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Implementation of ESPRIT Algorithm on GPS TEC for Percussive Signatures of Earthquakes in Ionosphere

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Abstract: As Global Positioning System is very effective mechanism to find out the disturbances in Ionosphere during the solar events. Spectral estimation of the ionospheric total electron content perturbations leads to better interpretation of their source mechanisms. Seismo-ionospheric perturbations of an earthquake occurred at 12th December 2013 was considered in the present work. Estimation of signal parameters via rotational in variance technique (ESPRIT) is implemented on the vertical total electron content data. It was clearly observed that during disturbance the power spectral density of the dominant frequency had reduced to -2.487 dB from 7.841 dB. The application of ESPRIT algorithm on seismic perturbations in GPS TEC has found the dominant frequency in the spectrum and new frequency present at the time of perturbations.

Keywords: Ionospheric anomalies, Earthquakes, Frequency estimation methods.

1. INTRODUCTION

Many secrets of our atmosphere has been revealed by the Geospatial Technologies. These studies led to do practical experiments of scientific hypotheses of natural disasters. One of such advancements of technology, the Global Positioning System (GPS) has a prominent role in understanding the earth's atmosphere. The neutralized layer of consists of free electrons, molecules which affects the high frequency radio waves passing through it. The ionization of this layer depends on the amount of solar radiation received by it. The solar radiation causes alteration in the number of free electrons resulting in perturbations in ionosphere. The perturbed ionosphere brings out changes in the radio waves propagating though this medium. The ionosphere which is a dispersive in nature affects the GPS signals. [1-4].

The coupling of seismicity and ionosphere has been physically explained by Pulinets [2004]. The earthquake occurred in Great Alaskan on 27th March 1964 is initial one for the investigations. There will be ground electromagnetic emissions, piezoelectric and piezomagnetic effects which are due to sress changes in rocks (Bishop, 1981), the movement of electric charges causes induction effects, (Revel et. al., 1999), emission of radioactive gas and metal ions, perturbation of the upper dynamic atmosphere by the ionization of the lower atmosphere are explained by many of the scientists. [5][6]. Anecdotal studies had showed that the ionospheric perturbations may be considered as short term precursors for earthquakes.

The time delay of GPS signal is due to disturbances of the seismic origin. When the time delay is expressed in total electron content (TEC). The variation of the refractive index 'n_p' of Ionosphere is

$$n_p = 1 - (40.3 \times n_d)/f^2 \tag{1}$$

In which 'n_d' – density of electrons, 'f' is GPS transmitted signal frequency. The '$\Delta\tau_p$' is excess phase delay

$$\Delta\tau_p = (1/a) \int_{\text{Satellite}}^{\text{Receiver}} n_p (\text{K} - 1)\, dk \tag{2}$$

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In which '*a*' – light speed. The slant total electron content (STEC(S)) is total electron density in between receiver and satellite (line of sight). The above equation (2) is simplified,

$$\Delta\tau_p = -(40.3 \times S)/af^2 \tag{3}$$

The phase delay is expressed in meters is

$$I_\varphi = c\Delta_p = -(40.3 \times S)/f^2 \tag{4}$$

where 'I_φ' – pseudorange in between satellite and receiver. The pseudorange and phase are magnitudally equal but they are opposite in sign. The 'ρ_{L_1}', is

$$\rho_{L_1} = (40.3 \times S)/f_{L_1}^2 \tag{5}$$

For dual frequencies receiver,

$$\rho_{L_1} - \rho_{L_2} = (40.3 \times S) \times [(1/f_{L_1}^2) - (1/f_{L_2}^2)] \tag{6}$$

where 'f_{L_1}', 'f_{L_2}' are the two frequencies transmitted by the GPS satellite. The STEC of a given GPS satellite is

$$S = (1/40.3) \times [(f_{L_1}^2 \times f_{L_2}^2)/(f_{L_1}^2 - f_{L_2}^2)] \times (\rho_{L_1} - \rho_{L_2}) \tag{7}$$

The GPS receiver records the STEC values when the satellite is moving and at any time 8 to 10 satellites are in visibility all over the world. The VTEC (V) are calculated from the STEC values using below equation

$$V = S \times (\sin(90 - (\xi))) \tag{8}$$

The 'ξ', is the angle between the point at which signal crosses the ionosphere and zenith angle.[7]

