

ECG De-noising using Hybrid Linearization Method

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Abstract

Electrocardiogram (ECG) is a non-invasive tool that monitors the electrical activity of the heart. An ECG signal is highly prone to the disturbances such as noise contamination, artifacts and other signals interference. So, an ECG signal has to be de-noised so that the distortions can be eliminated from the original signal for the perfect diagnosing of the condition and performance of the heart. Extended Kalman Filter (EKF) de-noises an ECG signal to some extent. This project proposes a method called Hybrid Linearization Method which is a combination of Extended Kalman Filter along with Discrete Wavelet Transform (DWT) resulting in an improved de-noised signal.

Keywords: electrocardiograph, extended Kalman filter, discrete wavelet transform

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1. Introduction

Electrocardiography is the process of recording the electrical activity of the heart. The Voltage versus Time graph produced by this non invasive medical procedure is referred to as an electrocardiogram which is a time varying signal [1].

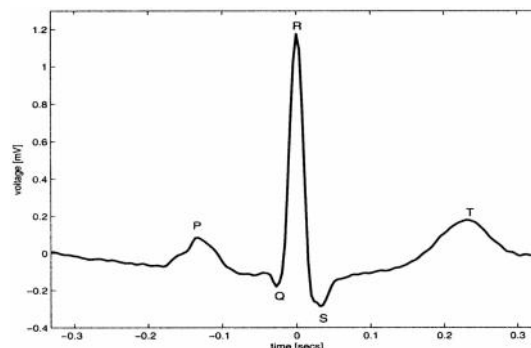


Figure 1. Morphology of a mean PQRST-complex of an ECG recorded from a normal human

A single normal cycle of an ECG waveform reflects the peaks and troughs labeled P, Q, R, S and T. An ECG signal may sometimes heavily mask by the noise so that the presence of the signal of interest may not be detected. Extracting useful clinical information from the real ECG requires R-peak detection [2] and QT-interval detection [4]. So, an ECG signal must be de-noised to estimate the condition of the heart. An ECG signal can be de-noised using Extended Kalman Filter (EKF) [5-6] which can extract the signal from the noise to some extent.

2. Proposed Method

The useful information in an ECG signal is observed from the intervals and amplitude of the signal. To estimate the condition of the heart, an ECG signal must be extracted from the noise i.e., an ECG signal must be de-noised. Extended Kalman Filter (EKF) de-noises the signal to some extent. To improve the quality of de-noising, Hybrid Linearization Method is proposed in

this paper which is a combination of Extended Kalman Filter followed by Discrete Wavelet Transform (DWT) [3] implemented using wavelet toolbox [7].

2.1. Extended Kalman Filter

The EKF is a non linear extension of conventional Kalman filter that has been specifically developed for systems having non linear dynamic model. A discrete and non linear system $x_{k+1} = f(x_k, w_k)$ and its non linear observation $y_k = g(x_k, v_k)$ can be approximated linearly near reference point $\begin{pmatrix} \hat{x}_k & \hat{w}_k & \hat{v}_k \end{pmatrix}$ as follows:

$$\begin{cases} x_{k+1} = f \begin{pmatrix} \hat{x}_k & \hat{w}_k \end{pmatrix} + A_k \begin{pmatrix} x_k - \hat{x}_k \end{pmatrix} + F_k \begin{pmatrix} w_k - \hat{w}_k \end{pmatrix} \\ y_k = g \begin{pmatrix} \hat{x}_k & \hat{v}_k \end{pmatrix} + C_k \begin{pmatrix} x_k - \hat{x}_k \end{pmatrix} + G_k \begin{pmatrix} v_k - \hat{v}_k \end{pmatrix} \end{cases} \quad (1)$$

Where x_k the state vector, w_k the state noise with zero mean and covariance matrices $Q_k = E\{w_k w_k^T\}$, $f(\bullet)$ the non linear dynamic, y_k observation vector, v_k the measurement noise with zero mean and covariance matrices $R_k = E\{v_k v_k^T\}$, $g(\bullet)$ the non linear sensor model and A_k , F_k , C_k , G_k are the jacobian matrices given by:

$$\begin{aligned} A_k &= \left. \frac{\partial f \begin{pmatrix} \hat{x} & \hat{w}_k \end{pmatrix}}{\partial x} \right|_{x_k = \hat{x}_k} \\ F_k &= \left. \frac{\partial f \begin{pmatrix} \hat{x}_k & \hat{w}_k \end{pmatrix}}{\partial w} \right|_{w_k = \hat{w}_k} \\ C_k &= \left. \frac{\partial g \begin{pmatrix} \hat{x} & \hat{v}_k \end{pmatrix}}{\partial x} \right|_{x_k = \hat{x}_k} \\ G_k &= \left. \frac{\partial g \begin{pmatrix} \hat{x}_k & \hat{w}_k \end{pmatrix}}{\partial v} \right|_{v_k = \hat{v}_k} \end{aligned} \quad (2)$$

