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Performance Analysis of PPG Signal Denoising Method Using DWT and EMD for Detection of PVC and AF Arrhythmias

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Abstract

Photoplethysmography (PPG) sensors have great potential for use in arrhythmia detection systems because they are inexpensive and can be used anywhere. PPG signals are often mixed with noise due to body movements or changes in room light during the recording process. The presence of noise in the signal can affect the detection results of premature ventricular contractions (PVC) and atrial fibrillation (AF). Discrete Wavelet Transform (DWT) denoising and Empirical Mode Decomposition (EMD) methods have good ability to remove noise. Most DWT and EMD methods are used to remove noise in image processing, ECG signals, Seismic signals, sound signals etc. However, the use of DWT and EMD methods is still rarely used to remove noise in PPG signals. This study aims to compare the performance of the two methods in denoising PPG signals in PVC and AF arrhythmia detection systems. The signal from the DWT method denoising results with an accuracy value of 89.3% and 82.1% for the EMD method. The experimental results show that the DWT method is better than the EMD method in denoising PPG signals for the detection of PVC and AF diseases.

Keywords: PPG, Denoising, PVC, AF, DWT, EMD

Abstrak

Sensor Photoplethysmography (PPG) memiliki potensi yang besar untuk digunakan dalam sistem deteksi aritmia karena biayanya yang murah dan dapat digunakan dimana saja. Sinyal PPG sering tercampur noise akibat pergerakan tubuh atau perubahan cahaya ruangan saat proses perekaman. Adanya noise pada sinyal dapat mempengaruhi hasil deteksi penyakit aritmia jenis Premature Ventricular Contractions (PVC) dan Atrial Fibrillation (AF). Metode denoising Discrete wavelet transform (DWT) dan Empirical Mode Decomposition (EMD) memiliki kemampuan yang baik dalam menghilangkan noise. Kebanyakan metode DWT dan EMD digunakan untuk menghilangkan noise pada pengolahan citra, sinyal ECG, sinyal Seismik, sinyal suara etc. Namun, penggunaan metode DWT dan EMD masih jarang digunakan untuk menghilangkan noise pada sinyal PPG. Penelitian ini bertujuan untuk membandingkan performansi kedua metode dalam meng denoising sinyal PPG pada sistem deteksi aritmia jenis PVC dan AF. Sinyal hasil denoising metode DWT mendapatkan nilai akurasi sebesar 89,3 % dan 82,1% untuk metode EMD. Hasil eksperimen menunjukkan metode DWT lebih baik dibandingkan metode EMD dalam meng denoising sinyal PPG untuk deteksi penyakit PVC dan AF.

Kata Kunci: PPG, Denoising, PVC, AF, DWT, EMD

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I. Introduction

Arrhythmias are diseases that cause the heartbeat to be too fast, too slow, or irregular. Arrhythmias are generally harmless. Until now, most people experience an irregular heartbeat that can become fast and slow suddenly. However, some types of arrhythmias can cause health problems that can be life-threatening. It is noted that deaths from heart disease are still number one in the world, and it is predicted that this will continue to increase until 2030. Arrhythmias may be associated with or without heart disease and may or may not be clinical. The most common types of arrhythmias are Premature Ventricular Contractions (PVC) and Atrial Fibrillation (AF). where the type of PVC most often occurs in men aged 50 years and over with the causative factor being hypertension [1].

Photoplethysmograph (PPG) is a method used to determine the condition of the cardiovascular system by measuring changes in blood volume in skin tissue. In its application, this method uses optical sensors to capture electrical signals originating from reflected light sources due to changes in blood flow during heart work. Many measurements of various health parameters have been developed from Photoplethysmograph (PPG) results, including heart rate, heart variability, respiratory rate and oxygen saturation in the blood [2]. However, PPG signals often contain noise due to internal or external factors such as sudden movement of objects or ambient light conditions. A signal that has noise can reduce signal quality, so it can affect the results of measuring health parameters [3].

Arrhythmia detection systems generally involve 3 stages. the first stage is preprocessing. At this stage, the signal captured by the PPG method containing noise is removed using the denoising method. the second stage is the feature extraction process from the noise-free ppg signal. where each signal has a different characteristic. The last stage is classification to determine whether there is arrhythmia in either Premature Ventricular Contractions (PVC) or Atrial Fibrillation (AF) type[4]. This research focuses on the denoising process and its effect on the detection system. The method used is Discrete Wavelet Transform (DWT) and Empirical Mode Decomposition (EMD). Then a comparison of the performance of the two methods will be carried out to see which method has better performance for cleaning noise in the PPG signal and its effect on the classification process.