A network of GPS receivers are used for the analysis of ionospheres' disturbances that was caused due to earthquakes. Due to improper installation of GPS receivers, the errors may arise. The extrapolation or interpolation of TEC data are done so as to reduce the above mentioned errors. The implementation of Spectral Estimation techniques on the global TEC data which were at different sampling periods is a challenging task [8-12]. The disturbances in the ionosphere due to earthquakes recorded using single ground base receiver are studied in the present work. The novelty of the present work is that the data is not contaminated with modeling errors. Integrated wave analysis is applied on global data for the identification of seismogenic disturbances.[13].

Using estimation of signal parameters via rotational in variance technique (ESPRIT), the analysis was performed.. The advantage of this method is that it provides better spatial resolution of the signal when compared with the other methods. ESPIRIT uses the underlying rotational in variance of the signal subspace for estimating the spectrum of the signals.

2. EVENT CONSIDERED

The Earthquake on 12th December 2013, universal time coordinate (UTC) 7:02 hours at Kawalu, West Java, Indonesia (7.823^{o}S, 108.185^o E) is considered. The local time coordinates (LTC) of the event is 12:32 hours. On Richter scale it is recorded as 4.3. The northward of Australian plate subduction dominates Australian plate. This plate converges at 95mm per year approximately towards northeast in the Solomon trench due to this earthquakes are common.

