Remote radar-camera vital sign monitoring system using a graph-based extraction algorithm

Xingyu Yang[1], Zijian Zhang[1], Yalin Zheng[2], and Yaochun Shen[1*]
[1]Department of Electrical Engineering and Electronics, University of Liverpool, Liverpool L69 3GJ, UK
[2]Department of Eye and Vision Science, University of Liverpool, Liverpool L7 8TX, UK

***Abstract*— Mm-wave radar and video-based technologies have shown potentials for contactless detection of vital signs. However, state-of-the-art signal processing based vital sign extraction methods are prone to disruptions, such as motion corruption. In this work, we propose a graph-based segmentation algorithm for improved accuracy and robustness. We developed a combined radar-camera system with a novel graph-based algorithm for the extraction of vital signs. The test results on both mmWave radar and camera systems were found to be of high correlations (0.95-0.97) with the golden standard. Our system provides a viable and robust approach for the increasingly popular remote cardiovascular sensing and diagnosing posed by Covid-19.**

I. INTRODUCTION

CARDIO-VASCULAR pulses are one of the most frequently measured and important human vital signs. Heart rate (HR) can be conventionally measured using contact-based technologies, including electrocardiography (ECG) and pulse oximetry [1]. As the Covid-19 pandemic is forcing the digital transformation of the healthcare industry, contactless and remote monitoring technologies become clinically critical [2]. Previous studies have explored the feasibility of remote heart rate monitoring using Frequency Modulated Continuous Wave (FMCW) radars [3] and recorded face videos separately [3, 4].

The most widely used method for the extraction of vital signs is finding the largest spectral magnitude of the detected photo-plethysmography (PPG) signal from the recorded videos. However, due to the intrinsic phase noise and motion of the subject, noise reduction and interpolation measures need to be performed to achieve acceptable accuracy [3, 4].

In this work we report the use of a combined FMCW radar and a digital camera system to measure vital signs in real-life situations. The HRs are extracted from the measured time-frequency map using a novel graph-based segmentation method. The proposed algorithm is validated with a contact-based golden-standard ECG device by calculating the Pearson Correlation Coefficients (PCC). The results demonstrate greatly improved measurement accuracy and robustness against conventional spectral methods.

II. EXPERIMENT SETUP

The FMCW device used in this work was an mm-wave radar chip (IWR 1843, Texas Instruments). It is capable of operating in the 76-81 GHz band with up to 4 GHz continuous chirp. The device was programmed to perform measurements at 20 Hz. The phase-resolved processing method is used to monitor small-scale displacements. The detected heart and chest vibration signals were organized into a time-frequency map for further extraction.

A consumer-grade webcam was used for video recording of the human face at 30 Hz with cheeks and nose areas as the region-of-interest (ROI). The pulses and chest movements are indistinguishable by human eyes but detectable by differences between frames. Similarly, the heart and chest displacements are presented in the same format as FMCW results.

The ground truth was simultaneous ECG measurements obtained by using the golden-standard Polar H10 heart belt. It measures ECG signals hence unable to be presented in the same map. The beats-per-minute (BPM) with respect to time results from three sources will be cross-compared as validation.

The subject was requested to exercise prior to the test and sit stationary during the test. However, unconscious body and head movements caused by hyperventilation might still occur. The system configuration is illustrated in Fig 1.