II. Literature Review

PPG sensors have been developed for health data retrieval needs, one of which is what Citra, Putri and Yusmar have done in their research. ppg signal was developed to be able to represent blood flow in a person's body. the system that has been built will look for the maximum and minimum values of the output signal in every one second. then the peak to peak (Vpp) voltage value will be calculated using the maximum and minimum value data that have been recorded. This Vpp voltage value will be displayed as blood flow data. The developed system successfully represents the blood flow in the body using the PPG sensor. The system developed successfully represents the blood flow in the body using the PPG sensor. However, the resulting data is still very susceptible to noise due to subject movement during the data collection process [2].

AlMahamdy and Riley[5] studied the comparison of the performance of the denoising method on the ECG signal. This research uses 3 different methods, namely wavelets with soft and hard thresholds, adaptive filters both LMF and RLF and the last is the Savitzky-Golay method. The test is applied to an ECG signal with a noise level of 5dB SNR to 45dB SNR. The results show that wavelets have better and more stable performance than other methods, although in some cases RLS and Savitzky-Golay have better performance for some middle class SNRs.

Jenkal, Latif, Toumanari, Dliou, El B'charri and Maoulainine [6] ECG signal denoising method has been developed using adaptive dual threshold filter and discrete wavelet transform. The sample data was taken from the MITH-BIH database which was given gaussian noise, this denoising method used three stages. The first stage is to decompose the signal using the DWT method with a coefficient of db6, the second stage is the application of an adaptive dual threshold filter (ADTF) and the last stage is the highest peaks correction. The proposed method produces an MSE value of 0.0042 on signal 101 with a noise of 5db.

Rakshit dan Das [7] This research implements the denoising empirical mode decomposition (EMD) method combined with the adaptive switching mean filter (ASMF) for denoising ECG signals. The method was tested on five different samples with various gaussian, baseline wander and EMG noise added. From the test results, the output of the denoising method has the highest increase in SNR at 9.2980 and the lowest at 5.6733. while the lowest MSE value is at 0.00050 and the highest is at 0.02022.

Kumar, Panigrahy and Sahu [8] In this study, the denoising method was developed using the empirical mode decomposition (EMD) method combined with the method non-local mean (NLM). The aim of this study was to investigate the effectiveness of the developed method for denoising ECG signals with gaussian noise from -5db to 20db. The performance of this method is compared with the results of conventional filtering, adaptive filtering, ordinary EMD, ordinary NLM and Wavelet Denoising methods using MSE, SNR and Standard deviation values. The proposed methodology shows that the average MSE value is smaller and has a better increase in SNR value than the existing denoising method.

Saxena, Jais and Hota [9] In this paper, an experiment to eliminate Power Line Interference (PLI) noise on the ECG signal is carried out using 4 different methods. The denoising methods used are Finite Impulse Response (FIR) Filter, Infinite Impulse Response (IIR) Filter, Discrete Wavelet Transform (DWT) and Normalized Least Mean Square Filter (NLMS). Experiments were carried out on 5 datasets of ECG signals obtained from the MIT-BIH datasets. measurement of denoising results from each method using Mean Square Error (MSE), Mean Absolute Error (MAE), Signal to Noise Ratio (SNR in dB), and Peak Signal to Noise Ratio (PSNR in dB). From the experimental results, it is known that the NLMS and DWT methods provide better performance results than FIR and IIR where the FIR method has the lowest SNR value and the highest MSE value, while the highest SNR value and the lowest MSE are owned by the NLMS method.

Wang, Zhu, Yan and Yang [10] proposed a new denoising method with a wavelet basis. To determine the effect of the proposed method, SNR and MSE were used as parameters for the denoising test results. The data used for testing are normal clinical ECG data and simulated AF signals obtained from SID Medical Technology Co. Ltd. The test results are compared with the db4 wavelet denoising and sym4 wavelet denoising methods. the proposed method is able to maintain weak features such as P wave, T wave and F wave. The test results also show that the proposed method can increase the signal to noise ratio and reduce the mean square error for denoising the signal effectively.

