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Research paper

A Novel Architecture for the Realization of an Internet of Things- Enabled ECG Signal Quality Aware using Empirical Mode Decomposition for Healthcare System

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Abstract

From the last few years, physical challenges in the field of ECG Framework are de-noising the signal and the improvement of battery-life of the system. This proposed paper consists of the 3 modules: 1) Denoising the ECG signal using decomposition techniques; 2) Implementing the Automatic Signal Quality-Aware algorithm and 3) Transmission of acceptable signal of ECG as a trigger to the IoT-Enabled ECG Telemetry system for achieving energy efficiency. Here in this paper the decomposition technique, namely EMD is implemented and its performance where compared and analyzed with the DWT technique using matlab by calculating correlation and SNR Thus the proposed paper has great potential in meeting up the two main challenges, namely denoising the ECG signal and improving the energy efficiency of the device.

Keywords: *Electrocardiogram (ECG); Empirical Mode Decomposition (EMD); IoT-Enabled Telemetry System; Signal Quality-Aware Algorithm.*

1. Introduction

In real time IoT enabled applications, power efficiency and de-noising are the two main key considerations to improve the network lifetime. Therefore, control the signal exchange helps in minimizing the power expenditure and can be used in further work improvement. Discrete Wavelet Transform (DWT) technique is applied to the standard ECG signal and de-noisy signal is obtained and referred as a reference signal. A clear noticeable observation is observed showing that the de-noisy signal obtained using EMD technique is more accurate when compared with the de-noisy signal obtained using Discrete Wavelet Transform (DWT) technique, which is taken as reference signal. The obtained ECG signal is now converted into binary signal and given as input to the IoT device with 9600 as its baud rate and transmitted the acceptable ECG signal heart rate to cloud for clinical diagnosis.

2. Method and Methodology

The main module of our SQA aware-IoT framework is as shown in Figure 1. It consists of three parts: 1) Data acquisition; 2) Filtering; and 3) SQA analysis and transmission stage. In this work, main intention to realize an automatic assessment of the suitability of signals for deriving reliable HR based on EMD based filtering for baseline wander (BW) removal and decision rules as shown in Fif.1.

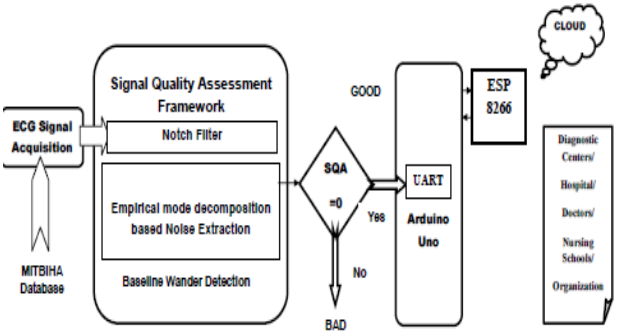


Fig 1: Proposed IoT – enabled framework.

3.1. De-noising the signal

ECG signals are distorted by Baseline Wander noise that are mainly caused by respiration, skin-electrode interface, body movements and skin due to poor contact. It reflects as a low frequency artifact in the ECG signal. The removal of this artifact is a major issue in ECG analysis. Various techniques were proposed for the removal of artifacts which are caused by BWs from the ECG signal, but the most widely used technique is EMD. In this paper, we describe and compare the EMD technique with DWT to find which technique gives the accurate and best results.

3.1.1. Empirical mode decomposition:

This technique is extremely popular in various fields including nonlinear and non-stationary mechanics and acoustics. EMD technique is mainly focused to decompose the signal into a series of

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intrinsic mode functions (IMFs). The steps of calculating the IMFs are known as Sifting process. Steps are explained below:

1. Finding the envelope by connecting maxima and minima points with cubic splines, respectively from the signal x(t).

2. By averaging the envelope, determine the local mean, $m_1(t)$.

3. Now subtract the mean from the signal i.e.

$h_1(t) = X(t) – m_1(t)$

4. Now by considering the $h_1(t)$ as the input and repeat the above steps to get

$H_2(t) = h_1(t) – m_2(t)$;

again repeat the above steps by considering $h_2(t)$ as the input

$h_3(t) = h_2(t) – m_3(t)$;

and repeat as necessary until we get

$h_{1n}(t) = h_{1(n-1)}(t) – m_{1n}(t)$

where $h_{1n}(t)$ is an IMF and here $m_{1k}(t)$ is the local mean of $h_{1(n-1)}(t)$.

