International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 12 (2019), pp. 3050-3055

Wavelets Based Signal Processor for Naval Surveillance Radars

N. Muralidhara[1], Rajashekhar C Biradar[2], Jayaramaiah G.V[3]

Rukmini Knowledge Park, REVA University, Yelahanka, Bengaluru, Karnataka 560064, India.

Near JnanaBharathi Campus, Bengaluru, Karnataka 560056, E_mail: gvjayaram@gmail.com[3]

[1]ORCID: 0000-0002-3266-8836 (N. Muralidhar)

Abstract

The aim of this research is to study the effect of Discrete Wavelet Transform based Radar signal processing for de-noising and subsequently use for better detection of the smaller targets during surveillance operation of the radar. In this research paper, the thresholding based noise reduction achieved using Wavelets and its performance is compared with conventional radar signal processing like Moving Target Detection operation by simulation and experimental results. The comparisons are based upon target range and Radar Cross Section and resulting reflected signals are in terms of Signal to Noise Ratios. The results shows that performance is obtained from wavelets are better compared to moving target indicator method in conventional radars.

Keywords: Wavelet Based De-noising (WBD), Discrete Wavelet Transform (DWT), Short-Time Fourier Transform, Radar Cross Section (RCS), Pulse Compression Ratio (PCR),

I. INTRODUCTION

Radar receiver signal contains echoes from the targets, unwanted signals like noise information which is very critical interference in the radar system and white Gaussian thermal noise [1] [2]. Generally noise can be represented as a random process during performance evaluation of a radar system [3]. Moving target indicators detect moving targets based on the Doppler shift of the echo pulses from the targets. Targets that are moving fast when compared to the noise are detected by using noise rejection methods (like hard thresholding) [4]. But, radial targets moving with the velocity as that of surrounding ground / intermittent noise cannot be detected using regular algorithms like Fast Fourier Transform (FFT) based methods.

Fourier coefficients of the transformed function represent the contribution of sine and cosine functions at each frequency. But, Fourier transformation cannot approximate a non-periodic signal, hence does not accurately represent the signal. Fourier transform cannot give good results in the case of signals with sharp discontinuities [5]. These sharp transition signals can be represented by using some very short basis functions, called “Wavelets” that can be scaled and translated [5].

With advancements of the surveillance radar systems, some methods for signal processing and target detection in radars for different Swerling models have been developed. The radar target detection in the presence of noise is a crucial problem in radar signal processing for Naval surveillance applications. In recent years, Discrete Wavelet Transforms (DWTs) has been introduced into signal processing [6]. DWT not only retains the features of Fourier transform (FT) but also has fine local feature of Short-Time Fourier Transform (STFT) and has become important analysis tool in applied mathematics, image processing, signal processing and other fields of science [6]. The application of wavelet analysis in radar systems has become an active research area [7][8]. In [9] radar pulse edges have been detected by DWT. In the wideband radars, delay and scale variation have been computed by DWT [10][11]. Obviously, one of the most important applications of WT in radar signal processing is Wavelet Based De-noising (WBD).

In this paper, introduction to radar and wavelet based radar signal processing is described. In Section II, an introduction to wavelet transform is briefed. Then a brief of wavelet based signal processing chain is modeled and de-noising application is presented in Section III. In section IV, wavelet based radar signal processing simulation using Matlab is introduced and results are analyzed.

II. WAVELET TRANSFORM

Wavelet Transform employs orthonormal basis functions with finite support (local in time), unlike Fourier Transforms whose orthonormal basis functions are sinusoids (infinite extent in time) [12]. Fourier Transforms span the signal space in linearly evenly spaced frequencies. Wavelet Transforms span the signal space via frequency scales which are logarithmically evenly spaced (constant Q). Wavelet Transforms represent signals in term of multiple resolutions.

