Telemedicine-based baby incubator system with DWT method to detect respiratory rate from electrocardiogram signals

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ABSTRACT

This pioneering research introduces a telemedicine-based baby incubator designed to accurately monitor premature babies' electrical heart signals and respiratory rates. The research aims to monitor premature babies, especially those related to heart and respiratory problems. This research combines telemedicine technology with the discrete wavelet transform (DWT) method to obtain respiratory rate values from electrocardiogram (ECG) signal leads directly. This research contribution can be used for simultaneous and non-invasive monitoring of heart electrical signals and respiratory rate. By leveraging existing telemedicine infrastructure, this incubator enables real-time monitoring. Using a data-driven approach with premature babies as subjects, respiratory signals are captured using sensitive sensors and analyzed via the DWT method. The results show that the accuracy of this telemedicine-based incubator is superior in monitoring respiratory rate compared to conventional methods with a P-value>0.05. This study confirms the effectiveness of DWT-based telemedicine incubators in monitoring the breathing of premature babies, thereby offering superior performance compared to traditional methods. The implications resulting from this research as a whole, this telemedicine-based baby incubator marks a significant advancement in the care of premature babies, ensuring precise and real-time breathing monitoring.

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1. INTRODUCTION

A baby incubator delivery is a tool used to warm newborns and is frequently used in preterm babies. It serves to maintain the warmth and humidity of the baby's body can help avoid infant respiratory infections and keep neonates, especially premature babies, isolated [1], [2]. Premature infants are those that are born under unusual circumstances, with birthweights of less than 1500 grams, below-average heights, or gestational ages of fewer than 37 weeks [3]. It's crucial to keep an eye on the infant's health, especially when trying to spot any issues specific to preterm infants. The critical care unit in the baby incubator is used to care for preterm infants. To keep a premature baby's temperature and humidity similar to those in the mother's womb, it's crucial to closely monitor their condition. Premature newborns require regular checks on their physical health, including heart rate, lungs, skin, respiratory system, and digestive system, as these have not fully developed due to early birth. This underdevelopment makes it challenging for them to adapt to life outside the womb [4], [5]. Regular monitoring of premature babies' vital signs is crucial, and it's essential to minimize the use of intrusive equipment to ensure their comfort. Utilizing electrocardiogram (ECG)-derived respiratory monitoring enables simultaneous tracking of vital parameters, such as ECG signals and respiratory rates, while minimizing the number of installed devices. Opting for non-invasive methods is particularly suitable, as they prioritize the baby's comfort throughout the monitoring process. Respiration is a vital physiological process that brings oxygen into the body and excretes carbon dioxide [6], [7]. Even respiratory abnormalities like sleep apnea are significant risk factors for many heart illnesses that offer early signs of heart failure. Respiration rate (RR) can be utilized for early diagnosis of chronic diseases such as chronic obstructive pulmonary disease (COPD) and congestive heart failure (CHF) [8], [9]. Adults typically breathe 12 to 20 times per minute, with an RR>27 condition suggesting problems in the cardiac system. Additionally, it is physiologically believed that the pulmonary system and the heart have a link [10], [11]. One of the main reasons for sudden death worldwide is heart attacks, which are caused by heart disease. This highlights the significance of knowing one's heart health [12]. According to Moody *et al*. [13], the ECG is affected by electrodes placed on the body's surface to monitor electrical activity in the heart, which is influenced by variations in the electrical impedance of the piston as the lungs fill and empty. As occurs in the ventilation of the alveolus (the product of respiratory rate and tidal volume), which is regulated by the activity of central, peripheral chemoreceptors, and pulmonary receptors, the respiratory rate is employed as one of the significant markers of diseases of body systems [14], [15]. It is clear from the data given above that effective and routine RR monitoring is necessary. A respirometer may be used to measure the quantity of RR, however, not all cases of RR can be measured because the patient has to be aware. If the patient snoozes in the operating room and intensive care unit (ICU), it is impossible. There are many methods regarding the ECG-derived respiratory (EDR) technique including signal extraction from the ECG and PPG can be used to get RR signals [16], [17]. The EDR approach uses a single lead ECG signal lead (lead II) and gel electricity when mounted on the person to extract the signal from the ECG [8], [18]–[20]. The goal of this work was to develop a filter technique for the extraction of RR signals from EDR data. When extracting the filter signal, either analog or digital filters may be employed to pass the required signal frequency while holding the undesirable signal frequency. The RR signal from the ECG signal is filtered using analog filters, however, there is a flaw in that there is still a lot of noise present after the filtering process, whereas the noise produced by the digital filter is lower [7]. The RR signal from the ECG can be reduced more effectively with the use of this digital filter, and its degree of accuracy and precision are higher as well [21], [22]. Maghfiroh *et al*. [23] conducted EDR research in real-time from ECG lead II signals. The study used analog filters and discrete wavelet transform (DWT) methods. Data capture in the age range of 20-30 at a frequency of 250 Hz. Researchers obtained results that the use of analog filters without a mixture of digital filters still has a lot of noise, the results of the RR signal have no effect on ECG signals and noise, but in this method there is a delay of 3 seconds and is displayed on delphi7 [23]. Additionally, Sharma *et al*. [19] study found that utilizing homomorphic filters and discrete Fourier transform (DFT) and discrete cosine transform (DCT) approaches, the RR signal from a single lead ECG was reduced. In the frequency range of 0.2-0.8 Hz, this study uses 3 band pass filters (Butterworth, Chebyshev-I, and FIR filters). The findings obtained using the Kaiser window for the extraction of RR indicate that order 50 and Butterworth filters produce superior filter results than Chebyshev-1 and FIR filters. Filter selection and order analysis for the extraction of the respiratory rate signal is still needed for this study [19]. Additionally, research conducted in Jagadev and Giri [6]. Using thermal cameras to monitor the RR with the ensemble of regression trees algorithm involves comparing the performance of various infinite impulse response (IIR) and finite impulse response (FIR) digital filters. The results indicate that extracting the RR with the Butterworth filter is more effective, and its performance improves consistently with an increase in the filter order [6].

