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Denoising ECG Signal using Adaptive Filter Algorithms and Cubic Spline Interpolation for Regaining Missing data points of ECG in Telecardilogy System

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ABSTRACT

Maintaining one's health is a fundamental human right although one billion people do not have access to quality healthcare services. Telemedicine can help medical facilities reach their previously inaccessible target community. The Telecardiology system designed and implemented in this research work is based on the use of local market electronics. In this research work we tested three algorithms named as LMS (Least Mean Square), NLMS (Normalized Mean Square), and RLS (Recursive Least Square).We have used 250 mV amplitude ECG signal from MIT-BIH database and 5mV(2 % of original ECG signal), 10 mV(4% of original ECG) 15mV (6% of original ECG),20 mV(8% of original ECG signal) and 25mV(10% of original ECG signal) of random noise and white Gaussian noise is added with ECG signal and Adaptive filter with three different algorithms have been used to reduce the noise that is added during transmission through the telemedicine system. Normalized mean square error was calculated and our MATLAB simulation results suggest that RLS performs better than other two algorithms to reduce the noise from ECG. During analog transmission of ECG signal through existing Telecommunication network some data points may be lost and we have theoretically used Cubic Spline interpolation to regain missing data points. We have taken 5000 data points of ECG Signal from MIT-BIH database. The normalized mean square error was calculated for regaining missing data points of the ECG signal and it was very less in all the conditions. Cubic Spline Interpolation function on MATLAB platform could be a good solution for regaining missing data points of original ECG signal sent through our proposed Tele-cardiology system but practically it may not be efficient one

Keywords: Telecardiology, Adaptive Filter, LMS, NLMS, RLS.

1. INTRODUCTION

The ECG signal measured with an electrocardiograph, is a biomedical electrical signal occurring on the surface of the body related to the contraction and relaxation of the heart. This signal represents an extremely important measure for doctors as it provides vital information about a patient cardiac condition and general health. Generally the frequency band of the ECG signal is .05 to 100 Hz [1]. Inside the heart there is a specialized electrical conduction system that ensures the heart to relax and contracts in a coordinated and effective fashion. ECG recordings may have common artifacts with noise caused by factors such as power line interference, external electromagnetic field, random body movements and respiration. Different types of digital filters may be used to remove signal components from unwanted frequency ranges [2].

As it is difficult to apply filters with fixed coefficients to reduce biomedical signal noises because human behaviour is not exact depending on time, an adaptive filtering technique is required to overcome the problem. Adaptive filer is designed using different algorithms such as least mean square (LMS), Recursive least square (RLS) [4]. Least square algorithms aims at minimization of the sum of the squares of the difference between the desired signal and model filter output when new samples of the incoming signals are received at every iteration, the solution for the least square problem can be computed in recursive form resulting in the recursive least square algorithm. The goal for ECG signal enhancement is to separate the valid signal components from the undesired artifacts so as to present an ECG that facilitates an easy and accurate interpretation.

The basic idea for adaptive filter is to predict the amount of noise in the primary signal and then subtract noise from it.

In this research work a Telecardiology system has been designed and implemented using instrumentation amplifier, band pass filter and Arduino interfacing between Smartphone and Arduino board. First of all raw ECG signal has been amplified and filtered by Band pass filter. Analog signal has been digitized using Arduino board and then interfacing between Arduino board and smart phone has been implemented and Digitized value of analog signal has been sent from Arduino board to smart phone and digitized value of analog signal has been stored in SD storage card of smart phone. Using Bluetooth or existing Telecommunication Network. As sinusoidal signals are known to be corrupted during transmission it is expected that similarly an ECG signal will be corrupted.

We have therefore designed an adaptive filter with three different algorithms and simulated in MATLAB platform to compare the performance of denoising of ECG signal. During transmission of ECG signals through existing Telecommunication networks some data pints may be lost .In this research work we have used cubic spline interpolation to regain missing data point's .If more data points are missing then reconstruction of an ECG signal becomes impossible and doctor can not accurately interpret a patient's ECG in an efficient manner. Cubic spline interpolation has been implemented for various missing data points of original ECG signal taken from MIT-BIH database. The normalized mean square error of cubic spline interpolation was very low. Cubic Spline interpolation in Matlab platform could be a better solution for regaining missing data points of ECG signal theoretically.

2. RELATED WORKS AND LITERATURE REVIEW

The extraction of high-resolution ECG signals from recordings contaminated with system noise is an important issue to investigate in Telecardiology system. The goal for ECG signal enhancement is to separate the valid signal components from the undesired artifacts, so as to present an ECG that facilitates easy and accurate interpretation. Many approaches have been reported in the literature to address ECG enhancement using adaptive filters [7] [8], which permit to detect time varying potentials and to track the dynamic variations of the signals. In N.V Thakor et al [9]-[10] proposed an LMS based adaptive recurrent filter to acquire the impulse response of normal QRS complexes, and then applied it for arrhythmia detection in ambulatory ECG recordings. The reference inputs to the LMS algorithm are deterministic functions and are defined by a periodically extended, truncated set of orthonormal basis functions. In these papers, the LMS algorithm operates on an instantaneous basis such that the weight vector is updated every new sample within the occurrence, based on an instantaneous gradient estimate.

There are certain clinical applications of ECG signal processing that require adaptive filters with large number of taps. In such applications the conventional LMS algorithm is computationally expensive to implement The LMS algorithm and NLMS (normalized LMS) algorithm require few computations, and are, therefore, widely applied for acoustic echo cancellers. However, there is a strong need to improve the convergence speed of the LMS and NLMS algorithms. The RLS (recursive least-squares) algorithm, whose convergence does not depend on the input signal, is the fastest of all conventional adaptive algorithms. The major drawback of the RLS algorithm is its large computational cost. However, fast (small computational cost) RLS algorithms have been studied recently. In this paper we aim to obtain a comparative study of faster algorithm by incorporating knowledge of the room impulse response into the RLS algorithm. Unlike the NLMS and projection algorithms, the RLS algorithm does not have a scalar step size.

