ISSN: 2321-8169
244 - 249

Filtering Techniques for Reduction of Motion Artifacts in Electrocardiogram Signals

Prof. Nilesh M. Verulkar[1]
Assistant Professor
Dept. of ENTC,
MGI-COET,
Shegaon

Prof. Rahul R. Ambalkar[2]
Assistant Professor
Dept. of ENTC,
MGI-COET,
Shegaon

Prof. Snehal R. Deshmukh[3]
Assistant Professor
Dept. of ENTC,
MGI-COET,
Shegaon

Prof. Pranali P. Chavhan[4]
Assistant Professor
Dept. of ENTC,
MGI-COET,
Shegaon

***Abstract*—** Electrocardiogram (ECG) is one of most powerful medical imaging modality which is use for the recording of the electrical activity of the heart. The ECG signal is very sensitive in nature; the noise produced by the environment and by the patient causes changes in characteristics of ECG signals. In this review article we have discussed different kinds noises that can be introduce in ECG signal along with some different filtering techniques used for cancellation of motion artifacts. Hence filtering remains an important task, as data corrupted with noise must be filter or discarded. Various types of filters have been suggested by the researchers. The results show the comparative analysis of various filtering techniques.

***Keywords*-** *Artifacts, Multi-Resolution Thresholding, Adaptive Filter, Wiener Filter RLS algorithm*

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I. INTRODUCTION

In last few decades there has been a huge increase in the number of people suffering from cardiac disorders. The electrocardiogram (ECG) is the best imaging modality used for diagnosing of heart diseases and evaluating the efficiency of therapeutic drugs, also it is widely used for the diagnosis of obstructive sleep apnea or wearable physiological monitor. ECG signal is an electrical signal that represents the depolarization/ repolarization of the atrium and the ventricle which occurs for every heartbeat It is needed when chest pain occurred such as heart attack, shortness of breath, faster heartbeats, high blood pressure, high cholesterol etc. ECG signal lies in the range of 0.05-100Hz and 50Hz. ECG is very sensitive signal to environmental noise. So, it is very important to remove these noises and interference from the ECG signal.

a) ECG signal generation

P wave: signal spread from SA node to make the atria contract.
P-Q Segment: signal arrives AV node stay for an instant to allow the ventricle to be filled with blood.
Q wave: After the Buddle of His the signal is divided into two branches and run through the septum.
R,S wave: Left and right ventricle contraction are marked by the R,S wave.
T wave: ventricle relaxing.

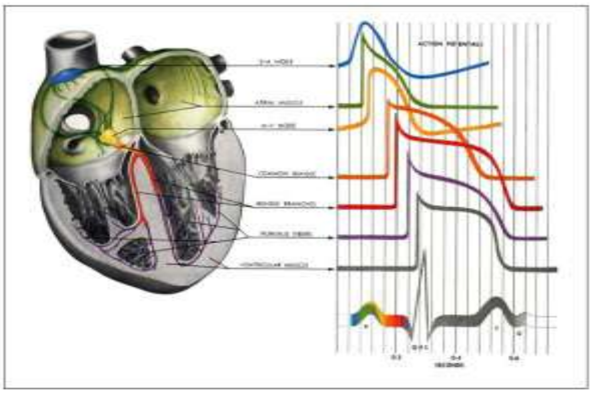


Fig. 1 ECG Signal Generation

b) ECG block diagram

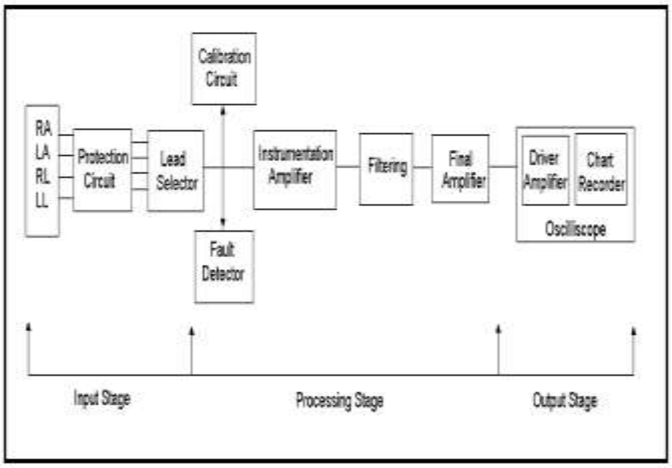


Fig. 2 ECG Block Diagram

Protection Circuit: It protects the system from high level voltages or DC shock used to resuscitate heart attack patients.
Lead Selector Design: Connect the patient leads to non-inverting amplifier terminal (+) & inverting terminal(-).
Calibration Circuit: It is a circuit consisting of resistive network connected to a voltage source that gives at its output 1mV. It is used to check the amplifying factor of the system before using ECG machine.
Fault detector: It can be detected manually or automatically, depending on operating modes and how quickly the system needs to be restored.
Oscilloscope: The oscilloscope is basically a graph-displaying device - it draws a graph of an electrical signal.