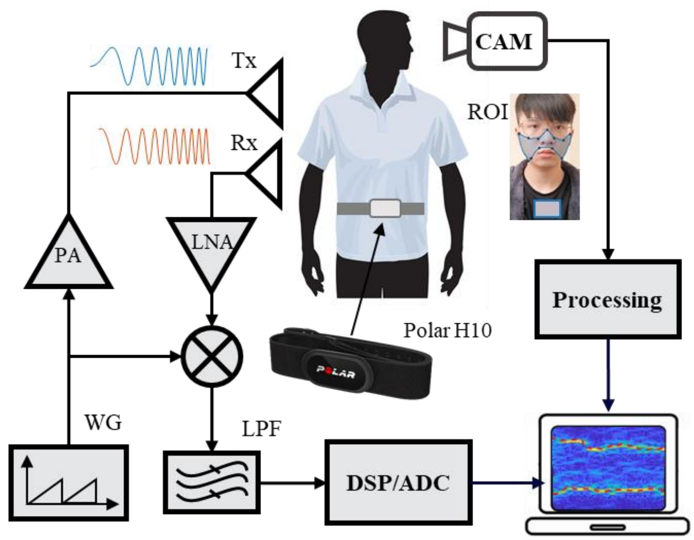

Fig. 1. The schematic diagram of the combined system based on a single FMCW chip and a consumer-grade camera. A Polar H10 ECG device is used for validation.

III. EXTRACTION METHOD

The short-time Fast Fourier Transform (FFT) is applied to the measured time-domain radar and video signals and the resultant time-frequency maps are shown in Fig. 2. The image pixel intensity represents the FFT spectral magnitude and the pixels with the highest intensity usually correspond to the heart rate (heartbeat frequency). However, spectral noise caused by motion disruption can be observed in the figure thus the pixels with the highest intensity may not always give the correct heart rate. To address this, we propose to use a graph-based method.

The method we proposed is morphological operation-based image segmentation [5]. Firstly, we employ a Canny edge detector with adaptive thresholds and sigma values to roughly localize the desired signals. Adaptive thresholding is also reported in [6, 7]. Then, image dilation and erosion are performed using two short and vertical linear structuring elements. The main structures of the signals are extracted. Lastly, spline interpolation was performed to remove minor discontinuities. The red dashed lines in Fig. 2 represent the extracted HR using the proposed method. The downward trend is in line with the post-exercise recuperation.

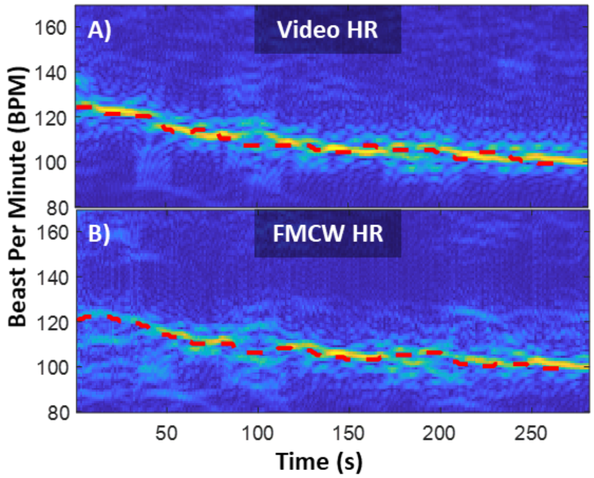

Fig. 2. Joint BPM-Time diagram of spectral energy. Red dashed lines indicate the HR signals extracted using the proposed segmentation algorithm. A) Result from face video. B) Results from FMCW radar.

IV. Results

The results from three sources of data are cross-validated using Bland-Altman Plot, as shown in Fig.3. The Y-axis indicates the difference between the two data, while X-axis indicates the mean of two data. The 95% prediction interval (p.i.) is the region between the two red dashed lines. The segmentation-based method is less scattered outside of the p.i. region compared to the spectral-based method. The plot demonstrates that the proposed approach generates HR signals with less discrepancy from both FMCW and video data.

The PCCs of the radar, camera and Polar H10 are listed in Table.1. Both the proposed and conventional spectral methods are highly correlated with the golden standard. Also, a high correlation is observed between FMCW and video signals despite the use of methods. It shows that the proposed radar-camera system is reliable.

The proposed extract method also demonstrates superior performance. The PCCs appear to be near 100% in all three comparisons. Furthermore, the segmentation method is found to be at least 13% higher than the conventional method.

Table. 1. Pearson correlation coefficient comparison

	FMCW vs Video	FMCW vs ECG	ECG vs Video
Proposed	0.9707	0.9493	0.9522
Spectral Mag	0.8533	0.8196	0.9549

V. Summary

A combined FMCW radar and camera system using a segmentation-based signal extraction method was reported in this work. It was found that the proposed system demonstrates high measurement accuracy and reliability, as validated by using golden standard ECG device. Secondly, the graph-based segmentation method provides a robust way for extracting the HR from both the video and radar signals. The obtained HR measurements are highly correlated with the golden standard device.