Therefore, the variation characteristics of an ECG signal cannot be reflected directly in the RLS algorithm. Here, we study the RLS algorithm from the viewpoint of the adaptive filter because (a) the RLS algorithm can be regarded as a special version of the adaptive filter and (b) each parameter of the adaptive filter has physical meaning. Computer simulations demonstrate that this algorithm converges twice as fast as the conventional algorithm. These characteristics may plays a vital role in biotelemetry, where extraction of noise free ECG signal for efficient diagnosis and fast computations, high data transfer rate are needed to avoid overlapping of pulses and to resolve ambiguities. To the best of our knowledge, transform domain has not been considered previously within the context of filtering artifacts in ECG signals.

In this paper we compare the performances of LMS, NLMS and RLS algorithms to remove the artifacts from ECG. This algorithm enjoys less computational complexity and good filtering capability. To study the performance of the algorithms to effectively remove the noise from the ECG signal, we carried out simulations on MIT-BIH database. During transmission of ECG signal through existing Telecommunication network it may be corrupted or some data points may be lost. Linear Spline interpolation was popular method for regaining missing data points of ECG signal [6].Cubic Spline interpolation has gained popularity very recently[8].In our research work, we have used cubic spline interpolation for regaining missing data points of ECG signal sent through telecommunication network.

3. SYSTEM DESIGN AND ALGORITHMS

In this research work a Telecardiology system has been implemented and proposed for sending ECG signal through smart phone.

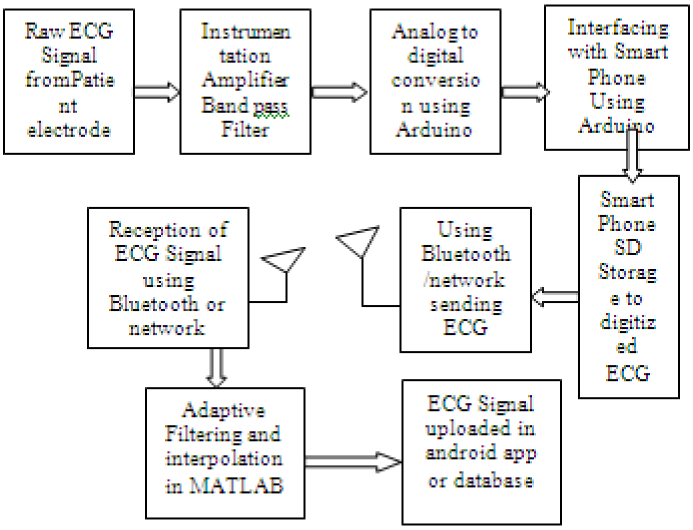

Fig 1: Our designed proposed Telecardiology System

The raw ECG signal will be taken from patient electrode and passed through instrumentation amplifier and band pass filter to amplify the signal and to reduce the noise coming from electrodes. Then that amplified and filtered analog ECG signal will be converted into digital signal by using Arduino AVR microcontroller based system. Then that digital value of ECG signal will be sent to smart phone by using Arduino interfacing with smart phone and digitized signal values will be sent to smart phone SD card .After that digital value will be sent to another smart phone by using Bluetooth technology. Digitized ECG value will be received to smart phone via Bluetooth .During transmission of ECG signal through Telecommunication network it may be corrupted by random noise or white Gaussian noise of the network. Adaptive filter using different algorithms have been used to reduce noise of the transmitted ECG signal. A MATLAB coding has been done to reduce the noise of the ECG signal and for reducing noise of digitized ECG signal, transmitted noisy ECG signal needs to be loaded in MATLAB and then it is filtered suing adaptive filter with different algorithms and performances of different algorithms are measured based on their de-noising capabilities. During transmission of ECG signal some data points may be missing and MATLAB spline interpolation algorithm will get them back so that ECG signal can be transmitted reliably.

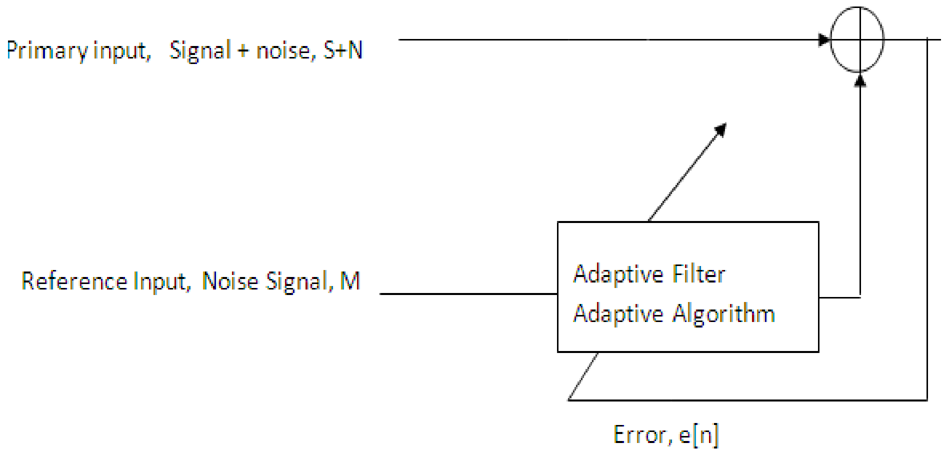

Fig.2: Adaptive Noise Canceller(ANC)

Least Mean Square (LMS), Normalised Mean Square Algorithm (NLMS) and Recursive Least Square Algorithm (RLS) has been designed and implemented for denoising ECG signal in MATLAB platform[4][5][6].Cubic Spline Interpolation has been used for regaining missing data points of ECG signal during transmission through existing Telecommunication network. The normalized mean square error was calculated for regaining missing data points of ECG signal and it was very less and so Cubic spline interpolation could be a better solution in MATLAB platform for regaining missing data points of ECG signal.

