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Infant heart rate estimation based on non-contact UV photoplethysmography

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ABSTRACT

Non-contact cardio signal monitoring is a requisite for premature infants, as adhesive sensors and electrodes such as that for an electrocardiogram can damage the epidermis. Many types of research on infants in the newborn intensive care unit (NICU) are still in their early stages with many challenges. Therefore, this study aims to use a digital camera as a non-contact photoplethysmography imaging method to measure and compare the heart rate from two experiments (without/with ultraviolet rays (UV)) inside the intensive care unit. The two experiments (without/with UV) rays yielded promising results in comparison with the reference measurements obtained from ten infants. The results reveal a robust correlation using the pearson correlation coefficients (PCC) of 0.99 (for without UV) and 0.96 (for with UV). Also, the spearman correlation coefficient (SCC) test of 0.97 and 0.95 for two experiments, respectively Bland–Altman analysis revealed a strong relationship between measured and reference readings from without and with UV. The experimental results obtained a low error rate for mean absolute error (MAE), and root mean squared error (RMSE). Therefore, this work presents a new aspect of non-contact monitoring, showing promising performance for upcoming medical applications.

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1. INTRODUCTION

Monitoring vital signs have an important role in preserving infants' lives, such as monitoring breathing rate (BR), blood oxygen saturation, and heart rate (HR), given their major role in diagnosing the health status of infants in the hospital or at home [1], [2]. Currently, many types of medical equipment utilized for monitoring vital signs are dependent on contact sensors and their accessories as they are adapted from contact-based electrodes, sensor modalities, probes, or straps in emergencies [3], [4]. Currently, non-contact methods are significant for the evaluation of vital signs and are one of most research interests in biomedical and clinical applications [4]-[6]. This is because traditional measurement methods use adhesive biosensors and electrodes for extracting parameters such as electrocardiograms (ECG), spirometry probes, and pulse oximeter electrodes in emergencies [7], [8]. The contraction and elimination of these adhesive biosensors and electrodes can harm the skin, and also restrict the infant's movement [9], [10].

Accordingly, these aforementioned limitations have spurred researchers to introduce alternative methods such as non-contact methods for measuring cardio signals, which include approaches based on the doppler and thermal imaging-based methods. However, these aforementioned methods are mostly affected by noise and motion artifacts. Besides, These techniques are limited in the distance they can cover and necessitate a distinct area of interest (ROI) for conducting measurements and analysis [11]. Thus, constraining the remote movement of the patient is quite a problem due to the cost of the sensor, which prevents the extraction of adequate sampling of the body. They have low resolution, limiting detection range. The radar energy used may be harmful to human health, causing future effects on skin tissue [12], [13].

These invisible cardiac signals can be significantly useful, especially in biomedical and clinical applications. The blood circulation generates subtle changes in skin color that can be enhanced to assess and extract information about heart activity when epidermis tissue is illuminated because hemoglobin absorbs light more efficiently than the surrounding epidermis tissue [14]. Thus, several works have improved a computer vision system based on video cameras as a non-contact sensors [15], [16]. Video camera imaging is an appropriate non-contact method where vital signs are extracted from distinct regions of the epidermis human. This innovative technique can be categorized into two significant classes, namely color-based techniques, which are widely known as imaging photoplethysmography (PPG) [17], [18], and motion-based methods [19]. For example, Takano and Ohta were the first to propose the extraction of non-contact imaging information using ambient illumination [20]. Several studies have utilized a digital video camera as a PPG signal detector for extracting the vital signal from the skin of the face using natural ambient light. However, the experimental results show that they are incomplete under illumination conditions. Thus, they achieved PPG signals at short distances of 0.07–0.25 [21], [22], 0.5m, 0.35m, and 1-1.5 m [5]. Other studies [23]-[25] have used the webcam camera technique to extract vital signals such are BR and HR under natural ambient lighting conditions. Though,these works introduced interesting techniques, their application obtained, unclear ROIs, and limited area at a short distance (0.5 m and 1 m). The second-based methods were available for monitoring vital signs in the various biomedical fields. For example, several researchers [26]-[28] proposed a non-contact method for evaluating the BR from chest movement by using a video camera at short distances (0.5–1 m). However, the results demonstrate a limited distance body to extract BR from the body with a range of 0.5–4.5 m.

