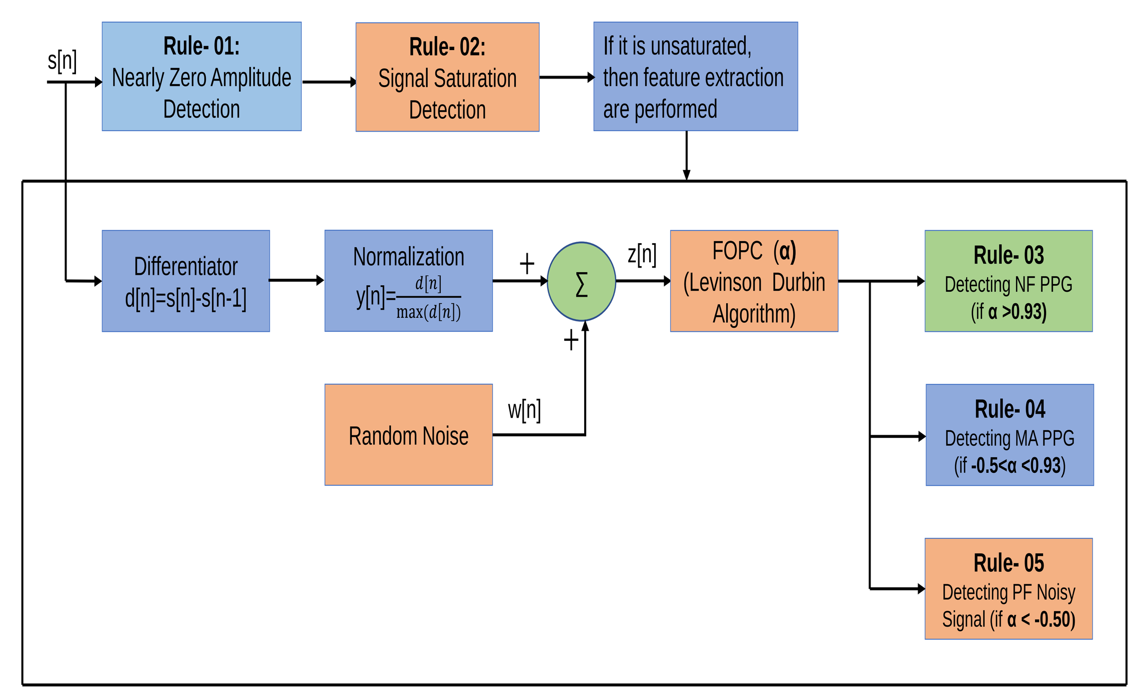

Figure: Block diagram of the proposed on-device integrated PPG quality assessment and sensor disconnection/saturation detection method

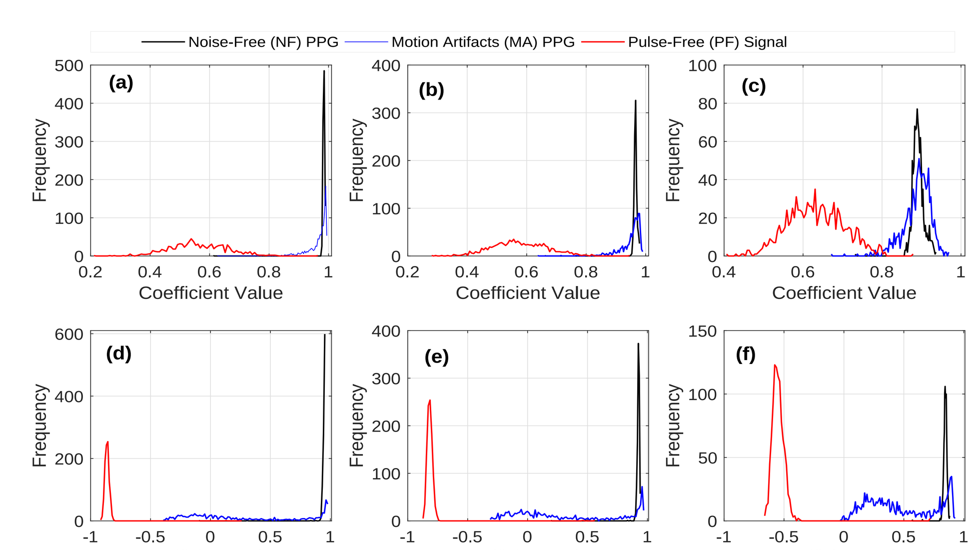

Figure: (a)-(c) Illustrates distributions of FOPC extracted from FS signal by adding random noise with different amplitude levels of (a) 10%; (b) 20%; (c) 50%; (d)-(f): illustrates the distribution of FOPC extracted from DS signal by adding random noise with different amplitude levels of (d) 10%; (e) 20%; (f) 50% of the sensor's operating voltage, V_{max}.