Because of the localization property of Wavelet Transform, it can provide nearly distortion less reconstruction of signals even in presence of sharp transitions [12]. The discrete wavelet transform (DWT) is a WT that enables a signal x(t) to be represented in term of scaling function φ (t) and shifted and dilated version of wavelet function ψ (t). Each function has an orthogonal basis [13] as shown in equations 1 and 2:

$$\Phi_{j,k}(t) = 2^{\frac{j}{2}}\, \Phi(2^{-j}\, t - k) \quad (1)$$

$$\psi_{j,k}(t) = 2^{\frac{j}{2}}\, \psi(2^{-j}\, t - k) \quad (2)$$

where j denotes scale or resolution index, and k denotes translation location index. Thus, larger j corresponds to a coarser scale. In order to obtain the wavelet coefficients for each basis in L2 (R), we take an inner product given by [5]:

$$v_{j,k} \leq x(t), \Phi_{j,k}(t) \geq \int x(t)\, \Phi^{*}_{j,k}(t)dt \quad (3)$$

$$w_{j,k} \leq x(t), \psi_{j,k}(t) \int x(t)\, \psi^{*}_{j,k}(t)dt \quad (4)$$

where $v_{j,k}$, $w_{j,k}$ and x(t) denote coefficient used for scaling, wavelet coefficient, and input signal to the DWT respectively. Implementation of DWT is done by multi-resolution analysis (MRA) using quadrature mirror filters [13]. One of the most important applications of the WT is noise reduction. Denoising can be done on the principle of shrinking wavelet coefficients toward zero to remove noise [14] [15]).

III. RADAR SIGNAL PROCESSING USING WAVELET TRANSFORM

Wavelet Transform of radar signal fully describes the signal in both time and frequency domain. The most noticeable character of wavelet based denoising is that, it not only suppress maximum of noise, but also it doesn't carry distortion to the reconstructed signal [14][15]. This is just what is required in radar signal processing. In this section, some conventional radar signal processing algorithms are introduced. Then wavelet based signal processing is explained. Wavelet base selection is the first step in wavelet decomposition. Whereas symmetric filters decrease distortion, near-symmetric Daubechies family such as Coiflet family is selected in this research work.

For removing noise and extracting signal from any data, wavelet analysis is one of the most important advanced methods. The wavelet denoising application has been used in cleaning the spectrum of the atmospheric signals. There are different types of wavelets available like Morlet, Coiflet, Mexican hat, Symlet, Biorthogonal, and Haar, which have their own characters such as filter coefficients and reconstruction filter coefficients. The wavelet filter Sym20 gives very good SNR in processing [16]. In this research, to eliminate noise embedded in the radar received signal 'Sym20' wavelet has been used.

Quite often radar community encounters the term 'de-noising' in recent wavelet literature, described in an informal way with various schemes that attempt to reject noise by damping or thresholding in the wavelet domain. The threshold of wavelet coefficient has near optimal noise reduction for different types of signals. Wavelets have many advantages over fast fourier transform. Fourier analysis has a major drawback, which is that time information is lost, when transforming to the frequency domain. Thus, it is impossible to tell when a specific event took place under Fourier analysis. Wavelet analysis is capable of retaining aspects of data those other signal analysis techniques, aspects such trends, breakdown points, discontinuities in higher derivatives, and self-similarity, are unable to reveal.

There are many de-noising algorithms such as Universal, Minimax, and Block thresholding [16]. Due to the fact that, WBD is not dependent on the signal parameters; it is beneficial in terms of retaining the signal characteristics even after processing. The wavelet de-noising implementation procedure proceeds in three steps:

Step 1.**Signal decomposing**

Choose the wavelet basis function, and to determine the decomposition level N, get the coarse and detailed coefficients by DWT.

Step 2.**Threshold detail coefficients**

For each level from 1 to N, compare the detailed coefficients to threshold values.

Step 3.**Reconstructing the signal**

Reconstruct the denoised signal using original approximation coefficients of level N and the modified detailed coefficients of levels from 1 to N.

Block thresholding is widely accepted useful de-noising method that simultaneous decisions are made to retain or to discard all the coefficients within a block [16]. Within each block (B), the coefficients are estimated via James-Stein-type shrinkage rule [16]:

$$\hat{d}_{j,k} = \left(1 - \frac{\lambda^{*} L \sigma^{2}}{S_j^2}\right) + d_{j,k} \quad (5)$$

Where λ^{*}=4.505, $S_j^2 = \sum_{j,k \varepsilon B} d_{j,k}^2$, $L = \text{Logn}$, σ^2 is variance, and n is the length of input signal. The noise suppression is the most important problem to which radar designer is facing. The simple solution used in radar used for noise rejection is general MTI filter. One of the major drawbacks in using general MTI filter is rejection of targets moving with small radial velocity. But, by using Wavelet Based Denoising by which the probability of rejection of such targets is decreased [16]. With respect to the fact that Wavelet Based Denoising is not dependent on the target Doppler frequency, this method is remarkable which is verified by our simulation results in further studies.