Based on the explanation from the results of previous research, it is known that several obstacles are still the main obstacles in the EDR system, including that there is still noise interference in the ECG signal, the EDR system used is still offline and the objects used are adults. So, from this problem the author will fix existing problems including improving the filter on the ECG, the EDR system is used in real-time and the object used is a premature baby. This research aims to create a baby incubator equipped with a premature baby monitoring system including the baby's temperature, ECG, and respiratory rate obtained from the ECG signals obtained. Development of a non-invasive method for detecting respiratory rate using ECG signals utilizing IIR digital filters and DWT techniques as well as real-time and this research is a continued development of previous research [24]. The method proposed in this study will developing a telemedicine-based baby incubator that can accurately monitor the electrical signals of the heart and respiratory rate of premature babies using the DWT method from ECG signals. IIR filters will be used to reduce noise and interference in the ECG signal, thereby enabling better assistance with the frequency components related to RR. Furthermore, the DWT technique will be applied to decompose the ECG signal into several different frequency levels, enabling more sensitive detection of changes in RR. By combining these two methods, it is hoped that this research can contribute, namely:

a. Significant contribution to the development of non-invasive techniques to detect and measure RR.
b. The results of this study are expected to increase our understanding of the relationship between ECG signals and RR.
c. As well as providing a stronger basis for medical and clinical applications in patient monitoring.

2. METHODS

2.1. Expriment setup

This study collected module data by comparing module readings and the YKDMED-1000 patient monitor. ECG data collection in this study was carried out with full attention to ethical aspects and patient consent, upholding the integrity of the research and the rights of the individuals involved. Data collection steps follow medical ethics guidelines and prioritize the safety and comfort of patients who are research subjects. Certificate with certificate number 206/HRECC.FODM/II/2023 issued by Airlangga University Faculty of Dental Medicine Health Research Ethical Clearance Commission. This step aims to ensure that the research has undergone careful ethical evaluation and that patient rights and safety are guaranteed. The number of patients involved in ECG data collection may vary according to the study design. In this case, the number of patients who will be research subjects are babies aged between 1 day to 3 months. ECG data is collected by placing the electrodes in the appropriate position for lead II. Lead II is one of the most commonly used ECG electrode configurations and produces a signal that allows good detection of cardiac changes. The position of the electrodes on the patient followed the placement guidelines established in clinical practice. This placement usually involves placing electrodes on the right wrist (RA), left wrist (LA), and left foot (LL).