Our study presents a unique technique for the ability to extract and measures cardiac signal when an infant exposure to ultraviolet rays. The experimental results have been compared to the ambient light-based color method of previous studies. In this work, our contribution i.e.,: i) proposed a unique non-contact system to measure a cardio signal with UV rays based on the color method utilizing video camera imaging, ii) an efficient and fast infant chest algorithm was proposed, and iii) proposed an improved ROI automatic selection technique that could deal with an infant in a different angled positions including unclear ROl. We discovered a significant correlation with a minimum error rate between data collected by the proposed technique and reference values, implying that the video imaging technique can be used in the newborn care unit (NICU). In addition, may have broader applications, such as home care monitoring.

2. METHOD

2.1. Ethics consideration

The study approval of this work was obtained from a pediatrician at NICU after fully explaining the objectives of the experiment before commencing the experiment. The approval was included to take video recorders at different times of infants at the Child Central Teaching Hospital (CCTH) in Baghdad, Iraq. After an explanation of the details works and objectives of the experiment.

2.2. Participants and reference standard

In this work, we used ten infants divided into two groups, the first consisting of five infants without UV rays over them, while the second consisted of five infants with UV rays used. Infants were aged 23 to 38 weeks and weights from 1,600 to 3,000 g. In this work, for evaluated purposes, an ECG monitor was utilized as a reference standard for comparing and analyzing the performance of the two proposed experiments. To extract the heart rate, the ECG device's impedance electrode measures the variation in electrical impedance.

2.3. Experiment setup

In this study, two experiments are carried out to measure the cardio signal of infants. In the first experiment, the surrounding light was the source of illumination in the room such as daylight through (windows or doors) or through fluorescent lamps installed in the ceiling walls of the central care monitoring rooms at night. The first experiment, the five infants were not exposed to UV rays, thus it called (without UV); whereas the second experiment was performed when exposure UV rays were on the second group (five infants). The second experiment investigated the influence of UV rays when extracting cardiac signals, so it is called (with UV).

Video cameras are used to overcome the critical limitations of contact-based techniques, thus the two digital cameras were utilized to register videos of ten infants placed in the incubators, while the ECG monitor as reference information presenting the bio signs continuously. To get the video recording of the infant and the ECG, for two experiments, a Canon 700D with a resolution of (1,920×1,080) at 30 fps and a Canon 650D were utilized, respectively. The digital cameras were fixed on tripods at a distance of approximately (1-3 m). To capture measured data from the ECG screen and contactless work, cardio signal information was recorded from both cameras simultaneously as revealed in Figure 1. The experiments were conducted on ten infants in the same environmental conditions of their care unit. Two experiments were conducted in the CCTH, Baghdad. Immediately after recording, the clips were downloaded to a laptop.

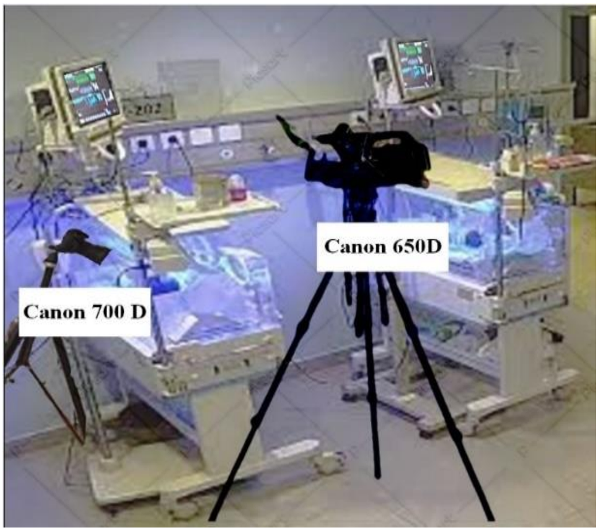


Figure 1. The experimental configuration for the proposed work where the information was recorded

3. SYSTEM FRAMEWORK OF PROPOSED WORK

To measure the cardio signal of infants based on the infant chest detection algorithm by using non-contact photoplethysmography. The proposed block diagram is illustrated for two experiments in Figure 2. The system framework work includes four-stage processing: ROI selection, signal extraction, a spectral analysis technique, and peak detection.