IV. RADAR SIGNAL PROCESSING SIMULATION

For pulse Doppler radars, consider pulse width τ_ρ and τ_n is the time that a target is illuminated by the radar. Thus, we can write, the received signal at time instant t is r (t) as

$$r(t) = V\text{rect}\left|\frac{t - t_p}{t_n}\right| \quad (6)$$

And hence, the SNR from a pulse can be written as

$$SNR_{pulse} = \frac{P_t G^2 \lambda^2 \sigma \tau_p}{(4\pi)^3 K T_o B F L R^4} \quad (7)$$

where P_t is the peak transmitted power of radar, G is the antenna gain, σ is the radar cross section (RCS), and R is the range which electromagnetic wave transmits, λ is the wavelength of the transmitted frequency, $K = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant, B is bandwidth of transmitted frequency, $T_0 = 290^{o}$K is the operating temperature of the antenna, F is the noise figure of the radar receiver, and L is named as the total radar losses.

One fundamental issue in designing a good surveillance radar system is its capability to resolve two targets that are located at a range with minimum separation between them. Pulse compression technique is used in these radar systems to achieve the benefits of large range detection capability of long duration pulse and good range resolution capability of a short duration pulse. In this technique a long duration pulse is used which is frequency modulated linearly before transmission and the received signal is passed through a match filter to accumulate the energy into a short pulse. A matched filter is used for pulse compression to achieve high signal-to-noise ratio (SNR). Two important factors to be considered for radar waveform design are range resolution and maximum range detection.

Range resolution is the ability of a radar system to separate closely spaced targets and it is related to the transmitted pulse width. The narrower the pulse width the better is the range resolution. But, if the pulse width is narrow down, the amount of energy in the pulse is decreased and hence maximum range detection gets reduced. To overcome this problem, pulse compression technique is used in the radar system.

In radar applications, the reflected signal is used to determine the existence of the target. The reflected signal is corrupted by additive white Gaussian noise (AWGN). The probability of detection is related to signal-to-noise ratio (SNR) rather than exact shape of the signal received. Hence it is required to maximize the SNR rather than preserving the shape of the signal. A filter which maximizes the output SNR is called matched filter [5].

This research is carried out for X band surveillance radar specifications. Simulation of wavelet based signal processing chain is depicted in Fig 1 as shown below. The real-time simulations are carried out with Matlab© for following Pulse-Doppler Radar parameters.

Frequency Band	: X band
Antenna Rotation	: 12 rpm
Instrumented Range	: 150 Km
Peak Power	: 5 KW
Antenna Gain	: 26 dB
Duty Cycle	: 10 %
RCS	: 0.1 m^2 to 10 m^2
Swerling	: Type 1
PRF	: 1000 Hz
No. Of pulses	: 16
PCR	: 100
Range Resolution	: 50 m
Waveform	: LFM (sinusoid)
Bandwidth	: 5 MHz
Sea State (Beufort)	: Three

Six moving targets scenario is generated for our experiment, where the targets are placed initially at different ranges having different velocities as listed in Table 1. Two small targets with RCS of 0.5 m^2 and 1 m^2 are placed at ranges of 40 km and 118 km respectively. Also targets numbered 3, 4 and 5 are placed very close at 45 m apart.

Table 1. Target Parameters

Target Parameters			
Target No.	Size (m^2)	Initial Range (km)	Velocity (m/s)
1	0.5	40.000	-1000
2	0.7	60.000	100
3	1	96.000	-200
4	2	96.045	300
5	1	96.090	-660
6	1	118.000	-100

Negative velocity indicated the receding targets and positive velocity represents approaching targets. The targets sizes (RCS) varies from 0.5 m^2 to 2 m^2. Three targets are being placed very close within 90 m. Targets velocities are simulated from 100 m/s to 1000 m/s (approx. 3 Machs). This simulation is carried out for 1000 ms time (1000 pulses). Frequency based pulse compression is used to achieve better range resolution and better signal to noise ratio. The pulse is compressed to 0.3 µs to achieve a resolution of 45 m.