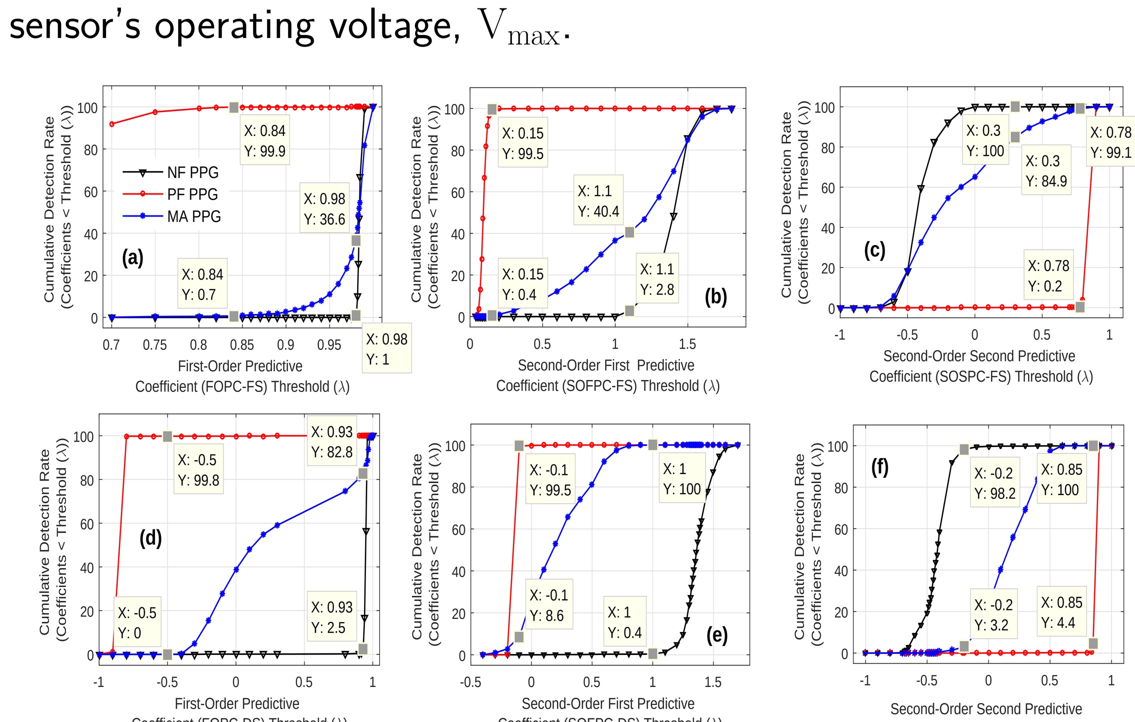

Figure: Illustrates percentage of the cumulative detection rate which is computed for specific range of the coefficient threshold.

Results

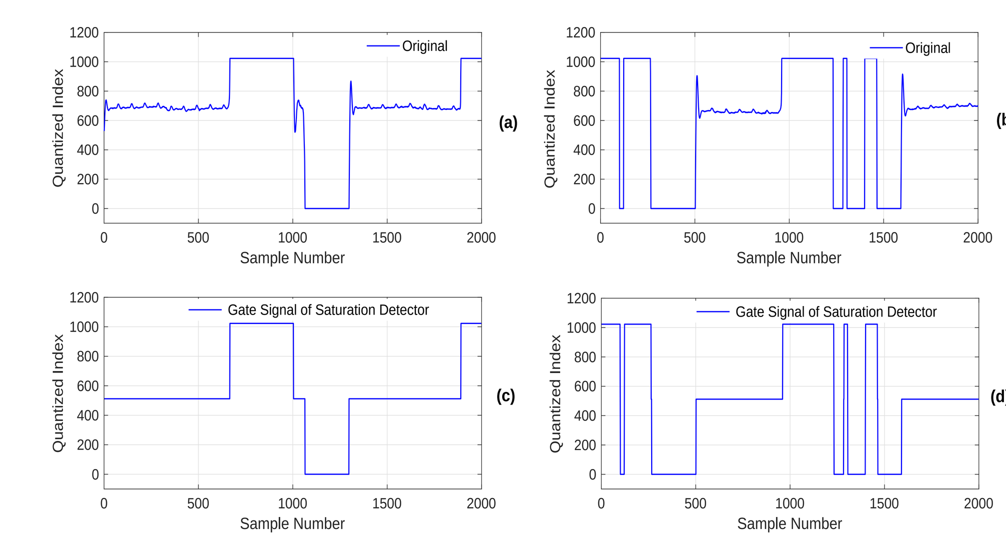

Figure: Sensor signal satutation detection results.