Then, extended Kalman equations can be given by:

$$\begin{aligned} \hat{x}_{k-1} &= f \begin{pmatrix} \hat{x}_{k-1} & \hat{0} \end{pmatrix} \\ P_{k-1} &= A_k P_{k-1} A_k^T + F_k Q_k F_k^T \\ \hat{x}_k &= \hat{x}_{k-1} + K_k \left[y_k - g \begin{pmatrix} \hat{x}_{k-1} & \hat{0} \end{pmatrix} \right] \\ K_k &= P_{k-1} C_k^T \left[C_k P_{k-1} C_k^T + G_k^T \right]^{-1} \\ P_k &= P_{k-1} - K_k C_k P_{k-1} \end{aligned} \quad (3)$$

Where $\hat{x}_{k-1}^{\wedge} = E\{x_k | y_{k-1}, y_{k-2}, \dots, y_1\}$, is estimate of the state vector x_k at instant k given observations y_1 to y_{k-1} , and $\hat{x}_k^{\wedge} = E\{x_k | y_k, y_{k-1}, \dots, y_1\}$ is estimate of the state vector x_k at instant at instant k given observations y_1 to y_k . P_{k-1} and P_k are defined in the same manner.

2.2. Discrete Wavelet Transform

A wavelet is a mathematical function used to divide a function or continuous time signal into different scale components assigning frequency range to each scale component. Discrete wavelet transforms are applied to discrete data sets which maps data from the time domain to the wavelet domain. It has its own advantages over Fourier transform in representing the functions that have discontinuities and sharp peaks for accurately deconstructing and reconstructing finite, non-periodic and non-stationary signals. The forward DWT coefficients for a sequence $f(n)$ are:

$$W_{\zeta}(j_0, k) = \frac{1}{\sqrt{M}} \sum_n f(n) \zeta_{j_0, k}(n) \quad (4)$$

$$W_{\xi}(j, k) = \frac{1}{\sqrt{M}} \sum_n f(n) \xi_{j, k}(n) \quad \text{for } j \geq j_0 \quad (5)$$

And the complementary inverse DWT is:

$$f(n) = \frac{1}{\sqrt{M}} \sum_k W_{\zeta}(j_0, k) \zeta_{j_0, k}(n) + \frac{1}{\sqrt{M}} \sum_{j=j_0}^{\infty} \sum_k W_{\xi}(j, k) \xi_{j, k}(n) \quad (6)$$

The DWT represents the temporal features of a signal at different resolutions, suitable to analyze the ECG signals characterized by a cyclic occurrence of patterns with different frequency content. The DWT is implemented on ECG signal using Wavelet toolbox. The wavelet toolbox is a collection of functions built on the Matlab technical computing environment which provides tools for the analysis and synthesis of signals and images using wavelets and wavelet packets within the framework of Matlab. The toolbox uses graphical interactive tools which is a collection of graphical interface tools that afford access to excessive functionality.

2.3. Description of the Algorithm

The algorithm used to de-noise an ECG signal is an efficient algorithm which uses Hybrid Linearization Method – a combination of Extended Kalman Filter (EKF) and Discrete Wavelet Transform (DWT). It has the following procedure of de-noising an ECG signal: first an ECG signal is loaded and Extended Kalman Filter is applied to it. The EKF linearize and de-noises the ECG signal to some extent. Root mean square error is calculated from the output of the EKF. Then the signal is applied to the Discrete Wavelet Transform using wavelet toolbox and then the output is calculated. The results from both EKF and DWT can be compared.