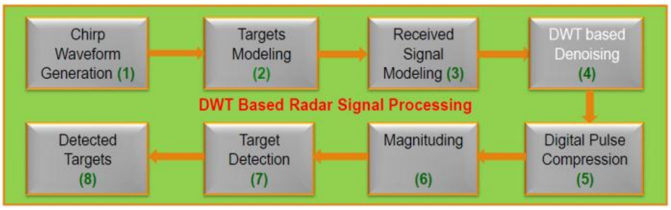

Fig 1. Mathematical Modeling of Wavelet based signal processing

As shown in Fig 1, up-chirp waveform (LFM) with a bandwidth of 5 MHz is generated as the basic waveform which is modulated with carrier frequency and transmitted. The targets are modeled as per the parameters listed in table 1. On receive, the signal processing chain was simulated with and without wavelets as shown in Fig 1.

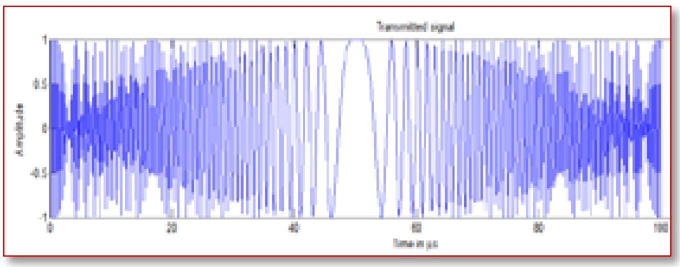

Fig 2. Transmitted LFM waveform

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 12 (2019), pp. 3050-3055

In Linear Frequency Modulation (LFM), the transmitted pulse is modulated with a chirp waveform whose frequency varies with respect to time. Fig 2, shows the modulated sinusoidal signal that is transmitted by the radar. The pulse is characterized by its uncompressed pulse width T and bandwidth B. The Pulse Compression Ratio (PCR) is proportional to the time bandwidth product. Pythagoras formula is used for magnituding purpose.

To recognize the presence of the uncompressed pulse, the matched filter performs a correlation between the received pulse and the transmitted pulse. The transmitted wider pulse is equally divided into B*T number of sub-pulses and then convolves with the receiver echo, resulting the output of the filter as shown in Figure 3.

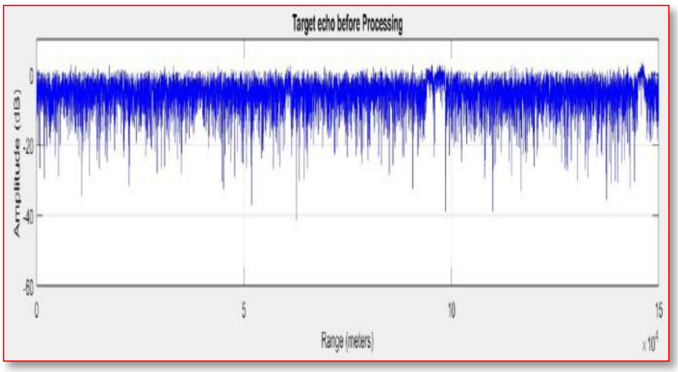

Fig 3. Received Signal with Noise

Fig 3 shows the received signal along with noise. It is very clear that the targets introduced at different ranges are not visible before wavelet processing.

Detection of slow speed targets that are moving at very low grazing angles is identified as the task of the hour in the case of surveillance radar, where dominant noise is surface echoes. These low height targets moving at speeds that are close to the huge noise can be detected effectively using wavelet based detection algorithms. The spectral resolution of the radar signal is enhanced using the DWT based decomposition techniques. These decomposition techniques involve sub-band filtering and down sampling of the low frequency and high frequency data of the received target signal.

Algorithms for detection of small targets are developed by using the wavelets based techniques and compared these results with that of MTI are reported in this paper.

IV a. FFT based Method

The amplitude response of the processed targets data was obtained using Fast Fourier Transform based Pulse compression method and response of Amplitude (dB) versus range (m) were drawn including the probability of detection. From the range response, targets which are very small size cannot be detected even at near ranges as shown in Fig 4a.

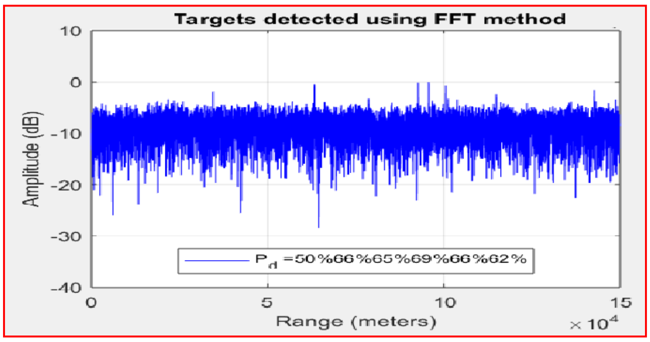

Fig 4a. Target detections using FFT method

Most of the time the radar is not able to detect the small target at even 40 km distance and other target at 142 km with conventional algorithms including MTI technique as shown in Fig 4a. But with DWT technique, the targets at 40 km and 142 km are also detected due to improvement in SNR as shown in figures Fig 4b. The probability of detection (P_d) and SNR is also compared in the following table 2.