4. RESULT

In this work we have taken pure ECG signal from MIT-BIH database. The amplitude of our taken ECG signal was 250 mV which is amplified from.5mV(2 % of original ECG signal), 10 mV (4% of original ECG) 15mV (6% of original ECG),20 mV(8% of original ECG signal) and 25mV(10% of original ECG signal) of random noise and white Gaussian noise is added with ECG signal .Three different algorithms of Adaptive filter was implemented and tested their performances of denosing ECG signal. We have taken ECG signal with 250 mV amplitude and 5000 samples were taken from MIT-BIH database.

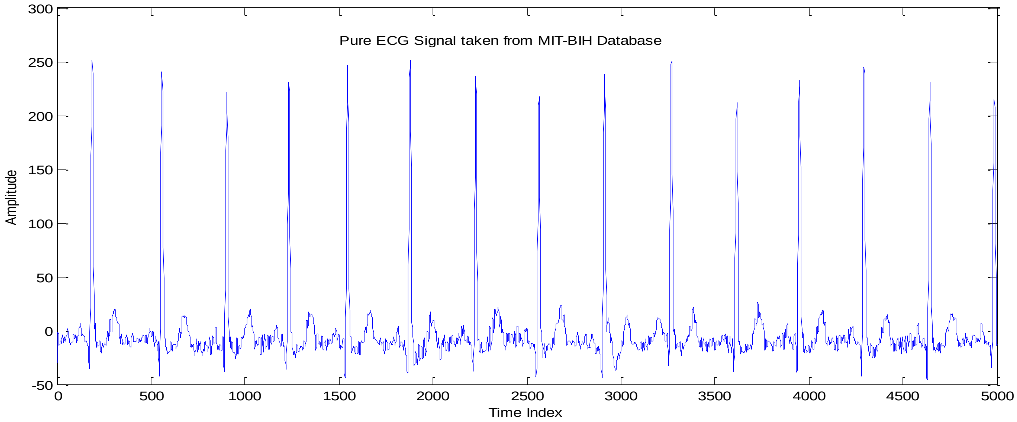

Fig. 3: Pure ECG Signal taken from MIT-BIH Database

In this case we will show only 25 mV for random and Gaussian noise with three different algorithms.

25 mV amplitude Random Noise(10% of Original Amplified ECG Signal Amplitude):

Least Mean Square (LMS) Algorithm:

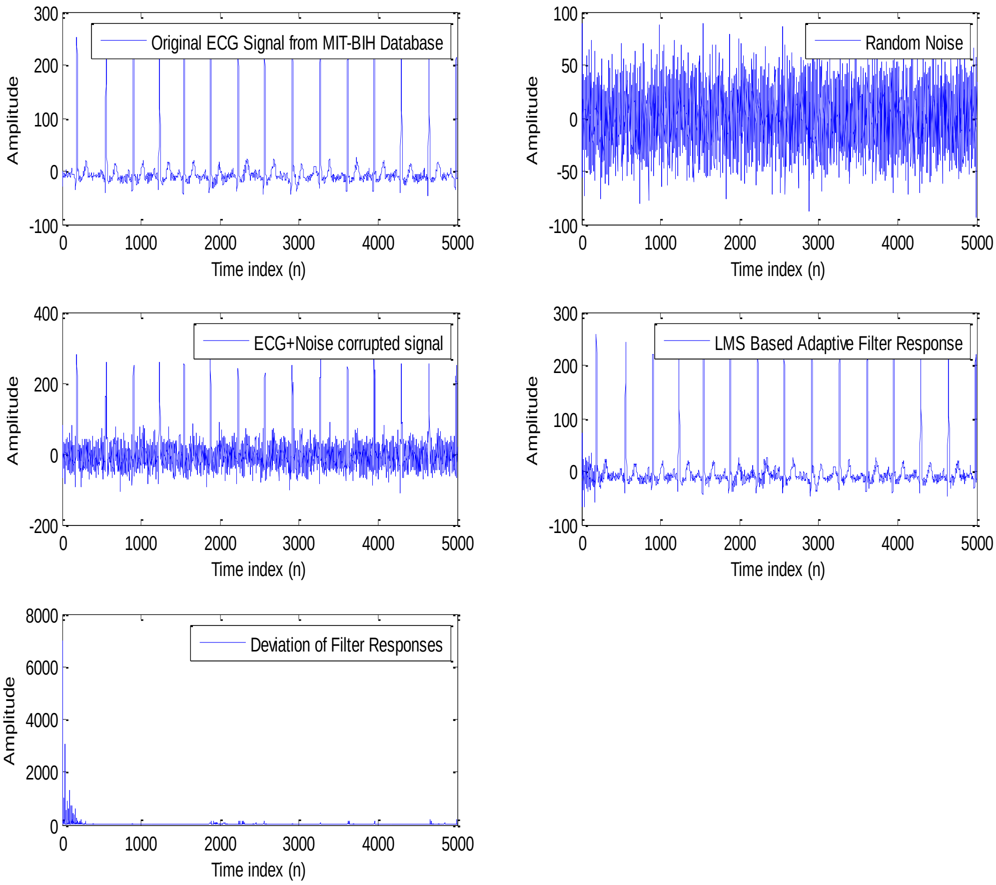

Fig.4: (a) Pure ECG signal taken from MIT-BIH Database (b) Random Noise with average amplitude 25 mV (c) ECG signal is mixed with pure ECG signal (d) LMS based Adaptive Filter response (e) Squared Deviation of LMS based adaptive filter

Normalised Mean Square Algorithm (NLMS):

