Non-Contact Heart Rate Monitoring in Neonatal Intensive Care Unit using RGB Camera

Qiong Chen, Xinyu Jiang, Xiangyu Liu, Chunmei Lu, Laishuan Wang, Wei Chen*

Abstract— **Heart rate (HR) measurement is crucial for newborn infant monitoring in the neonatal intensive care unit (NICU). The widely used contact HR measurement methods based on electrocardiography (ECG) and photoplethysmography (PPG) signals can lead to discomfort and possible skin irritation on neonates, which limit its application in NICU scenarios. In this work, we propose a non-contact HR monitoring method simply using a RGB camera. Eulerian video magnification (EVM) is employed to detect the subtle changes of neonatal faces results from blood circulation. The magnified signal is then transformed to the spectral domain to extract HR information. Compared with the widely investigated independent component analysis (ICA)-based HR measurement method using video recordings, the proposed method can achieve the real time HR measurement, which is a significant superiority in NICU neonatal monitoring. To the best of our knowledge, this is the first study to employ EVM algorithm in real time neonatal HR monitoring.**

Clinical relevance— **Premature neonates are prone to bradycardia induced by a variety of factors. A low cost and convenient non-contact HR monitoring system can help to trigger alerts when neonates are in a abnormal physiological status, which may further contribute to the improvement of neonatal survival rate in NICU.**

I. INTRODUCTION

Premature infants are prone to bradycardia induced by a variety of factors, such as sepsis [1] and immature respiratory development [2]. Accordingly, as a crucial physiological indicator, heart rate (HR) is of significance and necessity for neonatal health monitoring in the neonatal intensive care unit (NICU). The current golden standard of HR monitoring is based on electrocardiography (ECG) and photoplethysmography (PPG) signals measured by ECG sensors [3] or pulse oximeters [4]. Although these methods [3][4] are low cost and have been widely employed in healthcare services, they have shown great limitations in neonatal HR monitoring. First, neonates are highly susceptible to external interference. The skin-sensor attachment may lead to discomfort and pain of neonates, which may further result in a negative impact on neonates' cognitive development [5]. Besides, previous studies [6] indicate that the repetitive placement and removal of sensors is adverse to the health and development of neonates. Moreover, the electrode conductive gel and the cables in such contact HR monitoring scenarios also increase the allergic and electrical risks.

The alternative non-contact HR monitoring methods include laser Dopplers [7], microwave Dopplers [8], white noise [9] and thermal images [10]. However, these methods are both high cost and requiring extra specialized hardwares. Compared with the above methods, camera-based method is economical, with operation convenience and good performance as well. The principle is that hemoglobin and oxyhemoglobin in blood vessels can absorb specific wavelength of light, whereas the surrounding tissues can not. During each heart beat, changes in blood volume cause regulate light transmission and reflection, contributing to subtle skin color changes which are invisible for human eyes but can be captured by cameras. Poh et al. [11] proposed a method for non-contact HR measurement using a webcam. In their method, the red, green and blue (RGB) color channels are extracted from the video recording. Independent component analysis (ICA) is then performed on the obtained three channels to separate three underlying source signals including HR. The ICA-based method is the first attempt to extract HR from video recordings and has been widely applied in HR monitoring for adults. However, some drawbacks of this method limit its application in neonatal HR monitoring. [11] performs ICA on each 1-min trace of the video recording and achieves good performance in most offline signal processing tasks [12], but still challenging for online monitoring. However, real time HR measurement is required for the timely warning on the physiological status of neonates in NICU, how to improve the robustness of online ICA is still unsolved.

To address the aforementioned issue, we propose Eulerian video magnification (EVM) [13] instead of ICA to extract HR-related component from a video recording. We first extract the face of neonates as the region of interest (ROI) in HSV color domain. EVM is then performed to magnify the color signals in ROI and the green channel is selected as blood volumn pulse (BVP) component. Then the HR can be estimated in the spectral domain via fast Fourier transform (FFT). We extract HR from each $\frac{1}{9}$ s video recording, therefore, our method can achieve the real time HR monitoring. Also, compared with adults, non-contact neonatal HR monitoring using video recordings is much more challenging due to the obscure neonatal facial features. To the best of our knowledge, this is the first study to apply EVM to neonatal HR monitoring in NICU. Our method can further contribute to NICU neonatal healthcare and home care.