IV b. Wavelet based Method

Small targets which are moving with close velocities as that of surrounding noise has got importance in the case of pulsed Doppler radars for naval surveillance applications. The main objective of this research was to bring out the advanced applications of wavelets to achieve higher probability of detection compare to traditional methods like FFT followed by MTI in complex radar systems. Using Fourier transform based techniques it is not possible to distinguish targets less than certain size because of low SNR. DWT based techniques are able to solve this problem efficiently as discussed in this paper.

'Sym20' is selected as the wavelet filter for this work because of its good SNR improvement and better probability of detection. From the range response of the processed data, a small RCS (0.5 m^2) moving target at 40 km and target at 142 km (1 m^2) can be easily detected with better probability of detection as shown in Fig 4b.

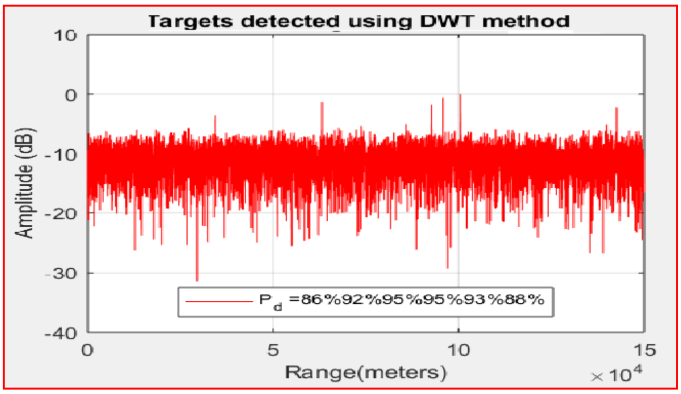

Fig 4b. Target detections using Wavelet method

Table 2. Comparison Results

Target No.	At range (km)	FFT Method		DWT Method	
		SNR (dB)	P_d	SNR (dB)	P_d
1	41	3.10	0.50	4.95	0.56
2	65	5.00	0.60	6.60	0.92
3	91	5.05	0.65	6.50	0.95
4	95	5.00	0.69	6.60	0.95
5	101	4.80	0.66	6.73	0.93
6	142	3.15	0.62	5.01	0.88

It is very evident from the above study that the targets are better detected in Wavelet based processing method due to the better SNR with better probability of detection obtained and hence very clearly visible.

V. CONCLUSION

This research paper presented a complete comparison of frequency based matched filtering technique and wavelet based processing in terms of noise reduction capabilities to enhance the SNR of the signal in pulse Doppler radar. The simulation results show that a significant improvement in signal to noise ratio achieved for pulsed radar by using wavelets.

The main objective of this paper was to validate the application of Wavelet Transform in radar signal processing over conventional FFT based processing. The Block thresholding as Wavelet Based De-noising was employed for noise rejection in the detection processing. Given the radar signal characteristics as outlined above, Wavelet Based De-noising appears to provide more benefit in detection of targets with small radial velocity than general MTI filter. Also, visual representation of sea noise as noise returns verified our claim. Also, due to availability of very high end computing platforms, easy implementation of this method is completely practical in real-time.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. S. Y Kulkarni, Vice Chancellor, REVA University and the management of REVA University Bangalore, for giving us the opportunity to work on this research area.