In this research, an ECG circuit is employed. The system features an ECG circuit composed of a basic instrumentation circuit. The output from this basic instrumentation is filtered to smooth the ECG signal. A filter with a lower frequency limit of 0.05 Hz is used to attenuate voltages below 0.05 Hz and allow voltages above this threshold to pass. Similarly, the filter has an upper limit of 100 Hz, which passes voltages below 100 Hz and reduces those above this limit. The output then goes through a notch filter circuit designed to reduce voltages at a frequency of 50 Hz while allowing other frequencies to pass. Following this, the signal enters an amplifier circuit to be strengthened. Subsequently, it goes into an adder circuit, which increases the ECG signal reference, ensuring all signals have a positive voltage for compatibility with the Arduino. Finally, the processed ECG signal is converted into data by the Arduino microcontroller.

2.2. The diagram block

Figure 1 shows the block diagram of the module design used in the system. The diagram is divided into three sections: input, process, and output. In the input section, the initial signal is captured from an electrode placed on the respondent using ECG lead II. After processing, the ECG signal is converted into data by the Arduino microcontroller.

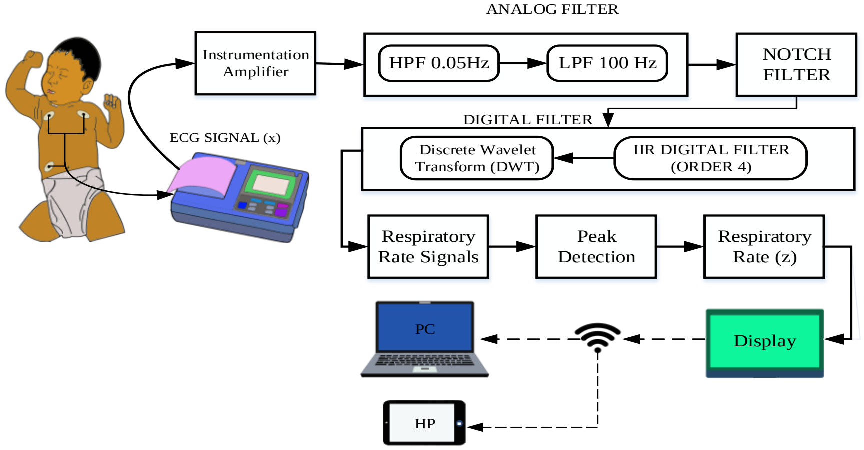


Figure 1. Respiratory system block diagram. The ECG signal obtained from lead II is then filtered analogously, to reduce noise, IIR digital filters are used, and then the DWT method is used to obtain respiratory rate values, next, the data is sent via internet of things (IoT)

In an ECG system, the data is processed through several analog circuits, including amplifiers, bandpass filters, and notch filters, to generate the desired ECG signal and eliminate unnecessary noise or signals. The processed ECG signal is then sent to a microcontroller, where a 4th-order IIR digital filter is applied to remove artifact noise. Subsequently, the data is processed to determine the respiratory rate. The ECG circuit is built with a basic instrumentation circuit. The output from this circuit is filtered to smooth the ECG signal. A filter with a lower frequency limit of 0.05 Hz attenuates voltages below 0.05 Hz and allows those above it to pass. Similarly, an upper limit of 100 Hz allows voltages below 100 Hz to pass and attenuates those above this threshold. The signal then passes through a notch filter circuit that dampens voltages at 50 Hz while allowing other frequencies to pass. Next, the signal goes to the amplification circuit to be strengthened. It then enters an adder circuit, which adjusts the ECG signal reference to ensure all signals have a positive voltage for compatibility with the Arduino. The processed ECG signal is then converted into data by the Arduino microcontroller. IIR filters are described using difference equations [25] and the transfer function of the IIR filter is explained in Figure 2 [26], the IIR filter is excellent and has a large processing capacity as shown in (1):