Once IMF is calculated from the sifting process it is defined as $a_1 = h_{1n}$. EMD technique is described below to obtain the series of IMFs.

1. Generate the residue r_1 of the data from the x(t) by subtracting the a_1:

$x(t) – a_1(t) = l_1(t)$.

2. But still the $l_1(t)$ contains the information about the longer period components. So now consider the $l_1(t)$ as the new input data and repeat the above step. This procedure is applied on all the residues $l_j(t)$:

$l_1(t) – a_2(t) = l_2(t)$, ……..

$l_{n-1}(t) – a_n(t) = l_n(t)$

3. This process will repeated until we obtain a residue $l_n(t)$.

Similarly superposition is used to reconstruct the original signal of all the components and it is represented as below:

$x(t) = \sum_{i=1}^{n} a_i(t) + l_n(t)$

Since the residue $l_n(t)$ is the last IMF function $a_{n+1}(t)$, so the above equation is modified as:

$X(t) = \sum_{i=1}^{n+1} a_i(t)$

The outputs of the EMD Technique are shown in below Fig.2 to Fig.7.

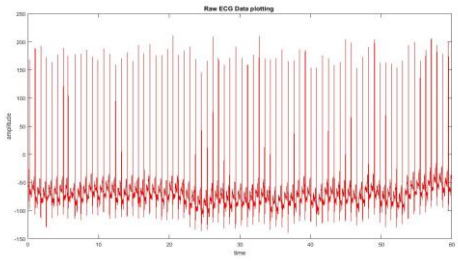


Fig. 2: Raw ECG Data signal 100

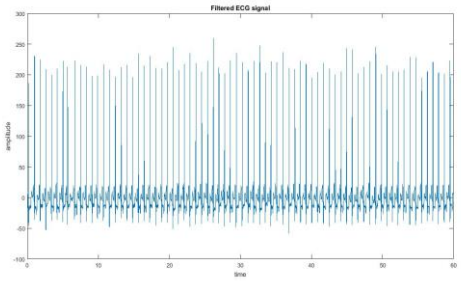


Fig. 3: Filtered ECG Signal 100

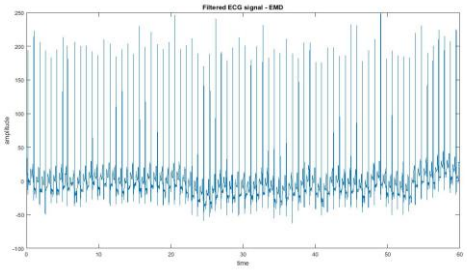


Fig. 4: EMD Filtered ECG Signal 100

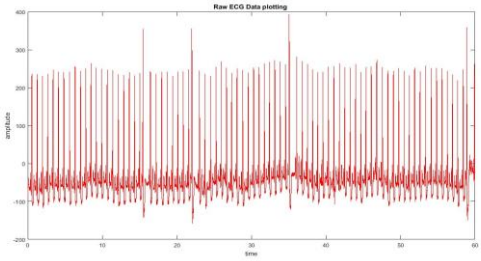


Fig.5: Raw ECG signal 105

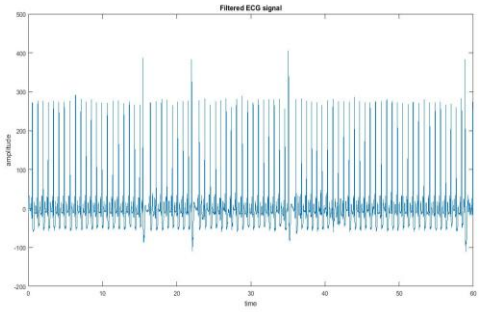


Fig.6: Filtered ECG signal 105

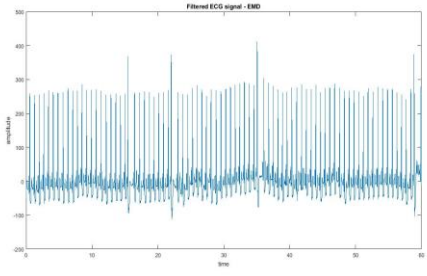


Fig.7: EMD Filtered ECG signal 105

The results obtained by implementing EMD Technique on some of the ECG signals that are collected from the Physionet Database are tabulated below in terms of Correlation and SNR.