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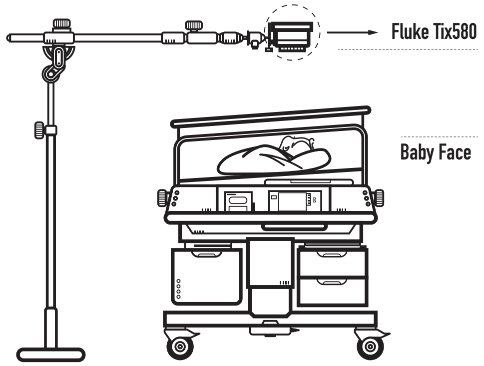


Fig. 1: Placement of camera and incubator during our experiment.

II. Materials

In our experiment, we record neonatal videos of 5 Chinese infants, aged 13-25 days, at the Children's Hospital affiliated to Fudan University. All videos are recorded via TiX580 camera of Fluke Corporation, in two types of color patterns, namely RGB and thermal. To develop a low cost neonatal HR monitoring system in NICU, only the RGB video pattern is employed in our work. The RGB videos are recorded at 9 frames per second (fps) with a 640×480 pixel resolution. The experiment is approved by the ethics committee of Children's Hospital affiliated to Fudan University, Shanghai, China.

During the video recordings, an FDA-approved and commercially available Nicolet EEG equipment with ECG leads (Phecda (China) Ltd) is used to measure neonates' ECG signals at a 500 Hz sampling rate. The video recordings are synchronized with the ECG signals. The ECG signals acquired in the golden standard are employed as the ground truth of the HR parameter, to evaluate the performance of our proposed method. The experiments are conducted in a quiet and private room. During the experiment, the neonates are lying relatively still in an incubator, which is around 0.25-0.36 m below the camera, as shown in Fig. 1. A 3-min video is recorded for all neonates.

III. Methods

All acquired data are analyzed in custom programming softwares (Python and MATLAB). Fig. 2 shows the framework of the proposed method to measure HR from video recordings. The details of the proposed method will be described in the following subsections.

A. ROI Segmentation

The first step to extract HR information from video frames is to define the ROI, which is the neonatal face in our work. For the particular image segmentation and ROI tracking tasks in our work, mathematical morphology-based method is employed. We segment the face of neonates in HSV domain using dilation and erosion operations [14]. First, we convert the video recordings from RGB color domain to

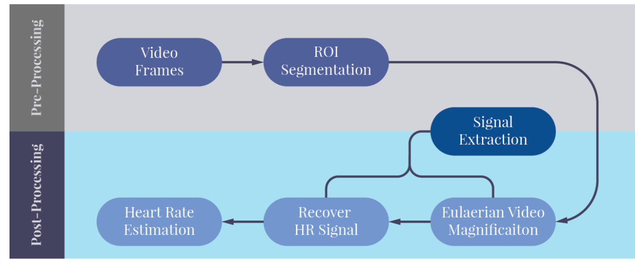
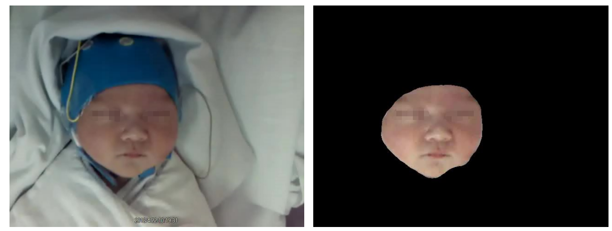


Fig. 2: Framework of the proposed non-contact HR monitoring method.



(a) ROI with background noise. (b) Result of ROI Segmentation.