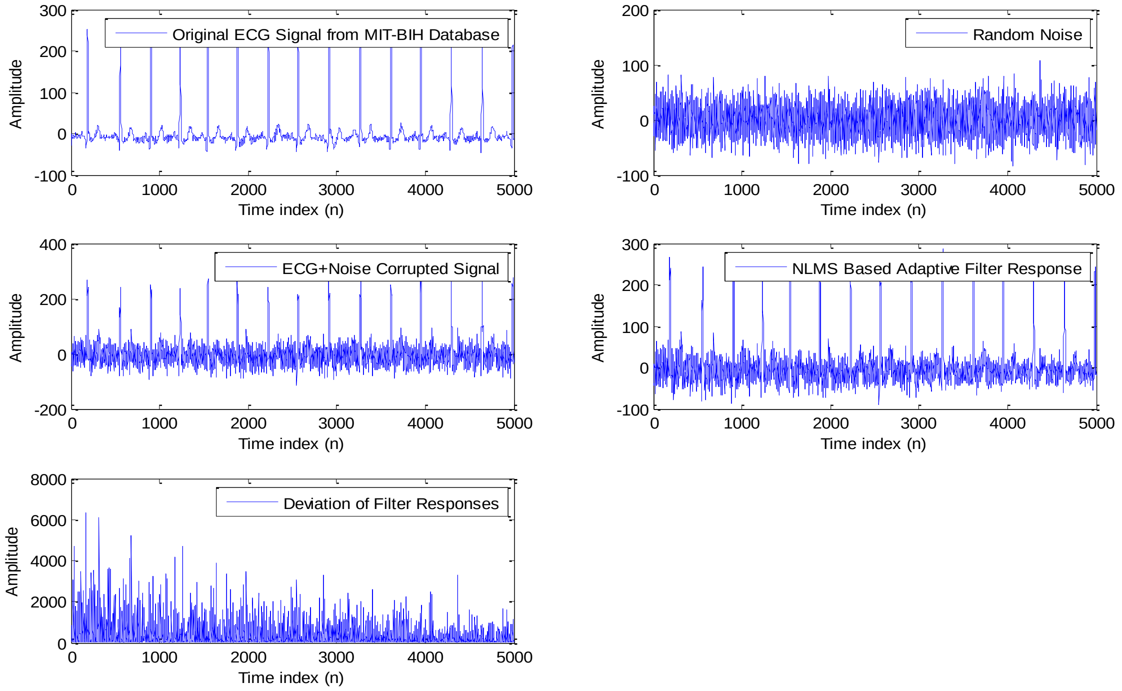

Fig. 5: (a) Pure ECG signal taken from MIT-BIH Database (b) Random Noise with average amplitude 25 mV (c) ECG signal is mixed with pure ECG signal (d) NLMS based Adaptive Filter response (e) Squared Deviation of LMS based adaptive filter

Recursive Least Square Algorithm (RLS):

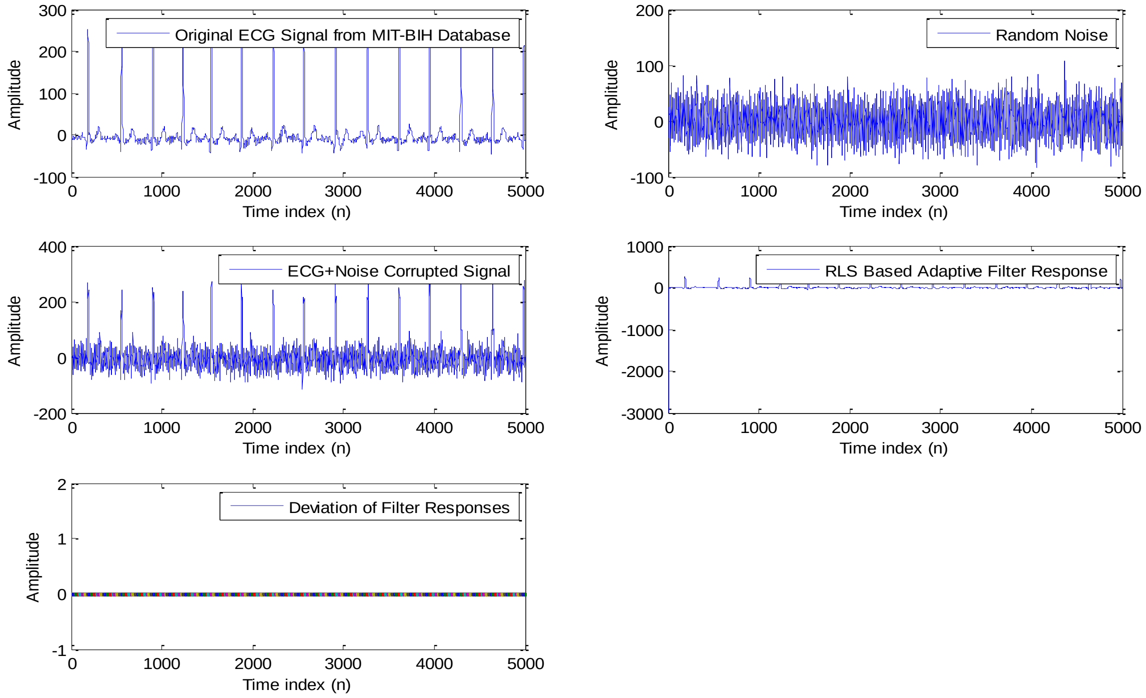

Fig.6: (a) Pure ECG signal taken from MIT-BIH Database (b) Random Noise with average amplitude 25 mV (c) ECG signal is mixed with pure ECG signal (d) NLMS based Adaptive Filter response (e) Squared Deviation of LMS based adaptive filter

In the case of Gaussian noise 25mV amplitude and its result is shown below:

25 mV amplitude White Gaussian Noise(10% of original Amplified ECG Signal Amplitude)

Least Mean Square (LMS) Algorithm:

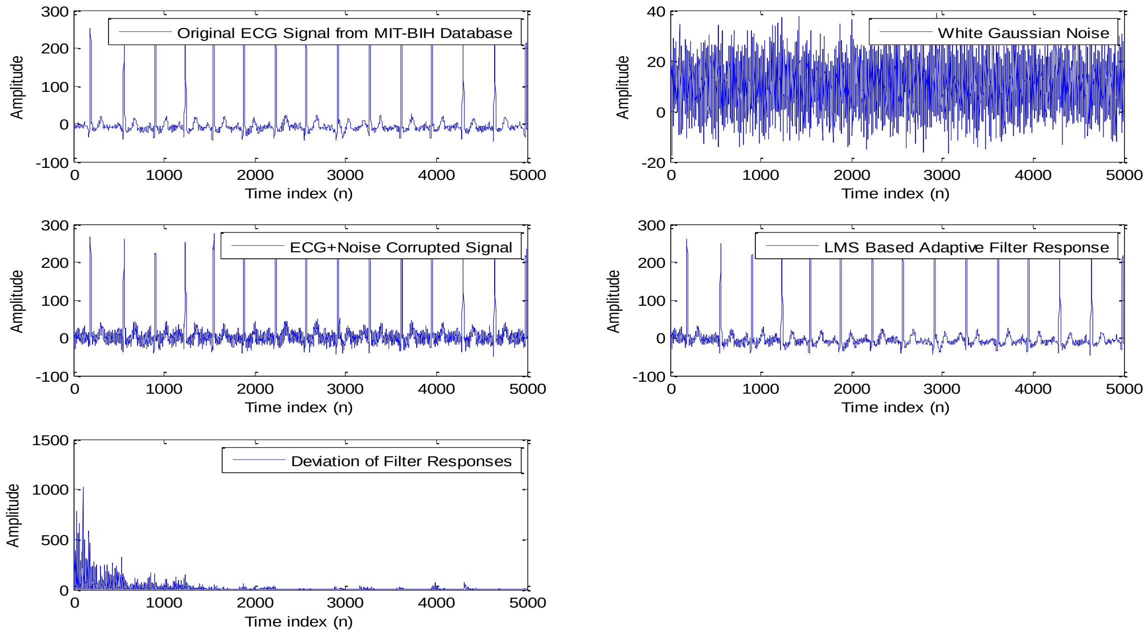

Fig.7: (a) Pure ECG signal taken from MIT-BIH Database (b) Gaussian Noise with average amplitude 25 mV (c) ECG signal is mixed with pure ECG signal (d) LMS based Adaptive Filter response (e) Squared Deviation of LMS based adaptive filter

Normalized Mean Square (NLMS) Algorithm:

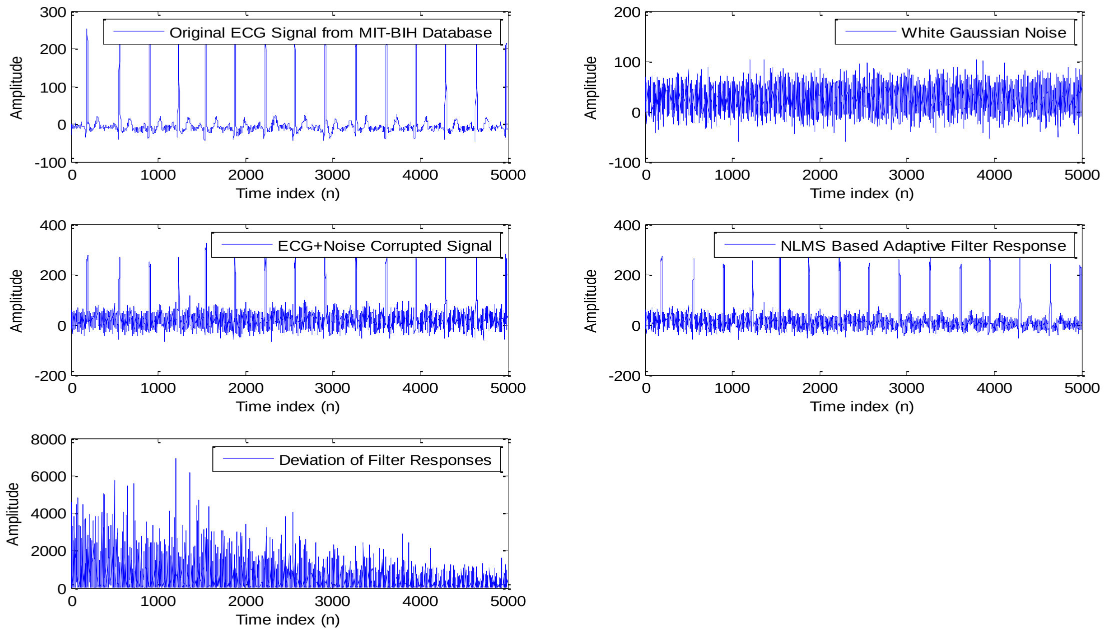

Fig. 8: (a) Pure ECG signal taken from MIT-BIH Database (b) Gaussian Noise with average amplitude 25 mV (c) ECG signal is mixed with pure ECG signal (d) NLMS based Adaptive Filter response (e) Squared Deviation of NLMS based adaptive filter

Recursive Least Square Algorithms (RLS):