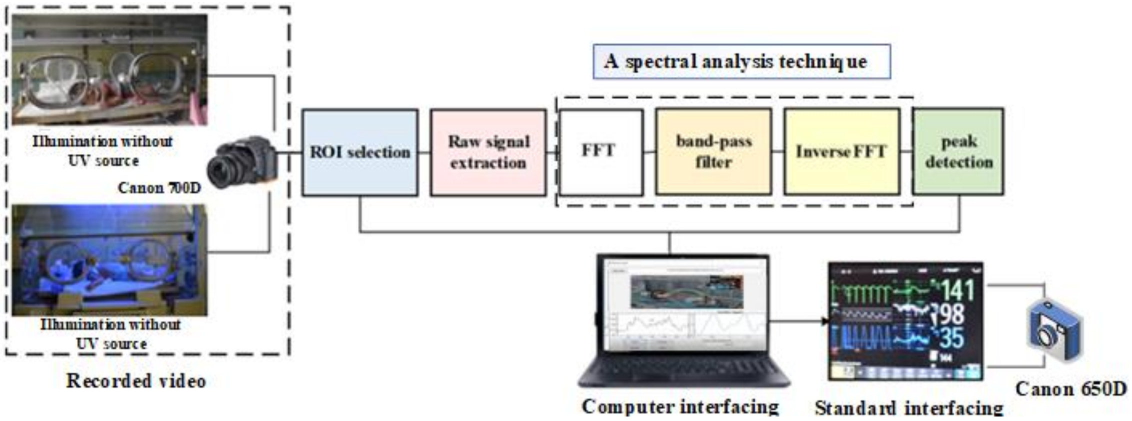


Figure 2. Block diagram for parts components of processing for non-contact photoplethsymography system proposed

First stage: ROI selection was achieved based on a chest detection algorithm to select ROI from the chest region of the infant from two experiments (without/with UV). Instead of utilizing a manual ROI selection technique, an automatic optimization ROI selection technique was proposed. A chest detection algorithm is achieved by MATLAB’s function [ginput], which can localize ROIs automatically (x-axis and y-axis). It could deal well with different positions in unclear regions of the infant, such as angled or inclined positions body.

Second stage: signal extraction was applied to extract a raw cardio signal by using principal the reflectance features of infant skin from video capture. The three-channel red, green, and blue (RGB) of the ROI are separated. RGB channels and it is taken spatially averaged for all pixel values at each channel RGB according to the image sequences as given in (1).

$$I_{RGB\ (t)} = \frac{\sum_{x,y \in ROI} I(x,y,t)}{|ROI|} \quad (1)$$

Where I (x,y,t) is presented as the illuminance values at the pixel image location (x,y) at time phase (t), and |ROI| indicates the size of the selected ROI from recorded video. The cardio signal obtained from the G channel information was chosen for evaluating the data on heart rate.

Third stage: the spectral analysis procedure depended on applying the fast fourier transform (FFT) to get the power spectrum. So, a cardio signal in the domain frequency was transformed into the time domain. To remove unwanted noise as the second step, noise artifact was achieved by using a perfect band-pass filter with selected frequencies of [0.5-3 Hz], which matched with the cardio signal range [30–180] beats per minute (bpm). Then, the inverse FFT (IFFT) method was then utilized for the filtered signal to get the unique data of the cardiac signal. Figure 3 demonstrates raw cardiac signals (450 frames) obtained after applying the spatial average overhead of all pixels.

Fourth stage: peak detection is carried out by computing the number peaks of the cardio signal in both experiments (without/with UV) rays. Figure 4 presents the cardiac signal obtained after using FFT, band-pass filtering [0.5-3 Hz], and IFFT. The red color markers refer to the peak locations of the filtered signal. The window length of the achieved filtered signal was 15 second. The function ‘find peaks’ was built-in in MATLAB to determine the periodicity of number peaks and their locations, the total duty cycle (D) of signal between two peaks is calculated by utilizing the following (2).

$$D = mean\ (diff(locsHR)) \quad (2)$$

Then, a number of peaks (p) can be evaluated as the following (3):

$$p = \frac{T}{D} \quad (3)$$

where T denotes the video length in seconds at 15 seconds. The heart rate of an infant can be calculated by the yield as shown in (4):

$$VHR = \frac{60\ P}{T} \quad (4)$$

where VHR represents the measured reading (heart rate).