$$y = b[0] * x0 + b[1] * x1\ b[2] * x2\ b[3] * x3 + b[4] * x4 - a[1] * y1 - a[2] * y2 - a[3] * y3 - a[4] * y4 \quad (1)$$

where x(n) being the adaptive filter's input and y(n) being the adaptive filter's output. IIR filters are described using differences as shown in (2):

$$y(n) = b_0 x(n) + b_1 x(n-1) + \cdots + b_M x(n-M) - a_1 y(n-1) - \cdots - a_N y(n-N) \quad (2)$$

where b_i, $0 \leq I \leq M$ and a_j, $1 \leq j \leq N$ represents the system coefficients and n is the time index. The (3) can also be written:

$$y(n) = \sum_{i=0}^{M} b_i x(n-i) - \sum_{j=1}^{N} a_j y(n-j) \quad (3)$$

From (1) and (2) it can be observed that the filter output is the weighted sum of the current input value x(n) and the previous value, namely x(n-1) …. x(n-M) and the previous output value, namely y(n). -1) …. y(n-N). Assuming that all initial conditions are zero, the Z transformation described in (4):

$$H(z) = \frac{Y(z)}{X(z)} = \frac{b_0 + b_1 z^{-1} + \cdots + b_M z^{-M}}{1 + a_1 z^{-1} + \cdots + a_N z^{-N}} \quad (4)$$

where H(z) is the transfer function of the system. H(z) and h(n) are called impulse responses.

$$yhigh[k] = \sum_n x[n].\, g[2k-n]$$
$$ylow[k] = \sum_n x[n]\,.\, h[2k-n] \quad (5)$$

where x is the ECG signal that is simultaneously dissected using a low pass filter that offers approximation information and a high pass filter that provides detailed information, as shown in Figure 3. In the meantime, g is the wavelet function coefficient and h are the scale function.

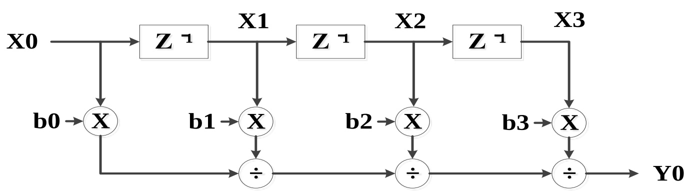


Figure 2. Transfer function digital filter

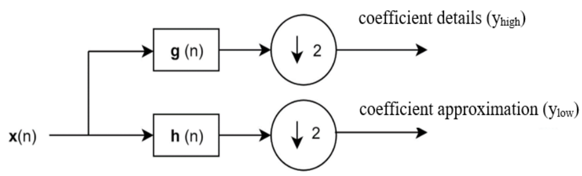


Figure 3. Block diagram of the wavelet transform decomposition process

2.3. Collect data electrocardiogram–derived respiratory

This research begins its analysis using offline data. This means that the data that has been collected will be processed and analyzed after data collection is complete, not directly while the data is being collected. The main goal of offline analysis is to understand the characteristics of the respiratory signal on the ECG. This may involve identifying specific patterns or parameters in breathing-related signals. In this study, data collection was obtained from the ECG simulator which simulated respiratory rate for offline analysis. The data is saved and data processing is carried out using DWT to obtain the decomposition level of the respiratory rate signal. Furthermore, this process will be used as a reference for creating a real-time EDR program which is displayed on the baby incubator display. The target subjects in this study were babies aged between 1 day and 3 months. Subjects used an ECG instrumentation and respirometer module. This instrumentation module is most likely used to record ECG signals and respiratory data simultaneously. An ECG respirometer may be used to measure respiratory rate. The ECG data used in the analysis comes from lead II. This refers to electrodes placed at specific locations on the chest, which are typically used in taking an ECG to monitor the electrical activity of the heart. ECG and respiratory data were recorded with a sampling frequency of 250 Hz. This sampling frequency indicates how often samples of the signal are recorded per second, and a value of 250 Hz indicates a high level of sampling speed.