Table 1: Results obtained by using EMD Technique on some of the ECG signals collected from the database in terms of Correlation and SNR

Records from Physionet Database	EMD	
	Correlation (ɤ)	SNR
100	0.98637868	27.1229
101	0.94212359	24.4681
102	0.99739324	28.2829
105	0.99110905	31.9607
109	0.98532469	18.8084
111	0.98566024	27.1252
112	0.95288089	21.8086
114	0.95746516	21.6429
115	0.98223207	28.4056
116	0.87563436	26.8662
118	0.95692183	24.9660
119	0.99129860	25.3790
121	0.67770319	18.1411
233	0.99447502	22.5150
234	0.93065476	20.8800

To test the performance of the proposed method, Different signals are taken from the Physionet database. A total of 17 ECG records, available at sampling rate of 360 Hz, are used to test the performance of the proposed algorithm.

Statistical parameters are also used to evaluate the algorithm by machine learning approaches. This is computed as:

$$Se\ (\%) = TP/\ (TP+FN)\ x100 \quad (1)$$

TP = true positive, FN i= false negative.

The performance of the proposed method is assessed by the correlation criterion (ɤ) and SNR.

Table 1&2 summarized the results of EMD in-terms of correlation, SNR and Sensitivity.

Table 2: Experimental results

ECG records	Actual no. of beats	FP	FN	FP+FN	Detection error rate = (FP+FN/Total no.ofbeats)x100	Sensitivity (Se)
200	2601	0	1	1	0.04	99.9
201	1963	2	12	14	0.71	99.3
202	2136	8	0	8	0.37	100
203	2982	2	30	32	1.07	98.9
205	2656	0	1	1	0.05	99.9
208	2956	0	5	5	0.16	100
209	3004	0	0	0	0	99.8
210	2647	0	4	4	0.15	99.8
212	2748	0	4	4	0.16	99.9
213	3251	0	2	2	0.06	99.9
215	3363	6	0	6	0.18	100
217	2208	0	0	0	0	100
219	2154	0	0	0	0	100
220	2048	0	0	0	0	100
221	2427	0	4	4	0.16	99.8
222	2484	0	20	20	0.81	99.2
223	2605	0	0	0	0	100
Average	2448	1	4.8	5.94	0.01	**99.84**

3.2. Signal Quality Algorithm:

Hamilton-Tompkins algorithm (Hamilton, 1986) is used to detect QRS detection. Heart rate is calculated based on RR interval. To classify feasibility rule and correlation template matching are introduced as shown:

SQA Algorithm

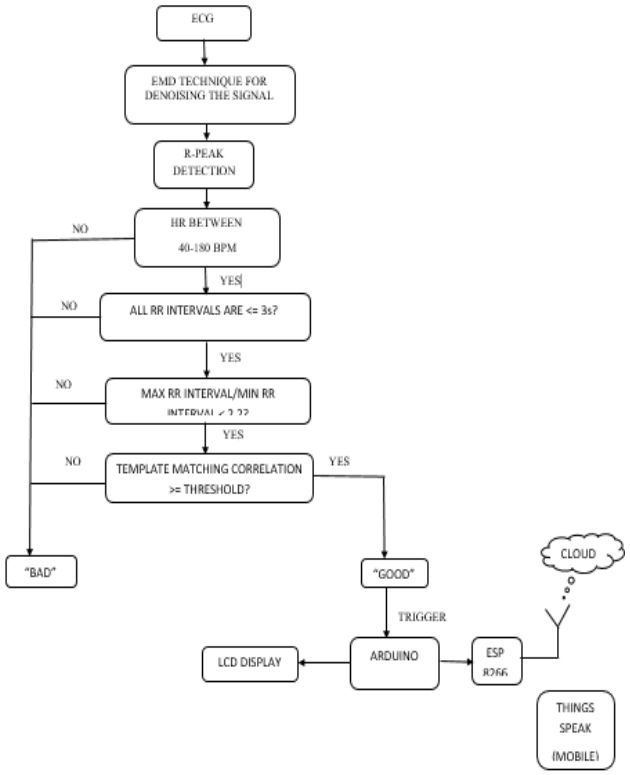


Fig 8: Flow chart of SQA Algorithm

The algorithm is explained in detail by the following steps.

a) Rules:

The First step is denoising the obtained ECG signal using EMD technique for better R-peak detection by removing Baseline Wander noise, and then the output of the detector is compared with a set of the following three relevant rules which are applied sequentially. If any one rule is not satisfied then the sample is classified as "bad". Otherwise it is classified as "good".

- **First Rule :** The range of HR value extrapolated from the 10-s sample must be in between 40-180 beats per minute (bpm).
- **Second Rule**: The maximum acceptable gap between successive R-peaks is less than or equal to 3s.
- **Third Rule:** The ratio of the maximum beat-to-beat interval to the minimum beat-to-beat interval within the sample should be less than 2.2.

If all the three rules are satisfied, an adaptive QRS pulse-waveform template matching approach is used, as explained next.

b) Matching:

Our approach through template matching is as follows:

1) The median beat-to-beat interval is calculated.
2) Individual QRS complexes waves are then extracted by taking a window.
3) The average QRS template is then obtained by taking the mean of all QRS complexes in the sample.
4) The average correlation coefficient is finally obtained by averaging all correlation coefficients over the whole ECG sample.

3.3. Power-Saving Strategy:

In this paper we proposed a power saving strategy of enabling the hardware device only by the non- corrupted ECG signals i.e., Once if the sample is classified as "good", then the HR value which is in decimal format converted into binary format in the matlab code which makes the serial transmission of data easier. Now it is given as trigger to the ARDUINO-UNO board where the HR value is calculated for the given ECG signal by using simple Embedded C program again to convert the data into decimal format to display the output HR value on the LCD Display. By using ESP-8266 Wi-Fi module, the data can be transmitted to the doctor or family members for longer distances through Cloud. Therefore the doctor can monitor on the condition of the patient depending on the obtained output values, which can be seen in the mobile phone using Things Speak app.

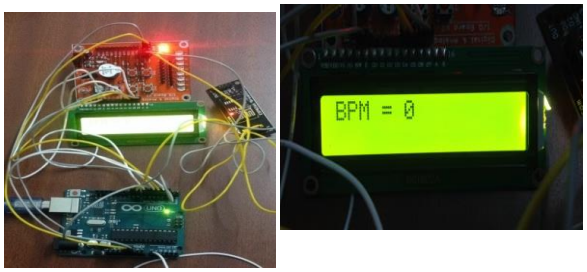


Fig 9: Continuous recording of heart rates (HRs).

By using an ESP8266Wi-Fi module, the data can be transmitted to the doctor or family members through longer distances through a cloud server. Therefore, the doctor can monitor the condition of the patient depending on the obtained output values that can be seen in the mobile phone using the Things Speak app, as shown in Figure 10.

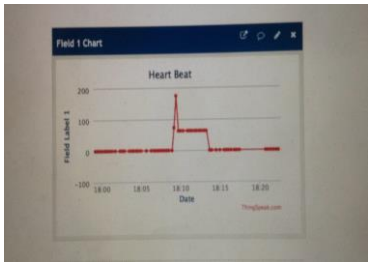


Fig 10: IoT enabled ECG telemetry system.

4. Conclusion

In this paper, we presented an automatically assessing the quality of ECG signals and a portable IoT-enabled ECG system for healthcare monitoring applications. The experimental results demonstrated that the proposed method performs better in terms of SNR, Correlation and sensitivity. Based on these findings the proposed quality IoT-enabled improves resource utilization efficiency and accurately.

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