Devi, Tyagi and Kumar [11] This paper discusses the comparison of the performance of the denoising method using the Least Mean Squares (LMS) algorithm, the Recursive Least Squares (RMS) algorithm and the Discrete Wavelet Transform (DWT) to denoise the ECG signal. The dataset used for the trial was taken from MIT-BIH Arrhythmia database. The performance parameters used are SNR, MSE, Percentage Root Mean Square Difference (PRD) and Peak Signal to Noise Ratio (PSNR). The test results show that the DWT method has better performance in eliminating various noises with a level range of -11dB SNR to 11 dB SNR. But to erase more solid random noise and the type of noise that suddenly changes, the use of an RLS filter can produce the best results.

Sujan, Priya, Pridhvi and Ramana [12] ECG signal feature extraction using the DWT method where the mother wavelet haar is used to decompose the signal. The tested samples were taken from ECG databases PTBDB & QTDB and checked against CSE tolerant limits. feature retrieval is done by decomposing the signal and then looking for the complex PQRS value of each coefficient. The algorithm is implemented in the ADSP-2181 simulator to see the algorithm's performance. The results show the algorithm can reduce the level of complexity of the algorithm with a repetition value of 106255 times and execution time for each instruction 2.656375ms.

Joseph G, Joseph A, Titus, Thomas and Jose [13] This paper discusses the testing of the denoising wavelet transform method on PPG signals that are given AWGN noise. The mother wavelets used in the denoising process are haar, db4 and Sym3. The performance of the wavelet used to denoise the signal is evaluated by calculating the cross correlation of the original signal and the denoised signal. The Sym3 wavelet has a Mean value of 10,512, a Std deviation value of 4,909 and a cross Correlation value of 0.9987. The Haar wavelet has a Mean value of 10,504, a Std deviation value of 4.854 and a Cross Correlation value of 0.9978. while the db4 wavelet has a Mean value of 10,506, a std deviation value of 5.962 and a Cross Correlation value of 0.9991. From the test results, it is known that the db4 wavelet is more effective in denoising PPG signals.

Mohanty, Biswal, Subudhi and Sabut [14] to detect ventricular fibrillation (CHF) and ventricular tachycardia (VT), a feature extraction algorithm is proposed using DWT and VMD on the ECG signal. The signal used comes from the physionet repository, namely CUDB and the VFDB Arrhythmia dataset. Then the signal is denoised using the HPF, LPF and Moving Average filter methods before the feature extraction process. To extract features from the signal, the signal is decomposed using mother wavelet db6 with decomposition level 8. From each decomposition signal coefficient, VMD will be applied to take 15 types of time-frequency features, namely LKG, TCSC, HURST, CO, FSMN, C1, SURE_ENT, TCI, VAL, MEA, CROSS, TH_ENT, A1, LOG_ENT, and FB. The test results show that the proposed method produces an accuracy rate of 99.13% using the CVR classifier.

III. RESEARCH METHOD

A. *Dataset*

The PPG dataset was taken from 11 patients ranging in age from 21 years to 73 years and with different genders. retrieval is carried out for 5 minutes using a PPG sensor connected to a microcontroller and stored in a file in csv format. Detailed data of the 11 subjects taken are shown in table 1. PPG signal has a wave morphology with 3 main characteristics called diastolic point, systolic point and dicrotic point. where the dicrotic point is the point between the systolic point and the second wave as shown in figure 1. The algorithm used in this study is shown in figure 1. The first step is PPG signal denoising, the second step is to extract the features and the last step is to classify Arrhythmia PVC/AF.

TABLE 1
SUBJECT PPG SIGNAL RECORD

No	Subject	Age	Gender	Medical Record
1	Subject 1	73	Male	AF
2	Subject 2	59	Female	N
3	Subject 3	65	Female	AF & PVC
4	Subject 4	75	Female	AF
5	Subject 5	65	Male	AF & PVC
6	Subject 6	75	Male	AF & PVC
7	Subject 7	64	Female	PVC
8	Subject 8	21	Male	N
9	Subject 9	21	Female	N
10	Subject 10	21	Male	N
11	Subject 11	21	Male	N