Fig. 3: ROI segmentation

HSV color domain. Normally, the skin color in HSV domain falls in a particular range (a range of [45, 60] in H and V channels for Chinese neonates). Accordingly, pixels with HSV values outside this range are filtered out. The close operation (the process of a dilation operation followed by an erosion operation) and open operation (the process of an erosion operation followed by a dilation operation) are applied in succession to optimize the ellipse boundary of neonates' face. The segmented videos in HSV domain are then transformed back to RGB domain. Fig. 3 presents an example of ROI segmentation. The face of a representative neonate before and after ROI segmentation are shown in Fig. 3(a) and Fig. 3(b) respectively. Since background noise is unavoidable in the entire frame, leading to deviation for the extracted blood volume pulse (BVP) signals, the ROI segmentation procedure removes the background noise, leaving infants' face as the only target in the following signal process pipeline.

B. Eulerian Video Magnification

EVM was first proposed by Wu et al. at MIT [13]. Instead of tracking the movement of specific pixels over time from Lagrange perspective, eulerian perspective can detect and magnify the subtle changes of the whole picture. In our EVM-based method, we first decompose the input frames of the neonatal face into different spatial and spectral bands through Gaussian Pyramid. A temporal filter is then applied to all spectral bands to remove noises. To make the HR signals visible to human eyes, the amplitude of the filtered spatial bands are magnified by a given factor α, (normally set between 100 to 200 to magnify the changes of face color). Finally, the original signal is added to the magnified signal to reconstruct the output video.

TABLE I: Metrics for HR Estimation

Metric	Definition	Formula
MAE	Mean Absolute Error	$\frac{1}{N}\sum_{i=1}^{N}\lvert H_e(i)-H_r(i)\rvert$
MRE	Mean Relative Error	$\frac{1}{N}\sum_{i=1}^{N}\lvert\frac{H_e(i)-H_r(i)}{H_r(i)}\rvert$
SD	Standard Deviation	$\sqrt{\frac{1}{N}\sum_{i=1}^{N}\lvert H_e(i)-H_r(i)-MAE\rvert}$
RMSE	Root Mean Squared Error	$\sqrt{\sum_{i=1}^{N}\frac{(H_e(i)-H_r(i))^2}{N-1}}$

C. Recovering HR signals

Since the green channel shows the highest signal-to-noise ratio (SNR), we select the green channel in the post processing procedure in our work. Because the neonates characterize a higher HR compared with adults (normally 110-160 bpm or 1.8333-2.6667 Hz), we set the smoothing bandpass filter to that specific spectrum range and apply FFT to obtain the signal power spectrum. Based on the fact that HR is a kind of strongly periodic signals, the frequency with the highest power in the spectral domain is defined as the HR estimated from the video recordings. The ground truth of HR is likewise extracted from the ECG power spectrum in the same manner.

D. HR estimation

Once we have detected the frequency corresponding to the highest peak of power spectrum, denoted as f_{peak}, HR is then calculated as follows,

$$\mathrm{HR} = f_{peak} \times 60. \tag{1}$$

E. Performance Evaluation

Due to the higher sampling rate of ECG (500 Hz) compared with the frame rate of camera (9 fps), we calculate a HR in each $\frac{1}{9}$ second for both ECG and video signals to synchronize the estimated HR values. The estimated HR value for the i_{th} video frame is denoted as $H_e(i)$. The corresponding HR estimated from the ECG signal is denoted as $H_r(i)$. Normally, neonates characterize higher HR values than adults. To conduct a fair comparison between our method for neonatal HR monitoring and the previous ones applied in adult HR monitoring without bias, mean relative error together with mean absolute error is used to evaluate the performance of non-contact HR measurement. All of the metrics used to evaluate the performance of proposed method are shown in Table I.

IV. RESULT

A. Intuitive Results

Using the method illustrated in the last Section, we extract BVP pulse wave from the recorded videos via EVM. The raw

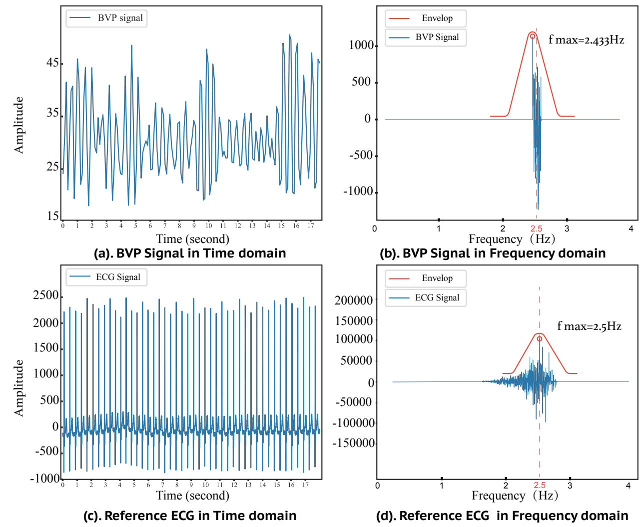


Fig. 4: Intuitive Result.