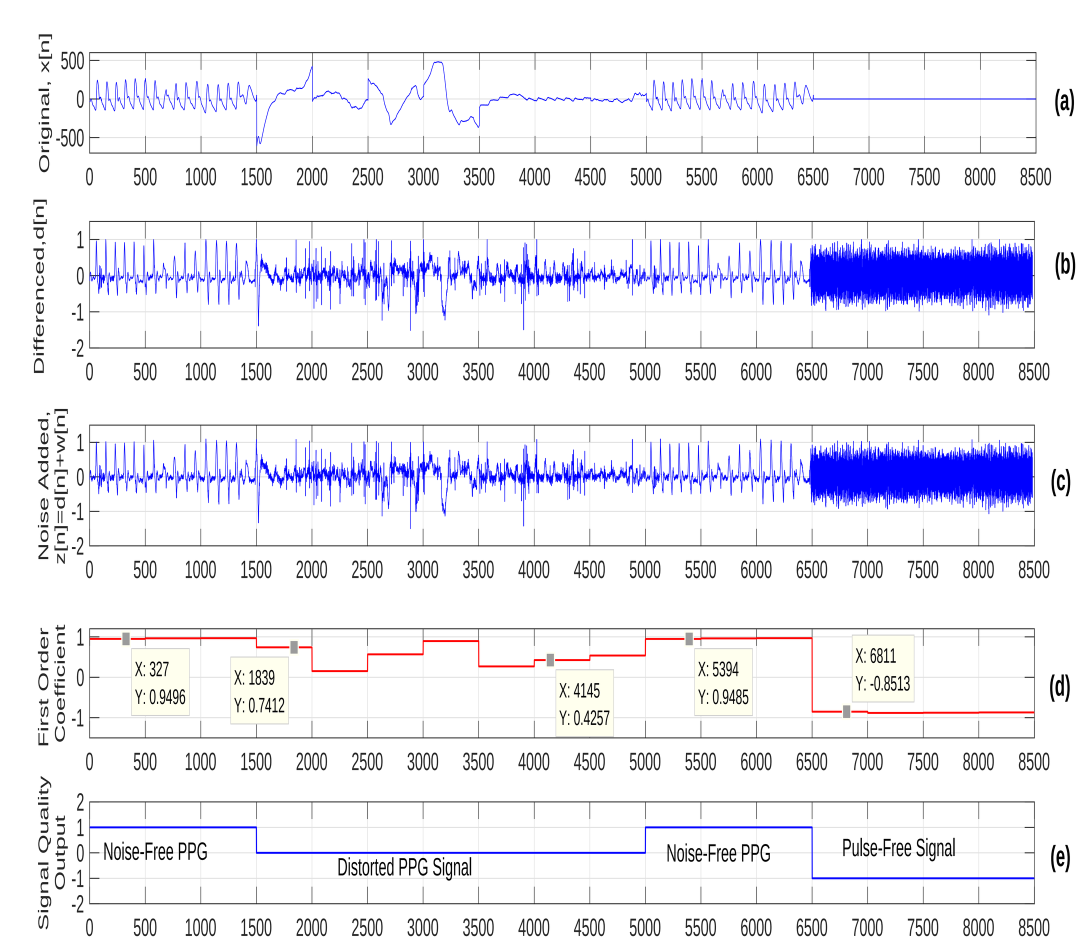

Figure: Illustrates the outputs of each stages of the proposed FOPC-DS feature based PPG SQA method.