c) Types of noise in ECG signal

ECG recordings are often corrupted by various kinds of noise such as power line interference, motion artifacts, electromyogram effects, and baseline drift with respiration. Recently, portable monitors incorporating the computational power of microprocessors have allowed us to implement digital filters for noise cancellation in real-time execution. However, motion artifacts that are part of the transient baseline change are caused by changes in the electrode-skin impedance with electrode motion. This is assumed to be vibrations or movement of the subject. In particular, the spectrum of motion artifact completely overlaps with the ECG signal when the subject is walking or running. Thus, motion artifacts are the most difficult type of noise to cancel.

1. Power line interference:

It consist of 50/60Hz pickup and harmonics, which can be modeled as sinusoids. Characteristics, which might need to be varied in a model of power line noise, of 50/60Hz component include the amplitude and frequency content of the signal. The amplitude varies up to 50 percent of peak-to-peak ECG amplitude, which is approximately equivalent to 25mv. Decomposing the power-line interfered signal into ten IMF's (Intrinsic Mode Functions), this power line information almost distributed to the 1st intrinsic mode functions.

2. Base line drifts with respiration:

The drift of the base line with respiration can be represented by a sinusoidal component at the frequency of respiration added to the ECG signal. The amplitude and frequency of the sinusoidal component should be variable. This baseline can be eliminated by decomposing the signal into 15 intrinsic mode functions reconstructing the signal with suppressing the final IMF is having the base line information.

3. Electrode contact noise:

It is a transient interference caused by loss of contact between the electrode and the skin that effectively disconnects the measurement system from the subject. The loss of contact can be permanent, or can be intermittent as would be the case when a loose electrode is brought in and out of contact with the skin as a result of movements and vibration.

4. Muscle contraction:

The MA (Muscle Artifacts) originally had a sampling frequency of 360Hz. The original ECG signal with MA is given as input to the filter. Muscle contraction cause artifactual milli volt level potentials to be generated. The base line electromyogram is the microvolt range and therefore is usually insignificant. It is simulated by adding random noise to the ECG signal.

5. Motion artifacts:

Motion artifacts are transient base line changes caused by changes in the electrode-skin impedance with electrode motion. As this impedance changes, the ECG amplifier sees a different source impedance which forms a voltage divider with the amplifier input impedance therefore the amplifier input voltage depends upon the source impedance which changes as the electrode position changes.

II. PROPOSED FILTERING TECHNIQUE

Many researchers have proposed methods for cancelling a interference namely as,

Falco Strasse, Michael Muma in their article entitled as Motion Artifact Removal in ECG Signals Using Multi-Resolution Thresholding have introduce a method of removing the motion artifacts by obtaining an estimate of the artifacts using the stationary wavelet transformation. For this purpose they have proposed an automatic multi-resolution thresholding scheme which uses robustified QRS detections. Finally the performance of the method.is illustrated with real data examples as well as simulation. It works fully automatic and independent of the specific subject.

Shing-Hong Liu in his paper Motion Artifact Reduction in Electrocardiogram using Adaptive Filter proposed an algorithm which used an accelerometer to measure the signal of the vibrations or movement of the trunk as the reference inputs which is applied to the adaptive filter. The optimal weight of the adaptive filter could be adjusted by an LMS algorithm. After 60 iterations, the MSE would begin to converge to a stable value for any noise level. Experiments with synthetic and real data were performed to demonstrate the efficiency of this method. Finally he conclude that by using this algorithm the QRS complex of the filtered ECG was clearly appeared.

Chinmay Chandrakar, M.K. Kowar in their paper Denoising Ecg Signals Using Adaptive Filter Algorithm used a RLS algorithm for removing artifacts preserving the low frequency components and tiny features of the ECG. Final results for this RLS algorithm has been concluded as given the following table.