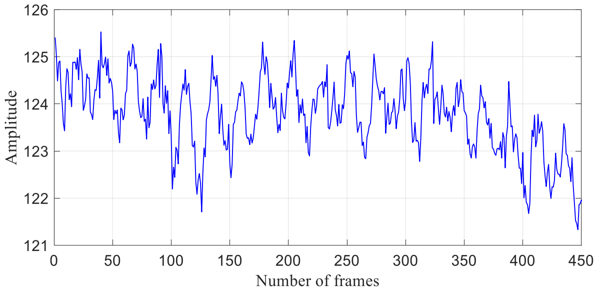


Figure 3. Raw cardio signals signal after filter

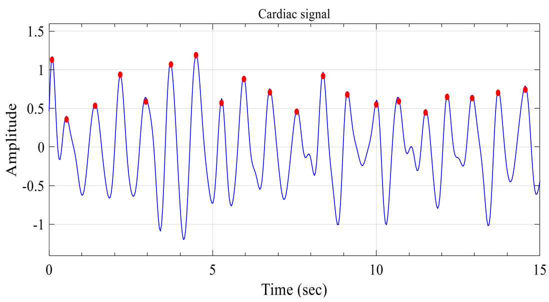


Figure 4. Cardio signal with computation the number peaks

4. RESULTS AND DISCUSSION

4.1. Data comparison

The procedure of collecting data from infants takes a lot of time and effort. In a hospital environment such as NICU, it is extremely defying to register ranked videos of infants. Medical devices or soft layers are typically used to cover or protect infants. For this work, we gathered a small database set to validate our work. Each infant was recorded five times with the best stable situation. Each video has been recorded for about 15 second, consequently, a total of 25 videos are captured for each experiment. The obtained results were displayed in a suggested GUI application as presented in Figure 5.

These obtained measured readings from (4) have been compared with the reference readings for all videos (without/with UV) as shown in Figure 6. It is obvious from Figure 6(a), that the curve of measured readings (without UV) rays and the curve of reference readings (ECG) have the same inclination and same match for data. In contrast, in the second experiment, Figure 6(b) shows a little variation between measured readings (with UV) rays and reference readings (ECG). The measured values without UV rays achieve the best performance than the second with UV rays in terms of matching the data acquired relative to reference readings.

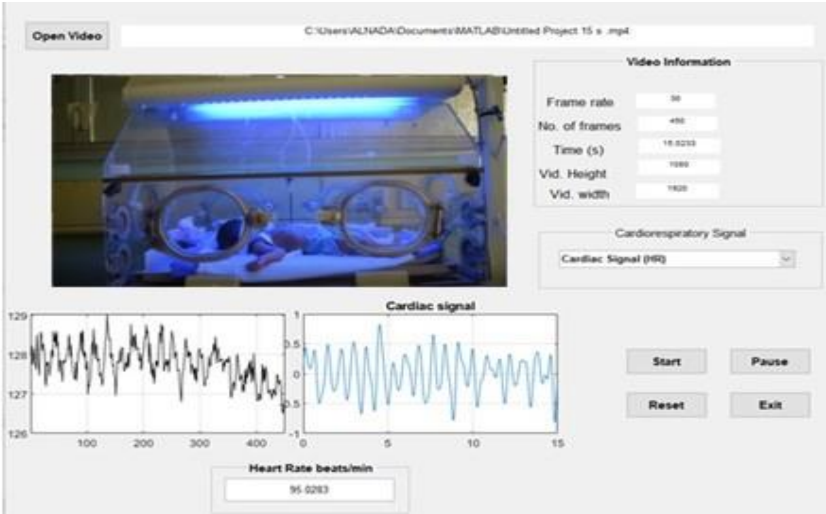
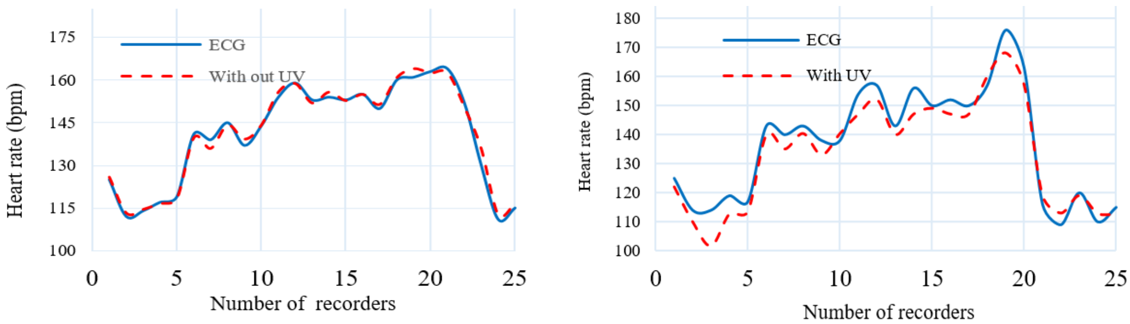