REFERENCES

[1] *Skolnik,M.I.,* " Introduction to Radar system*", New York ; McGraw-Hill, 1980.*

[2] *Lehmann, V., Teschke,G. ,* "Wavelet based methods for improved wind profiler signal processing", *European Geophysical Society, pp.825-836, 2001.*

[3] *Lampropoulos,G.A., Gigli,G., Damani,A. Rey,M.,* "A new adaptive coherent CFAR wavelet detector", *SPIE proceeding, vol.3491, pp.1010-1016, 1998.*

[4] *Sheikhi,A., zamani,A.,* "Simulation of base band ground surveillance radar signal", *ICEE2002, Tabriz university, 2003.*

[5] *Mallat,S.,* "A wavelet tour of signal processing", *Academic Press, San Diego , CA, 1998.*

[6] *Noel,S., Szu,H.,* "Wavelets and neural networks for Radar", *Russian Academy for Nonlinear Sciences, pp.105-158, 1998.*

[7] *Elsehely, E., Sobhy, M.I.,* "Detection of radar target pulse in the presence of noise and jamming signal using the multiscale wavelet transform", *IEEE International Symposium on Circuits and System, Vol.3, pp.536-539, 1999.*

[8] *Guohuo,W., Siliang,Wu.,* "Denoising radar signals using complex wavelet", *International symposium on signal processing, Volume1, pp.341-344, 2003*.

[9] *Peng ,Y.N.,Tian,L.S.,Zhang,X.P,* "Wavelet detectors for wide-band radar signals", *CIE International Conference of Radar, pp.289-292, 1996*.

[10] *Xing,S.,* "The application of wavelet packet to signal analysis of battle reconnaissance radar", *IEEE conference on radar, pp.562-566, 2001.*

[11] *Borda,M.,Isar,D.,* "Whitening with wavelets", *Proceeding of IEEE International conference, ECCTD'97, August, 1997.*

[12] *Vidankovic,B.,* "Statistical modeling of wavelets", *Johns Wiley&Sons Inc., 1999.*

[13] *Scheleher D.C. ,* "MTI and Pulsed Doppler Radar",*Artech House, 1991.*

[14] *Steinbrunner,L., Scrapino,F.,* "An analysis of wavelet-based denoising techniques as applied to a radar signal pulse", *SPIE proceeding, vol.3810, pp.72-83, 1999.*

[15] *Liu R., Liu X., Suo, J., Wang, X.,* "The radar clutter processor with wavelet floating threshold", *Proceeding of CIE International Conference on Radar, pp.1001-1005, 2001.*

[16] *Seena.V, Lineeta Gloria Prakash Joba,* "comparitive analysis of wavelet based method for Denoising of ecg signal", *International Journal of Electrical, Electronics and Data Communication, ISSN: 2320-2084 Volume-2, Issue-8, Aug.-2014*

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 12 (2019), pp. 3050-3055

ABOUT AUTHORS

Shri.N.Muralidhara is currently working in Bharat Electronics Limited, Bangalore as Deputy General Manager. He obtained his B.E (Electronics) from SJCE Mysore University in the year 1993, and M.Tech degree (Digital Electronics and Advanced Communications) from NIT Surathkal, Karnataka in 1997 and currently pursuing PhD in REVA University, Bangalore. His areas of interest are 3D Radar signal processing, Digital Beam Forming, and advancements in radar system designs.

Dr. Rajashekhar C. Biradar has 27 years of teaching and research experience. He has many research publications in reputed national/international journals and conferences including Elsevier, IET, Springer, Wiley and IOS Press. He has published 45 papers in peer reviewed national and international journals, 70 papers in reputed national and international conferences and 3 book chapters. As per Google Scholar, he has more than 447 citations (h-index = 10 and i-10index = 10) (Dec. 2017). He is involved in research which covers various sorts of wireless networks such as ad hoc networks, sensor networks, mesh networks, network security, smart antennas, Index modulation, etc. He has guided 2 PhD's and currently, he is guiding 6 PhD students. He is a reviewer of various reputed journals and conferences and chaired many conferences. He is a Fellow IETE (FIETE) India, member IE (MIE) India, member ISTE (MISTE), India and senior member of IEEE (SMIEEE), USA and member of IACSIT. He has been listed in Marquis' Who's Who in the World (2012 Edition), USA and Top 100 Engineers by IBC, UK. He received B.E. (Electrical engineering), and M.E. (Digital Electronics) from Karnataka University, Dharawad and Ph.D from VTU Belgaum.

Dr. G.V.Jayaramaiah currently working as Professor in Electronics and Communication Engineering department at Dr.Ambedkar Institute of Technology, Bangalore. He received B.E. (Electrical engineering), and M.E. (Power Electronics) from Bangalore University, in 1990 and 1994 respectively and Ph.D from Indian Institute of Technology, Bombay (IIT-B) in April 2008.He has published several IEEE papers in the application of power electronics in the area of renewable energy. His interests are in the field of Non-Conventional energy, Power electronics & Drives, Embedded systems and Microprocessors.