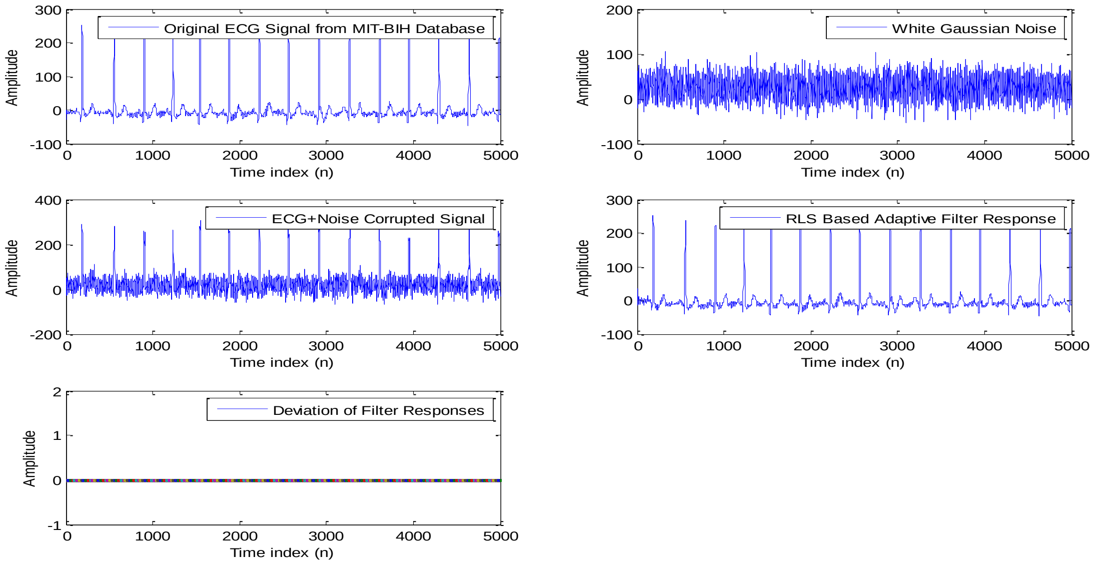

Fig.9: (a) Pure ECG signal taken from MIT-BIH Database (b) Gaussian Noise with average amplitude 25 mV (c) ECG signal is mixed with pure ECG signal (d) NLMS based Adaptive Filter response (e) Squared Deviation of NLMS based adaptive filter

Normalised Least Mean Square Calculation:

Random Noise Amplitude	**LMS**	**NLMS**	**RLS**
5 mV(2% of original ECG signal)	2.4360×10^{-4}	4.2620×10^{-4}	3.3103×10^{-5}
10mV(4% of original ECG signal)	7.9334×10^{-4}	1.6743×10^{-4}	2.2612×10^{-5}
15 mV(6%of original ECG signal)	2.2585×10^{-4}	1.3418×10^{-4}	1.2008×10^{-5}
20 mV(8%of original ECG signal)	5.9643×10^{-4}	2.4246×10^{-4}	6.2567×10^{-5}
25 mV(10%of original ECG signal	3.5566×10^{-4}	2.8322×10^{-4}	1.5938×10^{-5}
White Gaussian Noise	**LMS**	**NLMS**	**RLS**
5 mV(2% of original ECG signal)	1.6212×10^{-4}	1.1086×10^{-4}	7.5142×10^{-5}
10 mV(2% of original ECG signal)	1.9208×10^{-4}	6.5993×10^{-4}	3.4666×10^{-5}
15mV(4% of original ECG signal)	1.4405×10^{-4}	6.0342×10^{-4}	3.8241×10^{-5}
20 mV(6%of original ECG signal)	8.4139×10^{-4}	4.2179×10^{-4}	1.5327×10^{-5}
25 mV(8%of original ECG	4.2407×10^{-4}	2.4459×10^{-4}	7.0148×10^{-5}

The above simulation result suggests that Recursive Least Square algorithm (RLS) performs better than other two algorithms. RLS could be the best option for Telecardiology system to denoise ECG signal during transmission.

We have taken 5000 data points of ECG signal from MIT-BIH database. In our simulation 11data points (from 689 to 699 of original data points of ECG), 201 data points (from 800 to 1000 of original data points of ECG), 300 data points (from 1600 to 1900 of original data points of ECG), 500 data points (from 2000 to 5000) and 6 data points(from 4095 to 5000) are made zero and cubic spline interpolation function was called in MATLAB platform and it could regain the original data points of ECG signal.

The MATLAB coding result of Spline Interpolation is given below:

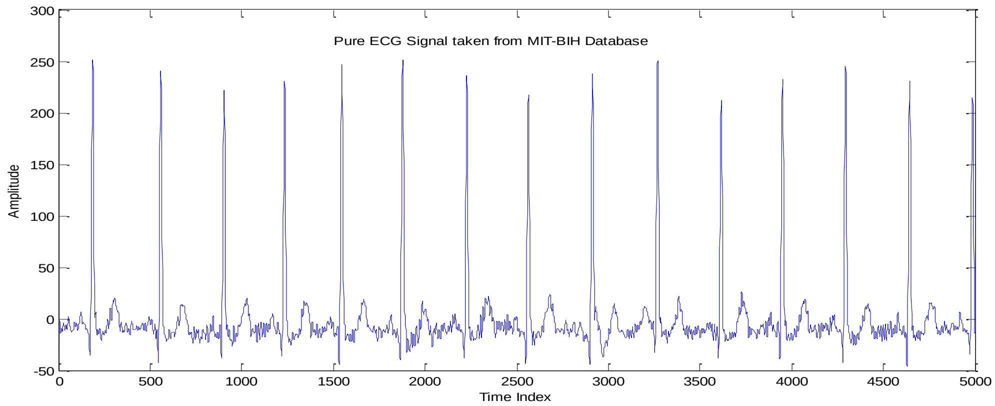

Fig.10: Pure ECG signal taken from MIT-BIH database

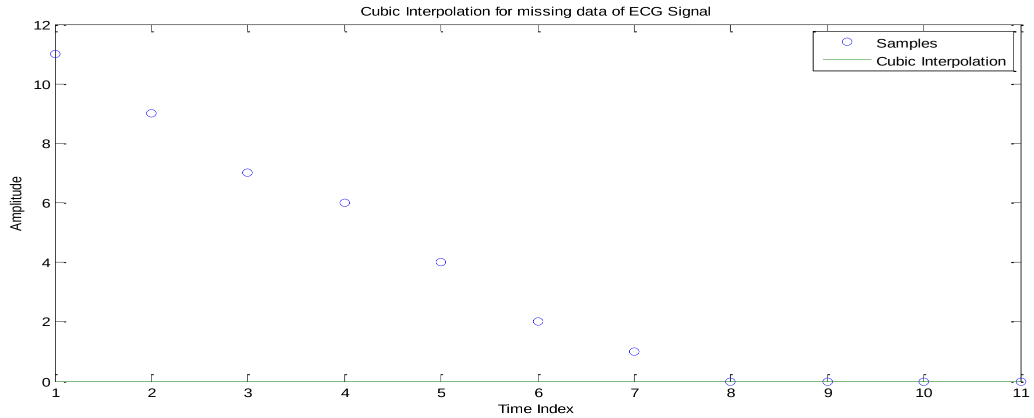

Fig. 11: Cubic Spline Interpolation for missing data Points of ECG signal from samples of 689 to 699.