Figure 4 shows a 60-second ECG signal alongside a recorded RR signal. Following this, the records are subjected to offline analysis, as illustrated in Figure 5. During this process, level 8 DWT decomposition using the Haar mother wavelet is employed to obtain characteristic respiration signals. To determine the approximate rate of return, using (6):

$$RR = \frac{60}{t_{(n+1)} - t_n} \tag{6}$$

where RR is respiratory rate, $t_{(n+1)}$ is the period time of the peak $R(n+1)$, and t_n is the period time for the peak R to n.

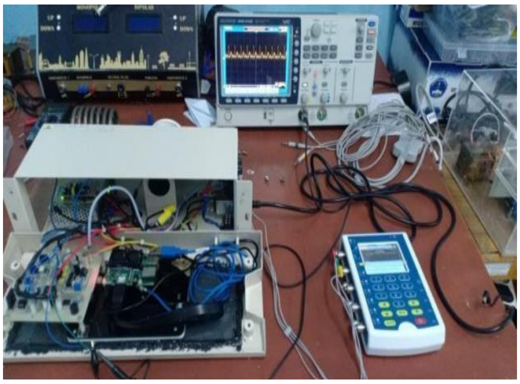


Figure 4. ECG data collection using an ECG simulator which is then used for offline EDR analysis

In Figure 5 explained that the decomposition process was carried out with data taken for 30 seconds and a respiratory rate signal was obtained in decomposition 8 with a resulting decomposition frequency of 0.39-0.78 Hz. As an absolute mistake, the respiratory rate measured by the sensor and the respiratory rate computed by the suggested approach are compared. A T-test was used to assess the suggested method’s accuracy. Any statistical hypothesis test in which the test statistic, under the null hypothesis, follows a student’s t-distribution is called a t-test. It is most frequently employed when the test statistic would have a normal distribution if the value of a scaling term in the test statistic were known. It can be used to assess if two sets of data are significantly different from one another. The T-test compares the means and standard deviations of two samples. The T-test formula is shown (7):

$$t = \frac{\dot{x} - \mu_0}{\frac{s}{\sqrt{n}}} \tag{7}$$

where $\dot{x}$ is the mean of the sample, μ is the assued mean, s is the standard deviation, and n is the number of observations.