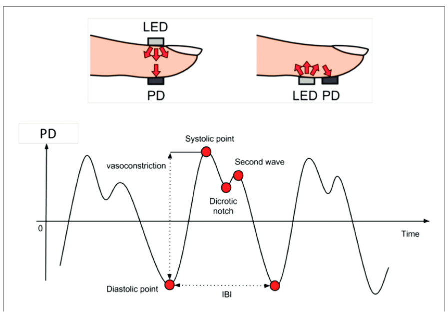


Fig. 1. PPG sensors can be used with two different setup and the shape of the PPG signal [15]

B. Denoising

The ppg signal obtained from the recording process is contaminated with various types of noise such as motion artifacts, power line interference and muscle contractions during the retrieval process. In this paper 2 types of denoising methods namely discrete wavelet transform (DWT) and Empirical mode Decomposition (EMD) are compared to see the performance of each method in denoising PPG signals.

1) *Discrete Wavelet Transform (DWT):* DWT is a method of converting a signal into a timescale domain by separating the signal into low pass and high pass components. All functions used in the DWT transformation are derived from the mother wavelet by shifting, or translation, and shifting or scaling [16]. DWT and its coefficients are defined as follows:

$$w_f(s,\tau) = \langle f(t), \psi_{s,t}(t) \rangle = \int_R f(t)\psi^*_{s,t}(t)dt \; .... \qquad (1)$$

Where $f(t)$ is the signal in the time domain, $\psi_{s,t}$ is the wavelet and * represented the complex conjugation. The signal from the decomposition using a wavelet is lossless or no features are wasted so that it can be reconstructed back into the initial signal using Inverse DWT.

2) *Empirical mode Decomposition (EMD):* EMD is an adaptive method for analyzing non-linear and non-stationary multi-scale signals by parsing the data into a finite number of simple orthogonal oscillation modes called the Intrinsic Mode Function (IMF). The process of decoding the signal on the EMD is called the shifting method. The screening process will be repeated until the IMF data meets these 2 conditions. The result of the shifting process is that the signal $\chi(t)$ will be decomposed into $IMF_j(t), j = 1, \ldots N$ and Residual $rN(t)$ it can be defined as follows:

$$x(t) = \sum_{j=1}^{N} IMF_j(t) + rN(t). \qquad (2)$$

To get a smooth signal, it is necessary to do a thresholding process on the IMF before signal reconstruction is carried out. Several types of thresholds that are often used in conventional EMD denoising processes are Universal threshold, Soft Threshold and Hard Threshold [17].

C. Feature Extraction

Feature extraction is a step that must be done before the classification process to obtain signal characteristics in the form of the required features. In this study, feature extraction was carried out using the DWT method where DWT is easy to implement and provides a fast computational process [18]. In this study, the DWT Haar wavelet is used with a decomposition level of 3. From each coefficient, statistical features such as Variance, Standard Deviation, Mean, Median and Entropy will be taken.

D. Classification

At this stage, a classification process will be carried out on PPG signals that have been denoised and have gone through a feature extraction process to determine the effect of the denoising method on the final result of arrhythmia disease classification. The classification method used in this paper is Support Vector Machine (SVM) [19].

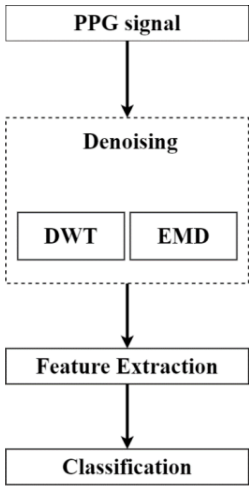


Fig. 1. Denoising method research system flow chart for detecting PVC arrhythmias and AF

E. Performance Metrics

To examine the denoising effect on the PPG signal of the method used, the signal-to-noise ratio (SNR) and mean square error (MSE) is used [10]. Meanwhile, to determine the performance of the denoised signal in the classification process, the terms accuracy, F1 score, precision, and recall are used with the following equation [19]:

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN} \quad (3)$$

$$Recall(R) = \frac{TP + TN}{TP + FN} \quad (4)$$

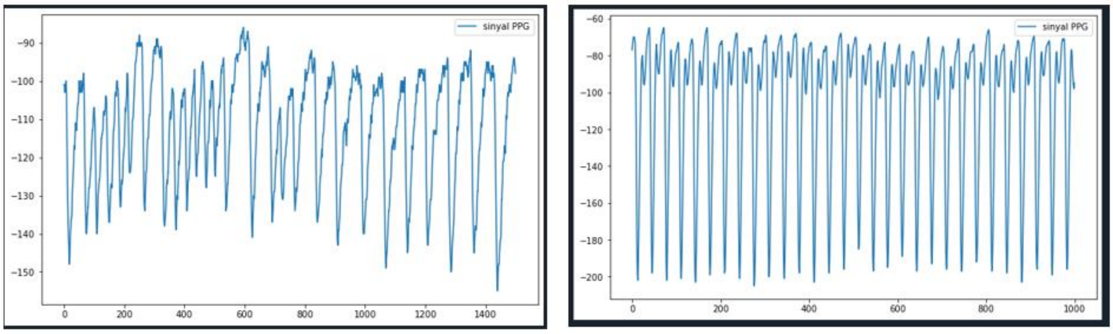
$$Precision(P) = \frac{TP + TN}{TP + FP} \quad (5)$$

$$F1\ Score = 2 \times \frac{P \times R}{P + R} \quad (6)$$

Where TP (True Positive) is the number of correct classifications of the AF/PVC signal and TN (True Negative) is the number of correct classifications not the AF/PVC signal. While FP (false Positive) is the number of misclassifications of AF/PVC signals and FN (False Negative) is the number of misclassifications not AF/PVC signals. When the recall and precision values are 1 indicates that the classification is ideal and F1-score is a parameter that considers the value of both precision and recall parameters whether it is good or not.

IV. RESULTS AND DISCUSSION

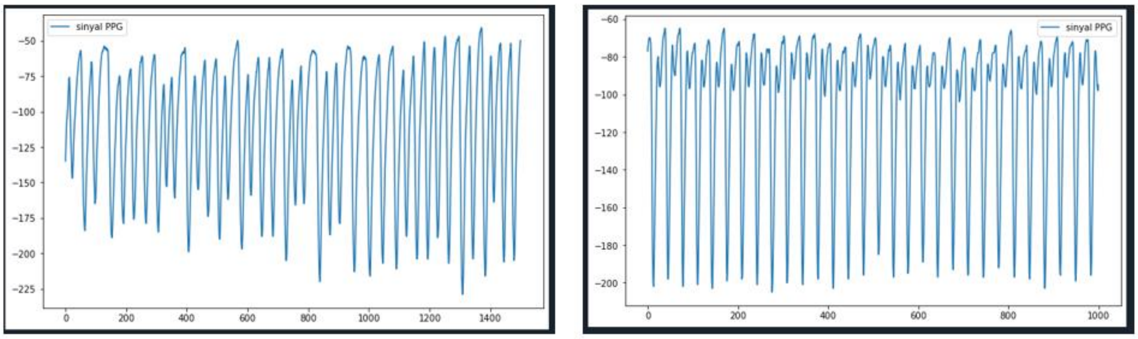
A. Signal Record



(a) (b)

Fig. 2. (a) PPG signal from a patient with PVC. (b) PPG signal from patient with normal heart

In the picture above is a comparison of the signal form of subjects who have PVC disease and subjects who do not have PVC disease (normal heart). It can be seen in graph (a) that the shape of the PPG signal curve is difficult to identify because of the irregular shape of the signal. It is a characteristic of the PPG signal which is stated that the subject has PVC disease. While in graph (b) is a form of PPG signal in normal subjects (people) without heart disease. It can be seen that the resulting waveform has a regular signal shape.



(a) (b)

Fig. 3. PPG signal from a patient with AF. (b) PPG signal from patient with normal heart

In Figure 3, this is a comparison of the signal form of subjects with AF disease and the signal form of subjects without heart disease. AF signals tend to have no dicrotic point or bottom point between the first peak and the second peak. Unlike the PVC signal wave, which still has a dicrotic notch even though it is irregular. The results above are signal waves from subject 4 for wave a and subject 8 for wave b, which are subjects without heart disease.

B. Denoising with DWT

In the denoising process using the DWT method, various mother wavelets with decomposition level 1 are used to denoise the signal. The threshold method used is the soft threshold. It is known that the bior3.9 wavelet has the highest SNR value and the lowest MSE value. An example of the results of denoising using the DWT method can be seen in table 2. The signal taken from patient 1 produces an SNR value of 43.25225, which is the highest value after denoising with the bior3.9 wavelet. From the SNR and MSE results, the bior3.9 wavelet in denoising method with decomposition level 1 and applying a soft threshold is the wavelet that has the best denoising performance from other wavelet types.