Table. 1 RLS Algorithm Results

Types of Noise	Algorithm	SNR before filtering (in dbs)	SNR after filtering (in dbs)	SNR improve ment (in dbs)
PLI	RLS	17.81	26.94	9.13
BW	RLS	18.73	23.70	4.97
MA	RLS	18.73	22.77	4.04
EM	RLS	18.73	20.53	1.8

Simulate the results for Adaptive Power-line Interference Canceller, Baseline Wander Reduction, and Adaptive Cancelation of Muscle Artifacts and for the Adaptive Electrode Motion. Following figures shows the results for these techniques.

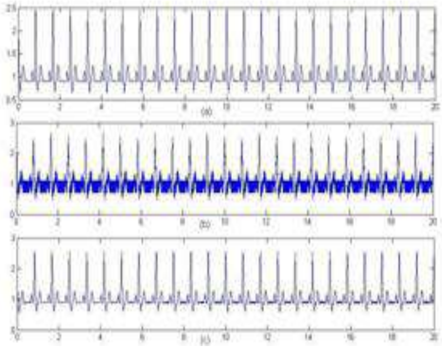


Fig. 3 a) Pure ECG signal, b) ECG with PLI noise, c) Filtered output by RLS algorithm

ISSN: 2321-8169
244 - 249

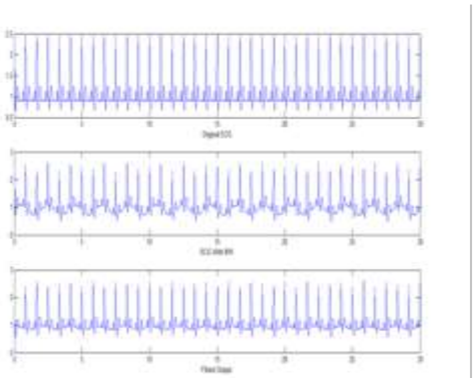


Fig. 4 a) Pure ECG signal, b) ECG with BW noise, c) Filtered output by RLS algorithm

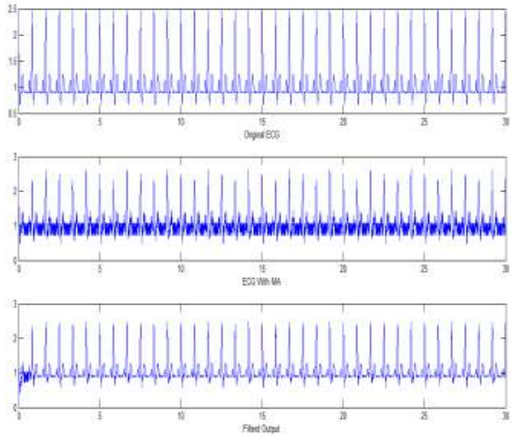
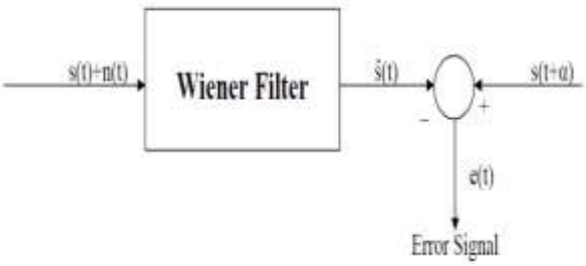


Fig. 5 a) Pure ECG signal, b) ECG with MA noise, c) Filtered output by RLS algorithm

Mohan M. Khambalkar in his paper Simulating Motion Artifact In ECG Using Wiener And Adaptive Filter Structures proposed. Several adaptive filter structures are proposed for noise cancellation, minimizes the mean-square error between a primary input, which is noisy ECG, and a reference input and also improve signal to noise ratio. The adaptive filter was developed to cancel motion artifacts and other noises in the ECG signal to detect diagnostically significant waves in ECG signal.

they discuss our results obtained by Wiener filtering in comparison with adaptive filtering results and show that the results obtained by the proposed approach provides better signal to noise ratios (SNRs) than the adaptive filtering even without the additional sensor information. They proposed wiener filter structure as,



Assumption: signal and noise are stationary linear stochastic processes, causal filter, MMSE. Where:

t g t * [s(t) + n(t)]

s(t) is the original signal , n(t) is the noise
t is the estimated signal the intention is to equal s t+α
g(t) is the Wiener filter's impulse response e t s t+α _ t
α is the delay of the Wiener filter since it is causal)
In other words, the error is the difference between the estimated signal and the true signal shifted by α.
The squared error is

e2(t) = s2 t+α _ 2s t+α t + 2(t)

Where: - s t+α is the desired output of the filter and e(t) is the error .