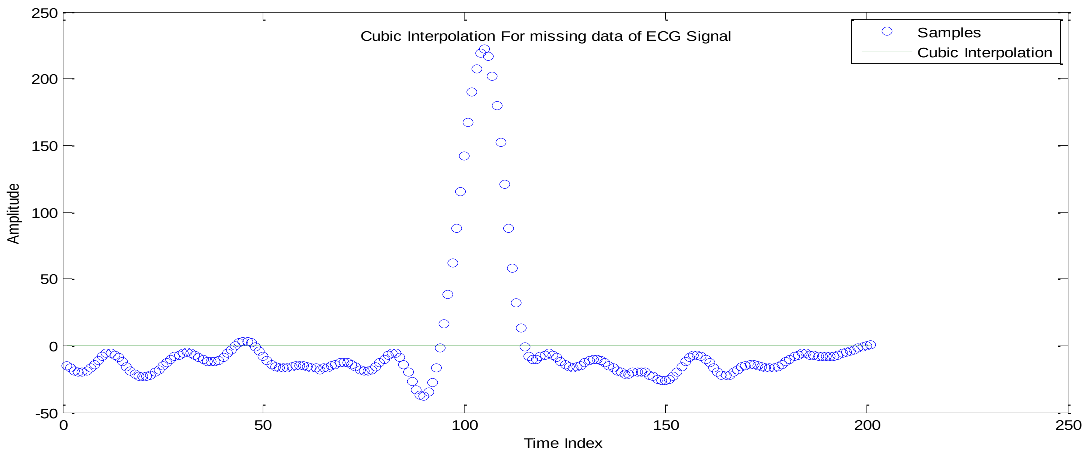

Fig.12: Cubic Spline Interpolation for missing data Points (200) from 800 to 100 samples (original ECG from MIT-BIH database).

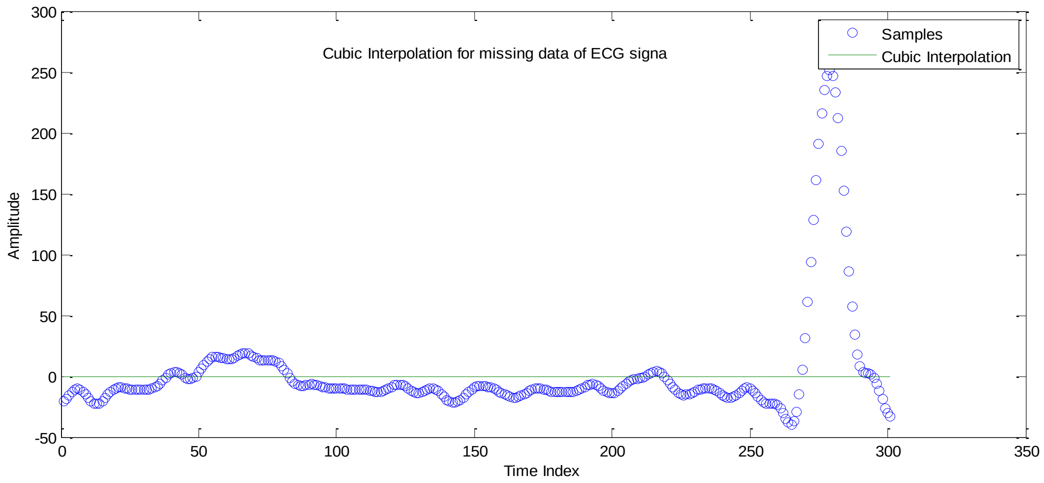

Fig.12: Cubic Spline Interpolation for missing data Points (300) from 1600 to 1900 samples (original ECG from MIT-BIH database).

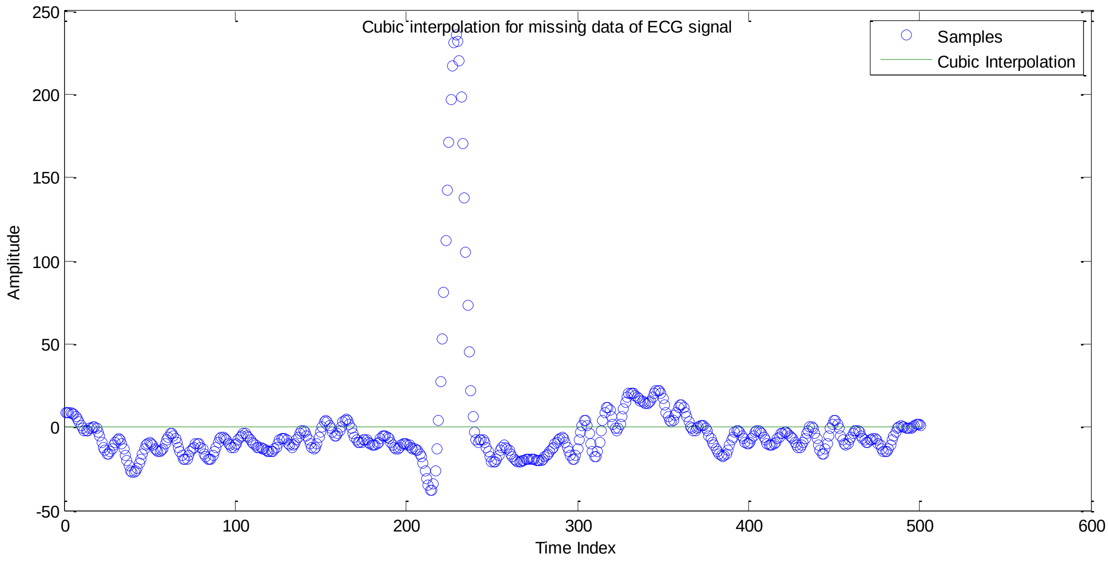

Fig.14: Cubic Spline Interpolation for missing data Points (501) from 2000 to 2500 samples (original ECG from MIT-BIH database