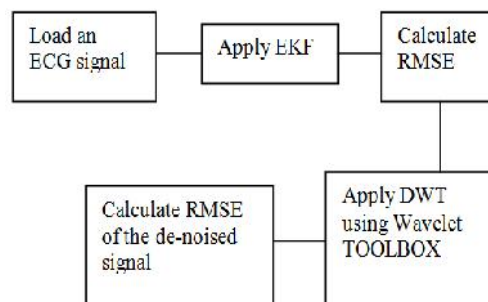


Figure 2. Describing the algorithm to de-noise and ECG signal using Hybrid Linearization Method

The steps of the algorithm are as follows:

STEP-1: Load the ECG signal

STEP-2: Apply Extended Kalman Filter

STEP-3: Calculate RMSE

STEP-4: Apply the output of EKF to Discrete Wavelet Transform using Wavelet toolbox

STEP-5: Calculate the RMSE of the de-noised signal

STEP-6: Compare the results of steps 3 and 5.

3. Results

The experimental study of both the Extended Kalman Filter and Hybrid Linearization Technique which is a combination of EKF and Discrete Wavelet Transform is carried out to evaluate the performance of the proposed method. Let an ECG signal which is a combination of both original signal with noise which is to be applied to the Extended Kalman Filter as shown in the Figure 3:

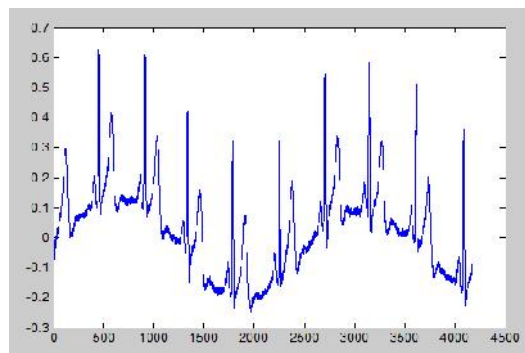


Figure 3. An ECG signal

When an ECG signal is applied to the Extended Kalman Filter the signal is de-noised to some extent and its root mean square error is $4.1322e-004$ as shown in Figure 4:

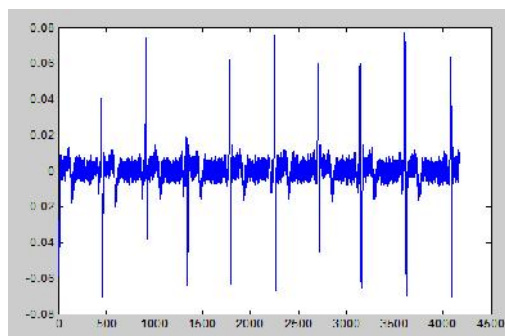


Figure 4. An ECG signal after de-noising with Extended Kalman Filter

The ECG signal extracted from the Extended Kalman Filter is applied to the Discrete Wavelet Transform which is nothing but Hybrid Linearization Method. Thus the Hybrid Linearization Method de-noises the signal improving the root mean square error to $3.1771e-004$ as shown in Figure 5:

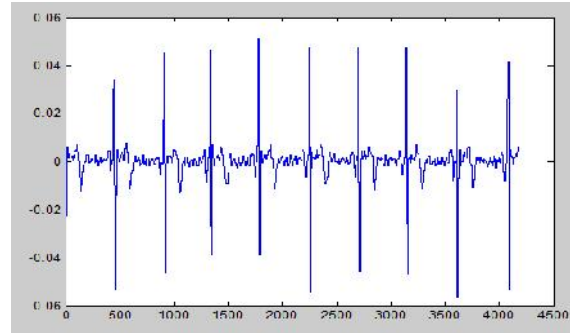


Figure 5. An ECG signal after de-noising using Hybrid Linearization Method

The results extracted from both the Extended Kalman Filter and Hybrid Linearization Method are tabularized in Table 1 through which it approves that the proposed method minimizes the effect of noise on the ECG signal.

Table 1. Performance results for ECG De-Noising

De-Noising using Extended Kalman Filter only		De-Noising using Hybrid Linearization Method	
Sum squares	RMSE	Sum squares	RMSE
1.7075e-007	4.1322e-004	1.0094e-007	3.1771e-004

4. Conclusion

Extended Kalman Filter removes the noise from an ECG signal by linearizing it. This process removes the noise to some extent. This paper proposes Hybrid Linearization Method, a combination of Extended Kalman Filter along with Discrete Wavelet Transform for the improvement of the de-noising of an ECG signal. The results of this paper prove the applicability of the Hybrid Linearization Method to de-noise the ECG signals.

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