They also proposed wiener Algorithms as,

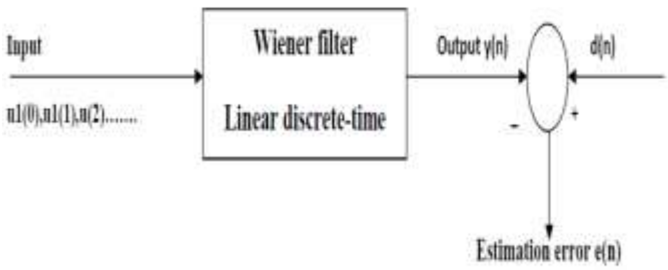


Fig. 6 wiener Algorithms

Wiener Hopf Equation is

R.w0 = p

w0 = Inv(R).p

R is Autocorrelation between u1 and u1
RM×M=E {u1[n].u1T[n]}
p is cross correlation vector between input and desired signal i.e. u1 and d
p = E [u1[n].d[n]]
p = [p (0), p (-1), p (-2) - - - - - p (1-M)] T
AR Coefficient is [1 , -w0]T

In case Adaptive Filter Structure
u(n)=[u(n) u n_1 …..u n_M+1]T
is an input vector and this is represent the elements of the time series.
w(n)= [w0(n),w1 n ,….,wM-1(n)]T
is weight vector and this is represent the filter weights or filter coefficients.
μ (n)=[μ0(n),μ1 n ,……,μM-1(n)]T is step size vector.

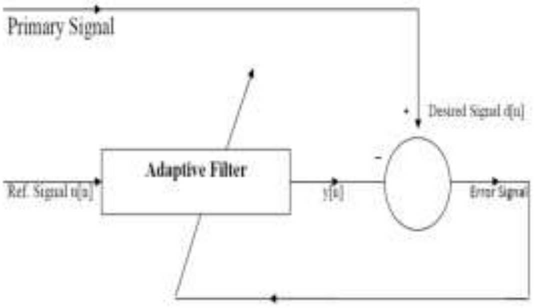


Fig. 6 Adaptive Filter Structure

The error signal

$$e(n) = d(n) – y(n)$$

y(n) is the adaptive filter output signal

$$y(n) = u (n). wT(n)$$

Weights update equation is:

$$w[n+1]=w[n]+\mu u[n](d[n]\_u(n).wT(n))$$

$$e(n) =(d(n) – u (n).$$

$$wT(n)) = (d[n] – y[n])$$

and hence w[n+1] we can write

$$w[n+1]=w[n]+\mu u[n]e[n]$$

$$MSE=E\{e2(n)\}$$

The adaptive filtering technique is the most commonly used algorithm for motion artifact removal.

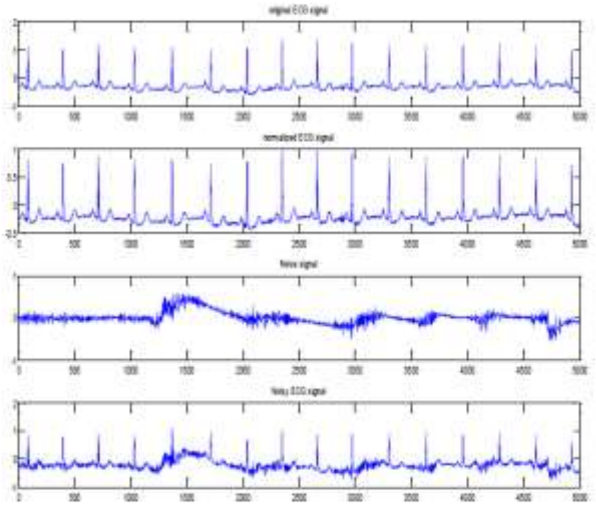


Fig. 7 (a) Simulating ECG Signal from Noisy ECG Signal (b) Compared Simulating ECG Signal to Original ECG Signal (c) Simulating Motion Artifact Signal from Noisy ECG Signal (d) Compared Simulating Motion Artifact Signal to Original Motion Artifact Signal