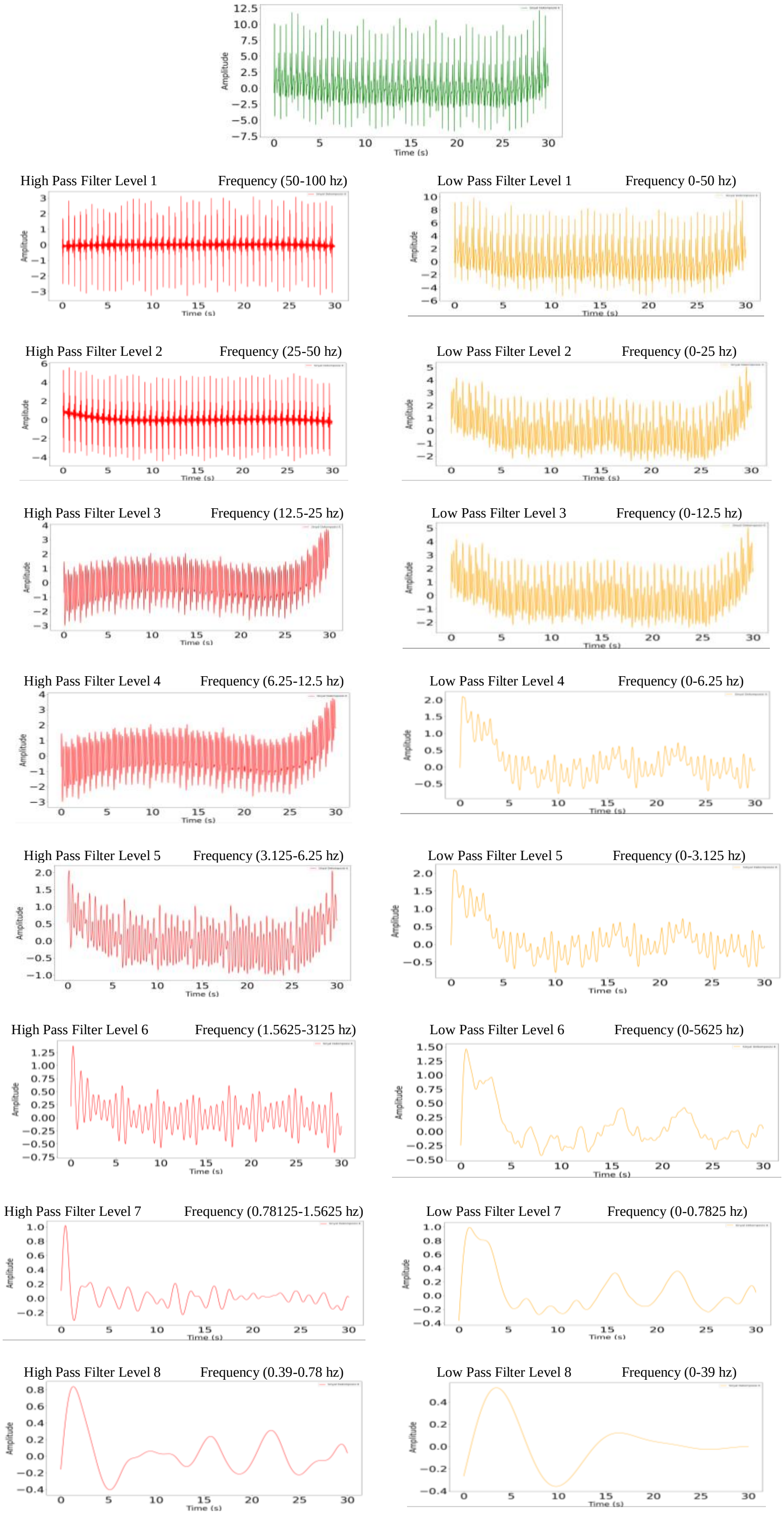


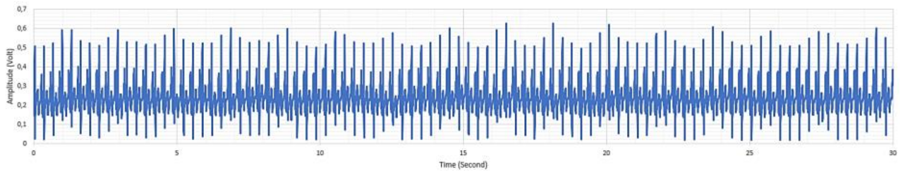
Figure 5. The results of the ECG signal decomposition analysis using DWT, the respiratory rate signal was obtained at level 8 decomposition

3. RESULTS AND ANALYSIS

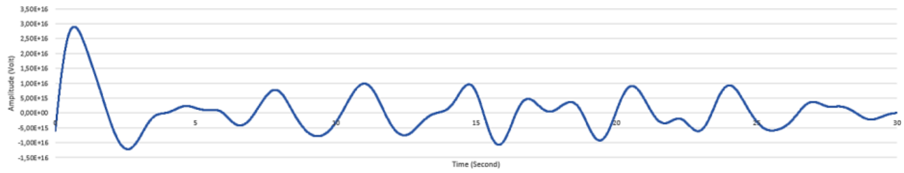
3.1. Electrocardiogram-derived respiratory based on discrete wavelet transform in real-time

At this stage, the EDR process is carried out in real-time before it is first displayed on the personal computer monitor screen in the form of an ECG signal and respiratory rate signal as explained in Figure 6 to ensure that the decomposition of the signal information is separated into various frequency components, which can provide insight. about signal characteristics. Furthermore, the data displayed on the baby incubator monitor display is in the form of an ECG signal and the total respiratory rate value. In the context of ECG signals, it is to obtain respiratory signals from ECG signals using DWT with level 8 decomposition and a frequency range of 0.39-0.79 Hz. The following is a comparison of ECG signals, DWT signals, and respiratory signals with respiratory module.