Figure 5. Screenshot of the proposed system's GUI

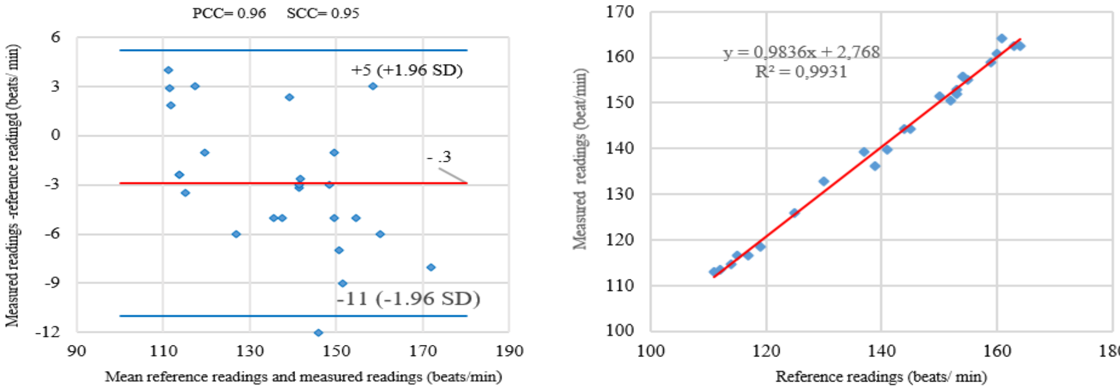


(a) (b)

Figure 6. Comparison of measured readings with reference readings to (a) first experiment (without UV) and (b) second experiment comparison (with UV rays)