TABLE 2
EXAMPLES OF DWT DENOISING RESULTS IN 3 SUBJECTS

wavelet	Subject					
	Patient 1		Patient 2		Patient 3	
	SNR	MSE	SNR	MSE	SNR	MSE
bior3.9	43.25225	0.562255	46.10932	0.59059	43.8232	0.528745
bior6.8	40.50758	1.057742	44.58381	0.839122	41.59161	0.883882
cgau1	40.50758	1.057742	44.58381	0.839122	41.59161	0.883882
coif3	40.3406	1.09921	44.49358	0.856745	41.30363	0.944477
db3	39.6831	1.278853	42.08842	1.490585	40.43234	1.154298
gaus1	40.52328	1.054003	38.50104	3.453338	41.54499	0.893894
gaus2	40.52328	1.054003	38.50104	3.453338	41.54499	0.893894
rbio1.1	37.9344	1.912797	26.75485	50.79135	32.65984	6.90823
rbio1.3	39.68616	1.277945	42.52095	1.349171	40.56543	1.119378
sym2	38.98474	1.501937	39.45843	2.731076	38.93089	1.630937
sym3	39.6831	1.278853	42.08842	1.490585	40.43234	1.154298
sym4	39.77551	1.251942	42.79286	1.26741	40.82425	1.054699

C. *Denoising with EMD*

While in the denoising process using the EMD method, the first IMF from the results of signal decomposition is carried out by a threshold process with a threshold value of 1 to 9 and with 2 different threshold types, namely soft and hard. then all IMF is combined and then calculated the value of SNR and MSE from each denoising result. An example of the results of denoising using the EMD method is shown in table 3. From the comparison results in table 3, it is found that at threshold 9, the soft type has the highest SNR value and the lowest MSE value with an SNR value of 53,97414 and an MSE of 0.051068.

TABLE 3
EXAMPLES OF EMD DENOISING RESULTS IN PATIENT 1

Threshold	Patient 3			
	Hard		Soft	
	SNR	MSE	SNR	MSE
1	35.0538	3.975652	37.16013	2.448459
2	35.50374	3.584293	39.15821	1.546031
3	36.02296	3.180924	41.10435	0.987919
4	36.59342	2.789277	43.08913	0.625691
5	37.29785	2.372337	45.14886	0.389489
6	38.08402	1.980196	47.29568	0.237623
7	39.09264	1.570237	49.5053	0.142883
8	40.44151	1.151331	51.73207	0.085573
9	41.87815	0.82729	53.97414	0.051068

D. *Classification*

After knowing the best denoising method from each method, the denoising signal will go through a classification process and be calculated using a measuring matrix with the results in table 4 to be compared with signals that have not been denoised. It can be seen that the precision values for the denoising signal of the DWT method are 0.884 and 0.812 for the denoised signal of the EMD method. As for the signal that has not been denoised, it only produces a precision value of 0.762. The signal from the DWT denoising method has an accuracy value of 0.893. For the denoising signal, the EMD method produces an accuracy value of 0.821. With this it is proven that the DWT signal is clearer than the EMD signal, so that the signal can be extracted better and classified better.

TABLE 4
CLASSIFICATION PERFORMANCE

Signal	Precision	Recall	F1 Score	Accuracy
Raw	0.762	0.698	0.685	0.679
DWT	0.884	0.874	0.875	0.893
EMD	0.812	0.822	0.815	0.821

V. CONCLUSION

This paper is the result of a comparison of two PP Signal Denoising methods using the DWT and EMG methods. Both methods were tested with the same subject, the same feature extraction method and using the SVM classification. The measuring matrices used in the denoising process are SNR and MSE. Meanwhile, for the classification process, Precision, Recall, F1 Score and Accuracy measurement metrics are used. From the results obtained from each method, it shows that the DWT method is better than the EMD method in removing noise in the PPG signal. From the results obtained, the accuracy value of the DWT denoising signal is greater than that of EMD with a total accuracy of 89.3%. With these accuracy results, the DWT method can be used for the PPG signal denoising process quite well. The accuracy value can be increased using different feature extraction and classification methods in future studies.

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