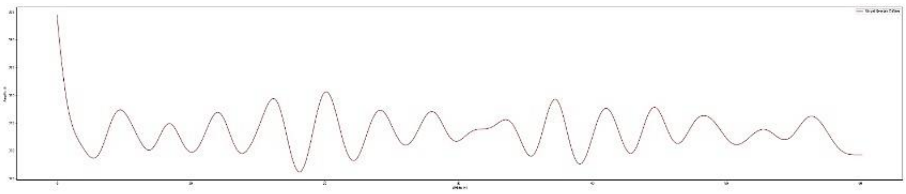
From Figure 6, it is explained that Figure 6(a) is the input ECG signal taken in real time, while Figure 6(b) is the result of the decomposition of the level-8 ECG signal using the DWT method, and Figure 6(c) is a comparison of the respiratory rate signal. taken simultaneously with taking the ECG signal as a comparison for the EDR results. After carrying out the EDR process using DWT on a personal computer monitor screen, the next step is to carry out the embedded system process so that it can be used in real-time which is explained in Figure 7. The subjects used in this study were premature babies or babies aged 1 day to 3 months. What is displayed on the baby incubator monitor display is the ECG signal and respiratory rate value.



(a)



(b)



(c)

Figure 6. is an EDR system using the DWT method in real-time; (a) is the input ECG signal taken in real, (b) is the result of the decomposition of the level-8 ECG signal using the DWT method, and (c) is a comparison of the respiratory rate signal

Figure 7. The ECG signal and respiratory rate value are displayed on the baby incubator monitor display

From what is shown in Figure 7, the results obtained were displayed on the pig incubator display in the form of ECG signals, heart rate and respiratory rate values. Next, to test the performance of the EDR system, a T test is carried out by comparing the results of the DWT method with the readings from the respiratory rate device to determine the accuracy of the DWT method before it is suitable for use for medical purposes. Table 1 based on the results of these tests; we lack sufficient evidence to reject the null hypothesis. A p-value higher than the alpha significance level of 0.05 indicates no significant difference between the two tested groups. Additionally, a T-statistic lower than the critical T value confirms the statistical insignificance of the difference. A low effect size (effect r) further suggests that the differences between the groups are minimal. Table 1 T-test statistical test results revealed a one-tail T-test result with p-value=0.379605 and a two-tail T-test result with p-value of 0.75921, indicating no significant difference because both the p-value>0.05 and the error rate remained within the acceptable range for medical purposes.

Table 1. Testing the difference using the T-test statistic

				Alpha	0.05	
	std err	t-stat	df	p-value	t-crit	effect r
One tail	0.996086	0.3112178	18	0.379605	1.734064	0.073158
Two tails	0.996086	0.3112178	18	0.75921	2.100922	0.073158

3.2. Internet of things approach for monitoring premature babies testing

In this study, it was equipped with a baby incubator monitoring system which can be monitored anytime and anywhere provided there is Wi-Fi or an internet connection. Trials were carried out and there was no difference in appearance between the monitor display on the baby incubator and the display on the cellphone layer. In this study, data transmission consisted of temperature readings, ECG signals, heart rate, and respiratory rate. The microdata is processed into digital data which is then sent via the resource pi. Resource data is sent via the internet to access the firebase cloud, and then from firebase data is downloaded from the Android system as explained in Figure 8. Next, data transmission testing was carried out to ensure that no data loss occurred and that the data displayed was the same between the display on the baby incubator and the display on the Android layer which is explained in Table 2.

Figure 8. IoT approach for monitoring premature babies

Table 2. Results of reading measurements from the baby incubator display with an Android display

No	Baby incubator display		Android display	
	Mean respiratory rate (Brpm)	Mean heart rate (BPM)	Mean respiratory rate (Brpm)	Mean heart rate (BPM)
1	33.2	120	33.2	120
2	34	125	34	125
3	34	123	34	123
4	32.6	123	32.6	123
5	31.4	123	31.4	123
6	35	125	35	125
7	33	120	33	120
8	30	125	30	125
9	32.8	120	32.8	120
10	34	120	34	120

Table 2 explains the reading results from the baby incubator display with the Android display. Testing was carried out on 10 babies and data collection was carried out 5 times for each. The data displayed in Table 2 is the result of the average test. From these results it was found that there was no data loss, the data displayed on the baby incubator display and the display on Android were the same. Research limitations and suggestions: this article has several limitations, such as the limited number of research subjects, the unexplained variation in clinical conditions of premature babies, and the lack of clinical validation of the telemedicine-based baby incubator system. This article also suggests several suggestions for future research, such as improving the quality of ECG signals by using better electrodes, developing more efficient and robust algorithms for extracting respiratory rate from ECG signals, and conducting more extensive and comprehensive clinical trials to evaluate performance and Benefits of a telemedicine-based baby incubator system.