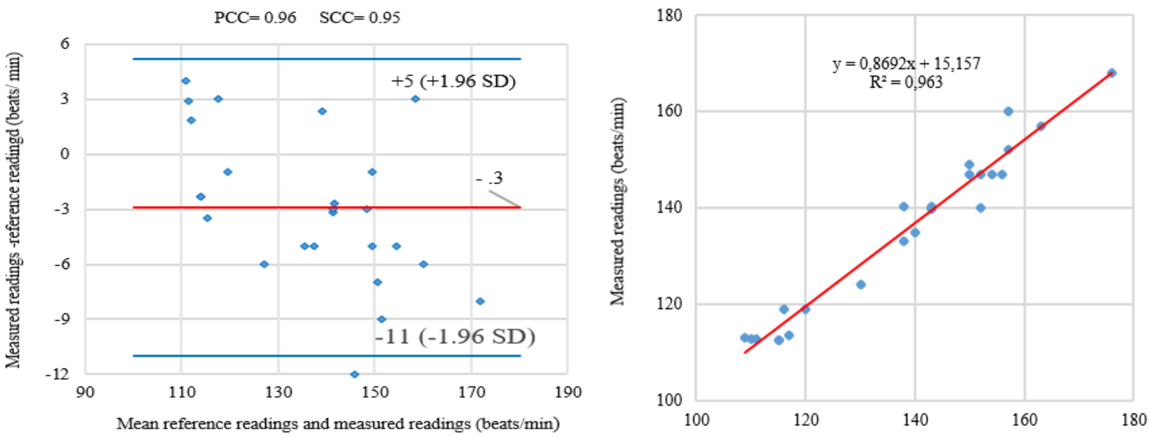
4.2. Statical analysis measurements

To validate the proposed non-contact system for two scenarios (without/with UV), we considered statistical analysis methods based on Bland–Altman plot, pearson's correlation coefficient (PCC) plot, spearman correlation coefficient (SCC) plot, linear regression, mean absolute error (MAE) and root mean squared error (RMSE) for comparison of the obtained results relative to a reference standard. The total sample size is considered n=25. To investigate the performance of the proposed work, the measured readings are compared with the reference standard obtained from monitoring ECG at the hospital. As exhibited in Figure 7, the Bland-Altman statistics based on (without UV) for first experiment as shown in Figure 7(a), has a mean bias of 0.45 (beats/min) with 95% limits of agreement -2.2 to 3.3 a against a mean bias of -3.1 (beats/min) with 95% limits of agreement -11 to 5 when the second experiment was adopted with UV rays. The PCC and SCC between measured and reference readings (HR) in the case of (without UV) method were 0.99 and 0.97, respectively, against 0.96 and 0.95 in the case of the (with UV) method. As it seems from the Figures 7 and 8, the most blue indicated points are within the identical boundary of 95%, and only one point is at a position somewhat deviated from the boundary in Figure 8(a). However, the results of the two experiments have a good indication result. As shown in Figure 7(b) and Figure 8(b), linear regression coefficients present a good match between the measured readings and linear fit with values (without/with UV) rays of 0.993 and 0.963, respectively. In addition, the Figure 9 exhibits that the lowest rate of MAE (0.775, 3.374) as shown in Figure 9(a), and RMSE (0.87, 3.75) as shown in Figure 9(b), which were recorded from the first and the second infant for two scenarios (without/with UV) rays.



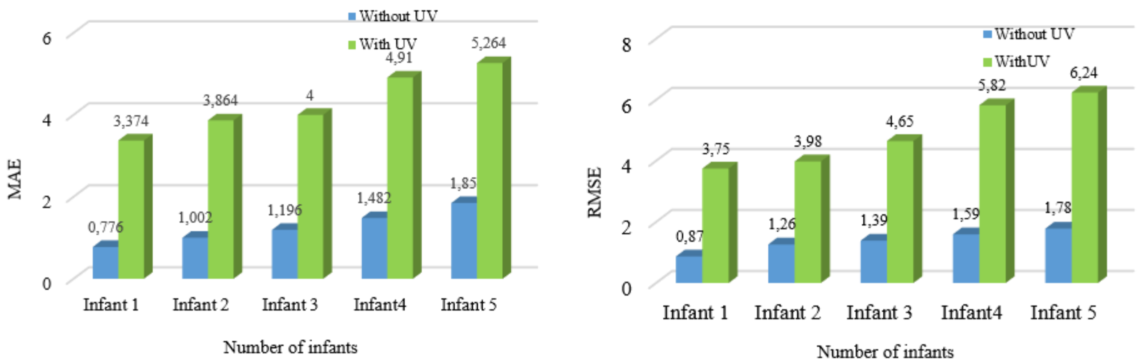
(a) (b)

Figure 7. Statistical measurements of first experiment in (a) Bland–Altman plotand and (b) linear regression



(a) (b)

Figure 8. Statistical measurements of second experiment in (a) Bland–Altman plotand and (b) linear regression



(a) (b)

Figure 9. Statistical analysis of cardio measurements (without/with UV) rays of in (a) MAE and (b) RMSE

5. COMPARISON WITH PREVIOUS WORKS

To validate the proposed work's performance, PCC result and determined distance between the camera and the infant as the main features are employed to compare the proposed system relative to the previous works. Seven reliable studies studies [17], [22]-[25], [29], have been compared with the current work (without/with UV) rays in terms of PCC results and distance in unit meters (m). These works are identical to our work on improving a computer vision system based on video camera imaging, where vital signs are extracted using non-contact sensors. Figure 10 illustrates that the proposed work outperforms the previous works. Essentially, when the PCC results of our system indicated higher values (i.e., 0.99 and 0.96) for the first and second experiments than that of the other studies. Figure 11 shows that the proposed work surpasses prior works, by its most considerable distance of 3m in the first and second experimentation compared to other studies that determined work distance as a range from (0.07 to 1.5 m) between camera to particapent. On another hand, all previous work mentioned above employed one participant to extract features from the vital signal (heart rate), while we used ten infants as particapent into two groups.