BVP signal of a representative subject (subject 2) recovered from the video recording is presented in Fig. 4(a). The corresponding reference ECG pulse signal of the same subject is shown in Fig. 4(c). Both signals in Fig. 4(a) and Fig. 4(c) last around 17 seconds. Obviously, both Fig. 4(a) and Fig. 4(c) show clear pulse waves in time domain. In Fig. 4(b) and Fig. 4(d), the highest spectrum peak can be detected at 2.433 Hz (145 beats/min) and 2.50 Hz (150 beats/min) respectively, indicating the promising performance of HR measurement using our method.

B. Quantitative results

The MAE, MRE, SD and RMSE value for all 5 subjects are shown in Table II. Our method achieves an average MAE of 7.4009 and MRE of 12.4639%. In particular, for subject 2, we yeild a MAE of 4.6256 and MRE of 4.04%. We compare the proposed approach with several state-of-the-art methods under similar experimental situations [15]. The performance among different methods is given in Table III (some experiments are implemented in an ideal laboratory environments, others carried out under realistic conditions like ours). As the first attempt to employ EVM in real time neonatal HR monitoring in NICU, our method achieves a promising performance compared with the state-of-the-art methods. The performance can be further improved by addressing the limitations of our work in the following studies, which we present in the following Discussion section.

V. DISCUSSION

As the first study, the preliminary results have shown the promising prospects of the proposed method in practical application scenarios. Some limitations can be hopefully addressed in our following future work to further improve the performance. First, the camera resolution and sampling rate is relatively low compared with previous studies, which reduces the computational complexity but at the same time, may lead to performance degradation during HR tracking. Moreover, the

TABLE II: Quantitative results for each subject

	MAE	*MRE*(%)	*SD*	*RMSE*
Sub1	9.0140	7.86	10.9545	15.7438
Sub2	4.6256	4.04	14.1940	18.0350
Sub3	5.6787	5.09	12.7997	16.6081
Sub4	5.7650	5.06	9.1725	9.1164
Sub5	11.9214	8.77	15.2001	16.4113
Average	7.4009	6.1640	12.4639	15.1829

TABLE III: Comparison among different methods under similar experimental situation

Method	*MAE*	*MRE*(%)	*SD*	*RMSE*
Poh et al. [11]	8.95	25.0	24.3	25.9
Balakrishnan et al. [16]	14.4	20.7	15.2	21.0
Kwon et al. [17]	7.96	23.6	23.8	25.1
Ours	7.4009	6.1640	12.4639	15.1829

neonates in the incubator may unconsciously and frequently swing their heads from side to side. The motion artifacts may reduce the robustness of ROI segmentation and video magnification in particular cases. This issue can be addressed in the future work by employing advanced techniques for the estimation and calibration of face orientation [18]. Adaptively switching between multiple cameras can also contribute to solving this problem. The current work is a pilot study and can hopefully broaden the horizons of current non-contact neonatal HR monitoring field.

VI. CONCLUSION

In this work, we propose a novel method for real time neonatal HR monitoring in NICU in a non-contact way. Morphology-based filtering and EVM are employed to extract the HR signal from subtle changes of facial features due to blood circulation, by simply using signals acquired via a RGB camera.To the best of our knowledge, this is the first study to employ EVM algorithm in real time neonatal HR monitoring, As a primary study, our work only attempts to extract HR information from video recordings. The non-contact measurement of a variety of other physiological parameters, such as breath rate and blood oxygen saturation, can be achieved in the recent future. Our work can contribute to the body of knowledge in neonatal health monitoring field and hopefully help to improve of neonatal survival rate in NICU.

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