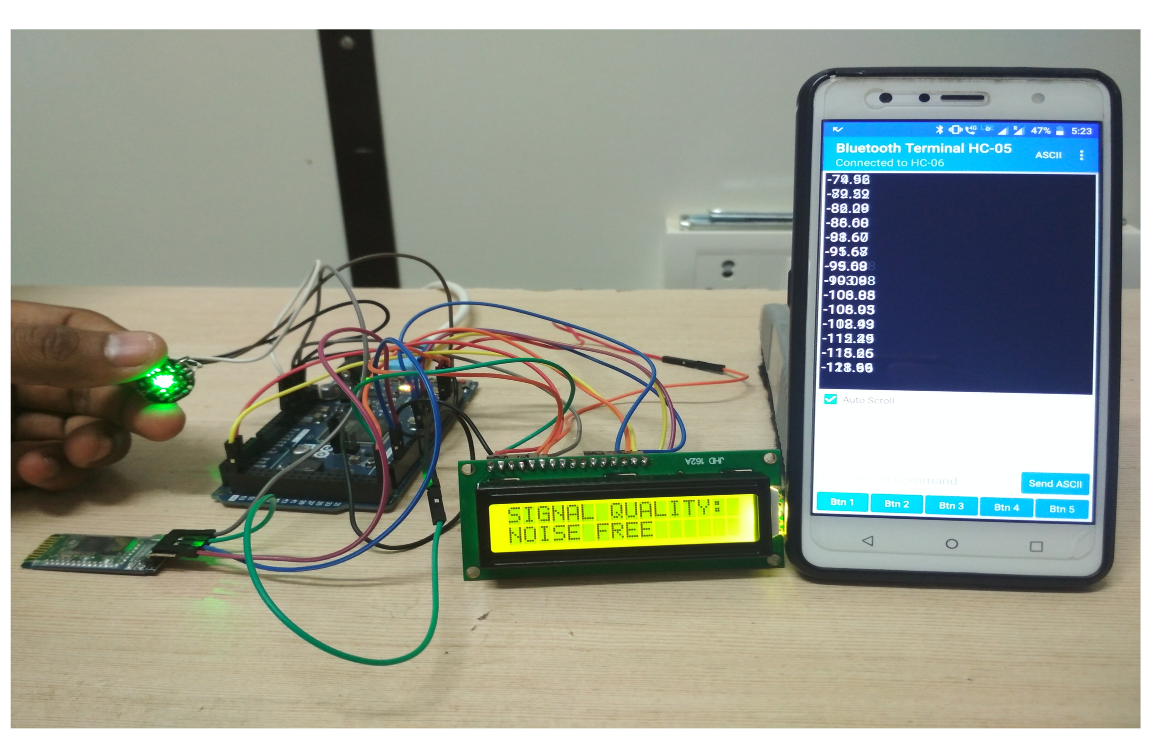

Figure: Real-time evaluation Set-up for evaluation of the proposed on-device PPG-SQA system on Arduino Due platform.

Table: Performance comparison of the SQA Methods

Method	TP	FN	TN	FP	Se (%)	Sp (%)	OA (%)	Time (ms)	Memory (kB)	EC (mJ)
Proposed	9822	178	18141	1859	98.22	90.71	93.21	420.1	29.56	0.141
SVM (RBF)	9822	178	17718	2282	98.22	88.59	91.80	420.4	126.85	–
SVM (Linear)	9839	161	17569	2431	98.39	87.85	91.36	420.2	141.7	–
Kurtosis [2] *	7748	2252	7026	12974	77.48	35.13	49.24	111.1	9.86	90.80
SE [2] *	7945	2055	4725	15275	79.45	23.625	42.23	122.4	9.03	52.13
Kurtosis+SE [2]*	6729	3271	5043	14957	67.29	25.21	39.24	138.5	10.98	109.08
Fiducial [1]*	7800	2200	14560	5600	78.00	72.22	74.13	540.6	28.02	6.71

RBF:(C=100; gamma=0.5); Linear (C=100); Memory space includes the model size for the SVM based method. * Thresholds are chosen as presented in Refs. [1] and [2]

Table: Energy saving analysis for the PPG monitoring system with and without SQA method.

Test Signal Scenarious	System without SQA			System with SQA			Overall Energy (with SQA) Saving/Extra
	EC_{SQA} (mJ)	**EC_{TR}** (mJ)	**TEC** (mJ)	**EC_{SQA}** (mJ)	**EC_{TR}** (mJ)	**TEC** (mJ)	
60 sec Noise free PPG Signal	NE	2562	2562	0.1415	2562	2562.14	0.005% Extra
60 sec-Noisy Signal	NE	2562	2562	0.1415	NE	0.1415	99.99% Saving
5-sec Noisy Signal out of 60 s Signal	NE	2562	2562	0.1415	2306	2306.14	9.98% Saving

Conclusion

- The method has overall accuracy of 93.21 % , false alarm reduction rate of 90.71% and a missed acceptable quality rate of 1.78%.
- The method has lower overall energy consumption of 141.49 μJ as compared to the other SQA methods.
- The proposed quality-aware PPG transmission system can save a transmission energy consumption from 9.98% to 99.99% for noisy PPG signals with a duration from 5 s to 60 s.

References

[1] C. Orphanidou et al., "Signal-quality indices for the electrocardiogram and photoplethysmogram: Derivation and applications to wireless monitoring," IEEE J. Biomed. Health. Informat., vol. 19, no. 3, pp. 832-838, May 2015.

[2] Selvaraj et al., "Statistical approach for the detection of motion/noise artifacts in photoplethysmogram," in Proc. IEEE Int. Conf. Eng. Med. Biol. Soc., pp. 4972-4975, 2011.

Publications

- G. N. K. Reddy, M. S. Manikandan and N. V. L. N. Murty, "On-Device Integrated PPG Quality Assessment and Sensor Disconnection/Saturation Detection System for IoT Health Monitoring," in IEEE Transactions on Instrumentation and Measurement.
- G. N. K. Reddy, M. S. Manikandan and N. V. L. N. Murty, "Integrated Data Compression and Pulse Rate Extraction Scheme Using Differential Coding for Wireless PPG Monitoring Devices," in Proc. IEEE Int. Conf. ICIIS., pp. 48-53, 2018.

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