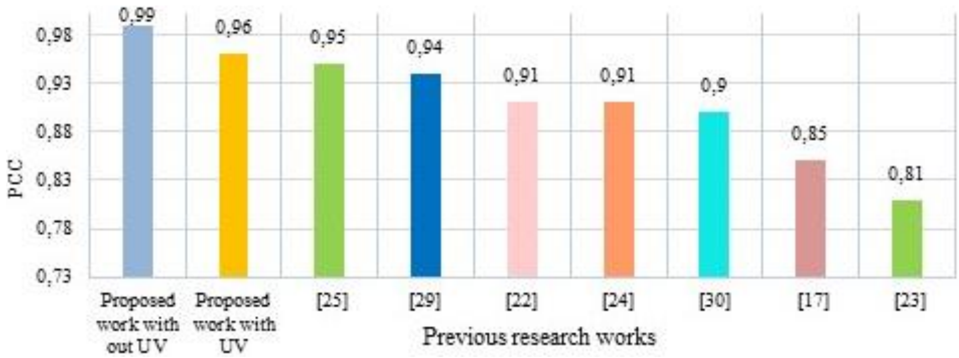


Figure 10. Comparison of PCC of proposed system with previous works

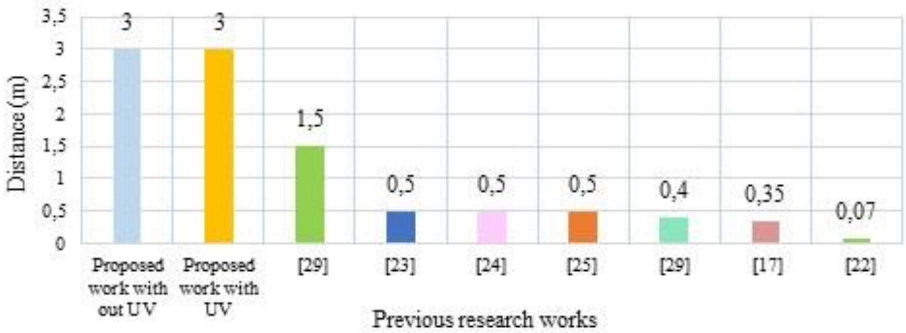


Figure 11. Comparison of the specialized distance of proposed system with previous work

6. CONCLUSION

In this work, we proposed an efficient and unique non-contact system to measure heart rate based on the color method utilizing video camera imaging. To increase efficiency and accuracy results, an infant chest detection algorithm with manual ROI selection technique were proposed in this study. This technique is a robust and simple method for defying inclined position infants. Also, to minimize noise artifacts, the spectral analysis technique was achieved. The our experimental results illustrate a high indicated correlation with PCC values of 0.99 and 0.98 for two (without/with UV) rays experiments, respectively. Bland–Altman analysis exhibited a close correlation between obtained measured and reference readings with a mean bias of 0.45 beats/min and -3 (beats/min), and the lower and upper limits of agreement of -2.4 and +3.3 (beats/min), and-11 and +5 (beats/min), for two (without/with UV) rays experiments, respectively. Moreover, the statistical analysis based on MAE and RMSE exhibited that the cardio signals estimated without UV rays were better than when used with UV rays. Consequently, the proposed system outperformed methods a proposed by other studies when the proposed system achieved 0.99 (without UV) and 0.96 (with UV) of PCC value. Furthermore, this system enables introduce enhancement of challenges related to signal extraction across extended distances. the system allows for the validation of optimal outcomes with the longest distance selected (3 m), compared to prior works. Therefore, it can be stated that this non-contact technique has significant possible as a non-contact, cost-effective, and easy method for monitoring systems in clinical situations. To improve the reliability of our future work, we will investigate adopting the signal decomposition technique, such as empirical mode decomposition.

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