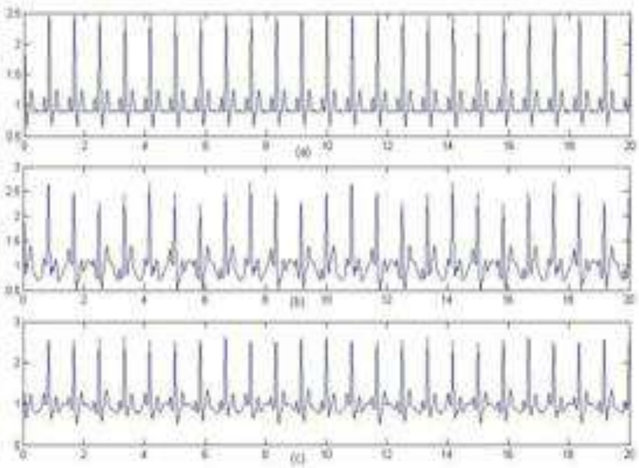


Fig. 8 a) Pure ECG signal, b) ECG with EM noise, c) Filtered output by RLS algorithm.

Weixuan Chen, Natasha Jaques, Sara Taylor, Akane Sano, Szymon Fedor, and Rosalind W. Picard in his paper Wavelet-Based Motion Artifact Removal for Electrodermal Activity Implementation of Denoising Methods on wavelet-based motion artifact removal to each SC time series in the dataset. The Haar wavelet was used as the mother

wavelet, because of its advantage for detecting edges and sharp changes [32], commonly seen in motion artifacts. The two tuning parameters of the algorithm, artifact proportion d and time window length L, were set to be 0.01 and 400 seconds respectively. Three previous methods removing motion artifacts from EDA were also implemented for comparison. They are 1024- point low-pass Hamming filtering (cutoff frequency = 3 Hz) [24], [25], Hanning filtering with a 1 second window [15] and exponential smoothing (a = 0:8) [14].

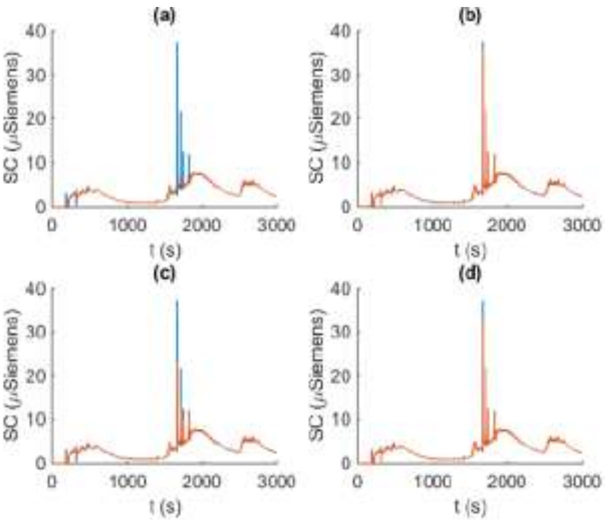


Fig. 9 Original EDA (blue lines) and denoised signals (red lines) processed by (a) wavelet thresholding, (b) Hamming filtering, (c) Hanning filtering and (d) exponential smoothing.

Hae-KyungJung, Yun-hong Noh, Do-un Jeong in his paper EMD Based adaptive filtering algorithm EMD is first introduced by Huang to be used in data analysis [3, 4]. EMD is suitable for analyzing nonlinear and non-stationary data set.

ISSN: 2321-8169
244 - 249

The concept of EMD is to decompose raw data into a set of functions, called intrinsic mode function IMF. The IMF has its unique analytical characteristic while the property of the original signal is still retained. When decomposition steps are increased, the complexity of IMF is reduced and the size of the signal also reduced. Therefore, each of the IMF has a wide range of data points and shows various signal size. EMD is a well-documented technique and useful for analyzing wide range of nonlinear and nonstationary bio signal [5-7]. ECG being a complex but important bio signal, we recommend EMD technique to be used for motion artifact removal. ECG signal S(t) is the sum of IMF in which one residual signal Rn(t) that decomposed into N. Lower order IMF represents the high-frequency information of the signal, the higher-order IMF shows the low-frequency components of the signal. The residual signal Rn(t) contained from higherorder starting the Lower order IMF CN,...,C2,C1 of reconstructed signal. EMD is based on the local characteristic time scale of the signal. It has a characteristic time-scale state and signal fluctuations is laid within a frequency tuning range. .Furthermore, a small scale to large scale different balance array elements can be obtained. Based on these characteristics, a new filtering method is created at time-domain-scale filtering. EMD

through signal S(t) is decomposed as n two IMF to equations (4).