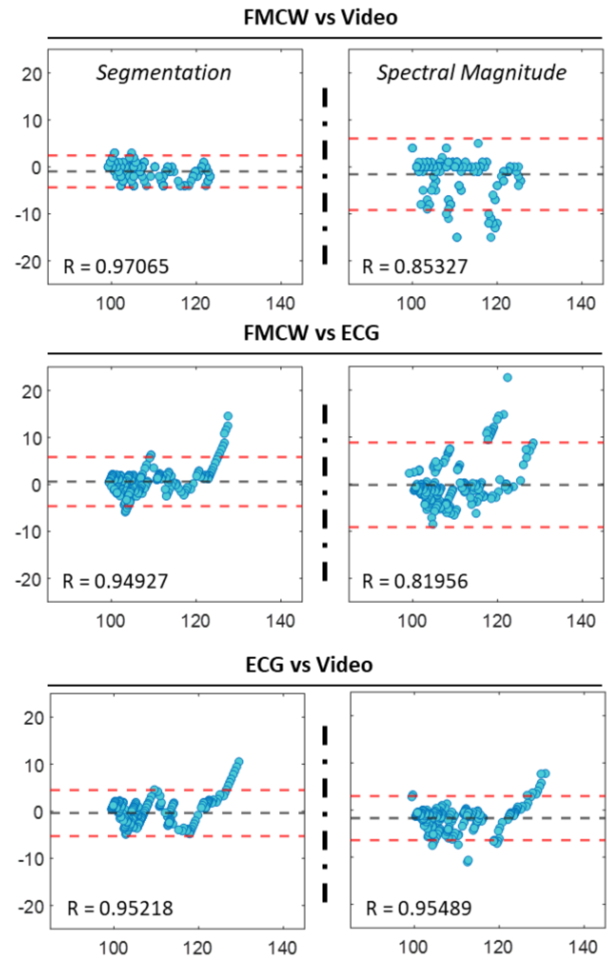

Fig. 3. Bland-Altman Plots of the cross-comparisons. Left column shows results from the proposed image segmentation method. Right column shows results from the conventional spectral magnitude method.

Acknowledgement: This work is partially supported by the Engineering and Physical Sciences Research Council (EP/R014094/1) and the Royal Society (IEC\NSFC\181415).

References

[1] Y. Hao and R. Foster, "Wireless body sensor networks for health-monitoring applications," *Physiological measurement*, vol. 29, no. 11, p. R27, 2008.

[2] N. Peek, M. Sujan, and P. Scott, "Digital health and care in pandemic times: impact of COVID-19," *BMJ Health & Care Informatics*, vol. 27, no. 1, p. e100166, 2020, doi: 10.1136/bmjhci-2020-100166.

[3] M. Alizadeh, G. Shaker, J. C. M. De Almeida, P. P. Morita, and S. Safavi-Naeini, "Remote monitoring of human vital signs using mm-Wave FMCW radar," *IEEE Access*, vol. 7, pp. 54958-54968, 2019.

[4] W. Verkruysse, L. O. Svaasand, and J. S. Nelson, "Remote plethysmographic imaging using ambient light," *Optics express*, vol. 16, no. 26, pp. 21434-21445, 2008.

[5] R. Van Den Boomgaard and R. Van Balen, "Methods for fast morphological image transforms using bitmapped binary images," *CVGIP: Graphical Models and Image Processing*, vol. 54, no. 3, pp. 252-258, 1992.

[6] W. Rong, Z. Li, W. Zhang, and L. Sun, "An improved Canny edge detection algorithm," in *2014 IEEE International Conference on Mechatronics and Automation*, 3-6 Aug. 2014 2014, pp. 577-582, doi: 10.1109/ICMA.2014.6885761.

[7] S. Z. Li, "Close-form solution and parameter selection for convex minimization-based edge-preserving smoothing," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 20, no. 9, pp. 916-932, 1998.