4. DISCUSSION

From the results of performance testing and performance measurement of the EDR system using T-test statistical calculations shown in Table 1, the results were one-tail p-value=0.379065 and two-tail p-value=0.75921. It may be concluded that the average P value was greater than 0.05 indicating there was no significant difference between the two group. Conversely, if the P-value is less than 0.05, it means there is a significant difference two groups and the error rate was still within a level suitable for medical purposes. This research also uses IoT technology to send real-time data to central monitors and smart phones as shown in Table 2. From these results it was found that there was no missing data, the data was displayed on the baby incubator display and display on Android the same. This research is different from previous research which used EDR in terms of research subjects, analysis methods, and monitoring systems. The subjects of this study were premature babies or babies aged 1 day to 3 months, while previous studies used adult subjects. The analysis method used is DWT with decomposition level 8 and a frequency range of 0.39-0.79 Hz, while previous research used methods such as homomorphic filter, DFT and DCT [19].

Jagadev and Giri [6] study using thermal cameras to monitor RR with the ensemble of regression trees algorithm method, a method comparing the performance of several IIR digital filters and FIR filters, the results showed that the extraction RR using the Butterwort filter was better and the filter performance was good every time there was an increase in filter order. The monitoring system developed is a telemedicine-based baby incubator system which can be accessed remotely via IoT, whereas previous research used a conventional monitoring system which was limited to the incubator room. This study has several weaknesses and limitations, such as the limited number of research subjects, unexplained variations in the clinical conditions of premature babies, and lack of clinical validation of the telemedicine-based baby incubator system. This study also suggests several suggestions for future research, such as improving the quality of ECG signals by using better electrodes, developing more efficient and robust algorithms to extract respiratory rate from ECG signals, and conducting more extensive and comprehensive clinical trials to evaluate performance. and the benefits of a telemedicine-based baby incubator system.

This research aims to developing a telemedicine-based baby incubator that can accurately monitor the electrical signals of the heart and respiratory rate of premature babies using the DWT method from ECG signals. This research aims to develop a telemedicine-enabled baby incubator that can precisely monitor the heart’s electrical signals and the respiratory rate of premature infants using the DWT method applied to ECG signals. This research is very important to develop a baby incubator system equipped with vital sign monitoring for monitoring premature babies, so that they can be monitored continuously to reduce the causes of death of premature babies, including lack of simple and inadequate services equipment such as baby incubators. In the research, the system developed was very effective, including a digital filter system using an IIR filter and a real time EDR system using the DWT method. However, DWT computing is quite heavy, so an EDR system with light computing is needed.

5. CONCLUSION

This research aims to developing a telemedicine-based baby incubator that can accurately monitor the electrical signals of the heart and respiratory rate of premature babies using the DWT method from ECG signals. Research results: shows that the telemedicine-based incubator method has better accuracy in monitoring respiratory rate compared to conventional methods with a p-value>0.05. This study also shows the effectiveness of the DWT technique in detecting changes in respiratory rate in premature babies. It indicates that there is a noteworthy distinction between the two groups and that the error rate remained within the acceptable range for therapeutic applications. For future research, researchers will improve the quality of the ECG signal by using better electrodes, develop a more efficient and robust algorithm for extracting respiratory rate from the ECG signal and conduct more extensive and comprehensive clinical trials to evaluate the performance and benefits of the infant incubator system. telemedicine based.

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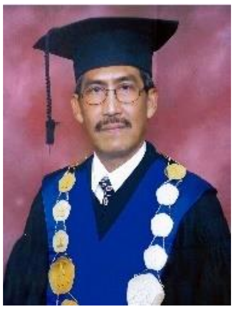

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