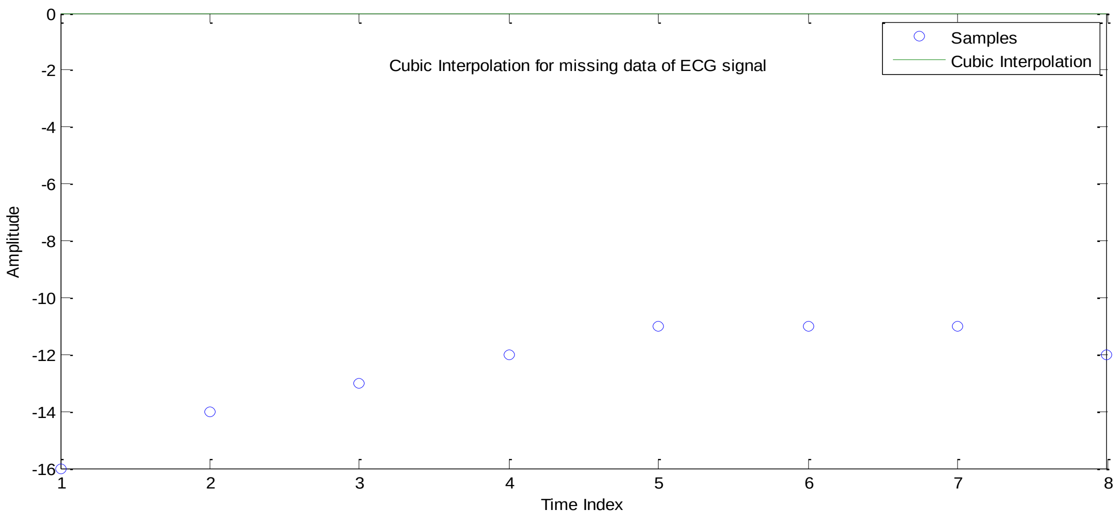

Fig.15: Cubic Spline Interpolation for missing data Points (6) from 4095 to 5000 samples (original ECG from MIT-BIH database).

Normalized Mean Square Error Calculation of Cubic Spline Interpolation

Missing Data Points of ECG samples	Normalized Mean Square of Cubic Spline
11 data points(689 to 699 samples)	.0909
201 data points (800 to 1000 samples)	.0050
300 data points (1600 to 1900 samples)	.0033
500 data points(2000 to 2500 samples)	.0020
6 data points(4095 to 5000 samples)	0.1667

In all of the cases normalized mean square error is very less and it suggests that Cubic Spline Interpolation performs satisfactorily for regaining missing data points of ECG signal.

CONCLUSION

In this research work Telecardiology system has been designed and implemented and sinusoidal signal could be sent though our designed system as raw ECG signal was not available so we have used sinusoidal signal. During transmission of ECG signal it may be corrupted due to random noise and Gaussian noise. So we have testes the performances of LMS, NLMS and RLS algorithm of adaptive filter. Our simulation result suggests that RLS could be the best option for recovering ECG signal or denosing ECG signal during transmission through Telecardiology system. We have used cubic spline interploation for regaining missing data points of ECG signal. We have taken 5000 data points of ECG signal from MIT-BIH database. In our simulation 11 data points,200 data points,300 data points and 6 data points are made zero randomly and cubic spline interpolation was called and it could regain the original data points of ECG signal. The normalized mean square error was calculated and it was very less. So Cubic Spline Interpolation could be a good solution for regaining missing data points of original ECG signal.

5. ACKNOWLEDGMENT

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REFERENCES

[1]. Noor, K., 2010. Comparison of the RLS and LMS Algorithms to Remove Power Line Interference Noise from ECG Signal, Al-Khwarizmi Engineering Journal, 6(2): 51-61.

[2]. Yue-Der Lin and Yu Hen Hu, 2008. Power-Line Interference Detection and Suppression in ECG signal Processing, IEEE Transactions on Biomedical Engineering, 55(1).

[3]. Dhubkarya, D.C., 2012. Aastha Katara and Raj Kumar Thenua Simulation of Adaptive Noise Canceller for an ECG signal Analysis, ACEEE Int. J. Signal & Image Processing, 03(01).

[4]. V.John Mathews, Scott C. Doughlas, Adaptive Filter, Chapter 4, pp. 17-23

[5]. D. Morgan and S.Kartzer, On a class computationally efficient rapidly converging generalized NLMS algorithms, IEEE Transaction Education, Vol.41, pp.83,Feb 1998

[6]. Marzieh Golabbakhsh, Monire Masoumzadeh and Mohammad Farzan Sabahi, 2011. ECG and power line noise removal from respiratory EMG signal using adaptive filters, Majlesi Journal of Electrical Engineering, 5(4).

[7]. Paulo S.R Denis, "Adaptive Filtering Algorithm and Implementation".

[8]. O. Sayadi and M. B Shamsollahi, "Model-Based fiducially points extraction for Baseline wander Electrocardiogram," IEEE Transaction on Biomedical Engineering, Vol. 55, pp.347-351, Jan, 2008.

[9]. N.V Thakor and Y.S Zhu, "Application of Adaptive Filtering to ECG analysis: noise cancellation and arrhythmia detection" IEEE Transaction on Biomedical Engineering, Vol. 38, No.8,pp 785-794,1991

[10]. Farhang-Boroujeny, B., "Adaptive Filters: Theory and Applications, John Wiley and Sons. Chichester, UK, 1998.