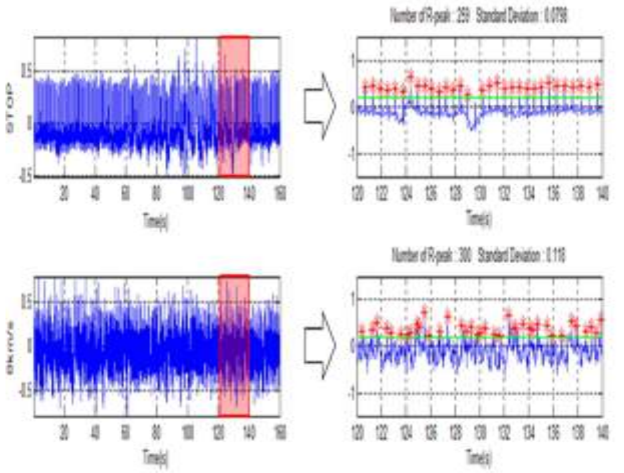


Fig. 10 Result of general filtering technique

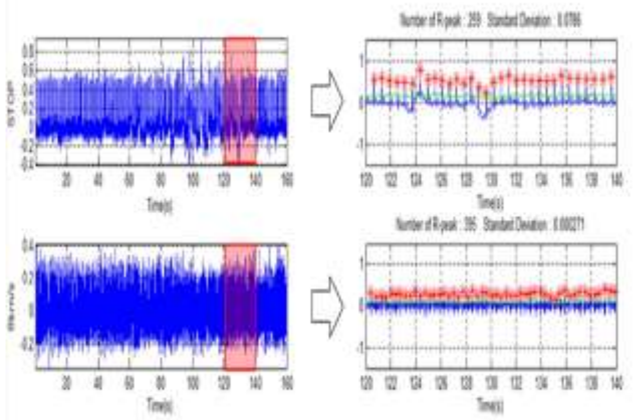


Fig. 11 Result of EMD filtering technique

At the end they propose an efficient method to remove motion artifact by using EMD as a filtering technique. EMD filtering level is subjected to the change of activity status and therefore it is filtering effective.

III. Conclusion

The ECG is the record of time varying bio – electric potential generated by electrical activity of heart. Various filters have been used to het noise free signal. The all of above method provides an overview of different methods. The future work primarily focuses on to designing of ECG signals with a designing a filter which provide noise free or accurate ECG signal.

As we gone through various types of filter method, we can say that the EMD Based adaptive filtering algorithm is giving good performance for removal of motion artifacts is ECG signal and providing noise free signal at the output terminals.

Acknowledgment

The authors would like to thank Dr. C. M. Jadhao, Principal at MGI-COET Shegaon for his help also thanks to Dr. U. S. Bhadade, Head IT dept., SSBT COET Jalgaon, Prof. P.S. Gawande Head ENTC dept., RSCE Buldhana & Prof. P.R. Wankhede, Asst. Prof.at SSGMCE, Shegaon for their valuable guidance and support.

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Nilesh M. Verulkar received the BE degree in ENTC Engg. from SGBAU, Amravati in 2012 and ME degree in Digital Eletronics from NMU, Jalagon in 2014. He is currently working as an Asst. Prof. at Mauli College of Engineering & Technology, Shegaon, Maharashtra, His research interests include Wireless Networking and Microwave Engineering. He has published 6 International and 2 National papers.

Rahul R. Ambalkar received the M.E (Digital Eletronics) degree in SGBAU, Amravati in 2011.He is currently working as an Asst. Prof. at Mauli College of Engineering & Technology, Shegaon, Maharashtra and His research interests include Image Processing and Embedded Systems. He has published 8 International and 2 National papers.

Snehal R. Deshukh received the B.E in the year 2008 & M.E (Digital Eletronics) degree in 2014 from SGBAU, Amravati. She is currently working as an Asst. Prof. at Mauli College of Engineering & Technology, Shegaon, Maharashtra and Her research interests include VLSI. she has published 2 International papers.

Pranali P. Chavhan received the BE degree in ENTC Engg. from SGBAU, Amravati in 2013 and persuing ME degree in Digital Eletronics from SGBAU, Amravati. She is currently working as an Asst. Prof. at Mauli College of Engineering & Technology, Shegaon, Maharashtra, Her research interests include Image Processing and

VLSI.