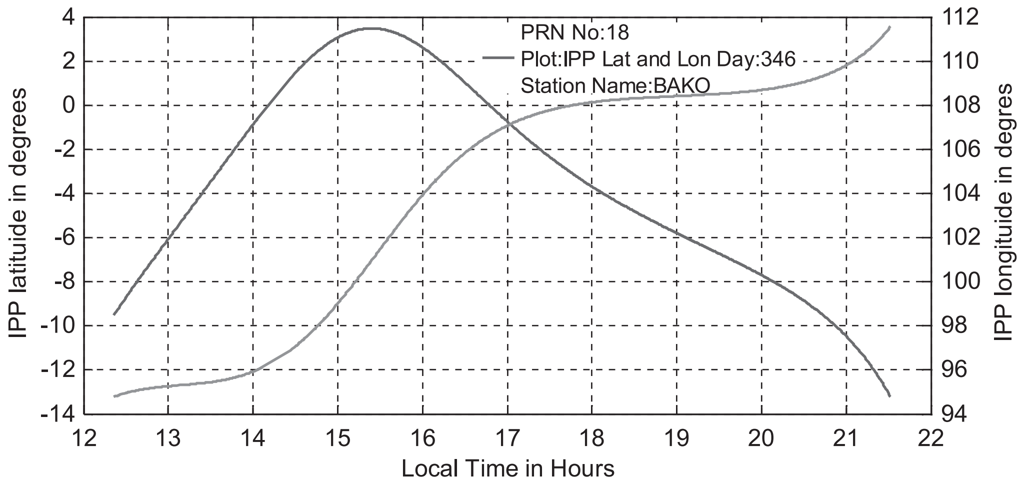

Figure 1: VTEC plot of satellite PRN 18

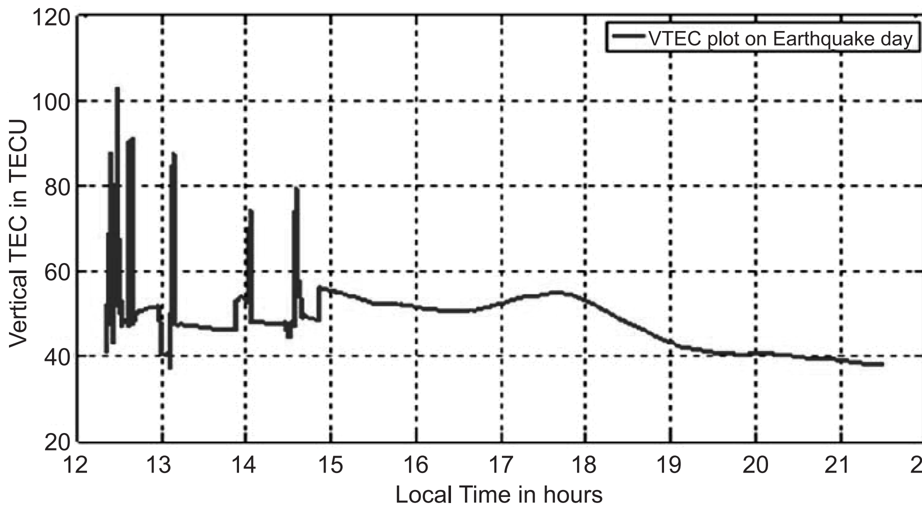

Figure 2: Satellite path of PRN 18

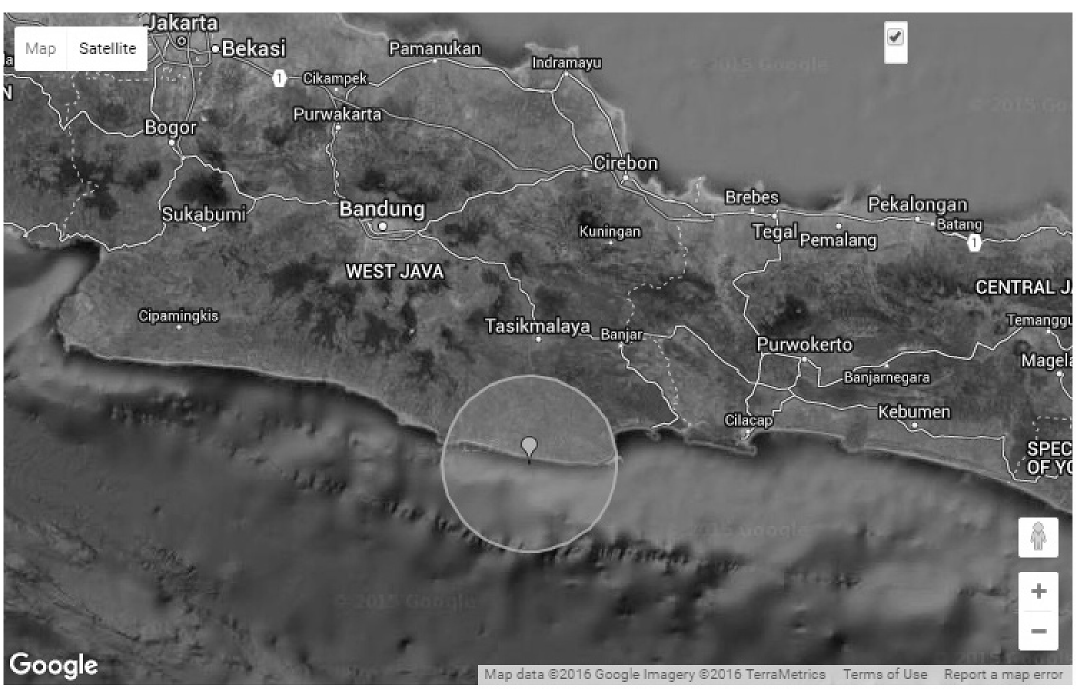

Figure 3: Earthquake Location

3. DATA

The RINEX data is collected from the International Global Navigation Satellite System (IGS) network and by using equation 7 & 8 data is converted into VTEC values. The plot for VTEC is in Figure 1. The ray path of the satellite which was found disturbed is given in Figure 2, and earthquake location is shown in Figure 3. The station is 209 KM far from the epicenter of event.

4. ANALYSIS

The stochastic algorithms are used to identify disturbances in the signals.[14-17]. In this research work, ESPRIT was explored. This algorithm accomplishes the rotation in variance in the signal subspace by translation in variance structure. This method outperform than all other spectral estimation methods in performance and computation. A synthetic signal was simulated in matlab using this algorithm for frequencies 0.4 and 0.45.

The signal $X(m)$ having the random processes of sinusoidal signal and white noise. The Power Spectral Density (PSD) is shown in the Figure 4.

$$X(m) = j(m) + k(m) \text{ where}$$

$$j(m) = 5 \sin(m((1 - 0.6)\pi)) + 5 (\sin(m((1 - 0.55)\pi)) \quad (9)$$

where $n = 64$, $v(n)$ is the zero mean unit variance white noise.

The detrended disturbed and as well as undisturbed VTEC plots are shown in Figure 5 and Figure 6.

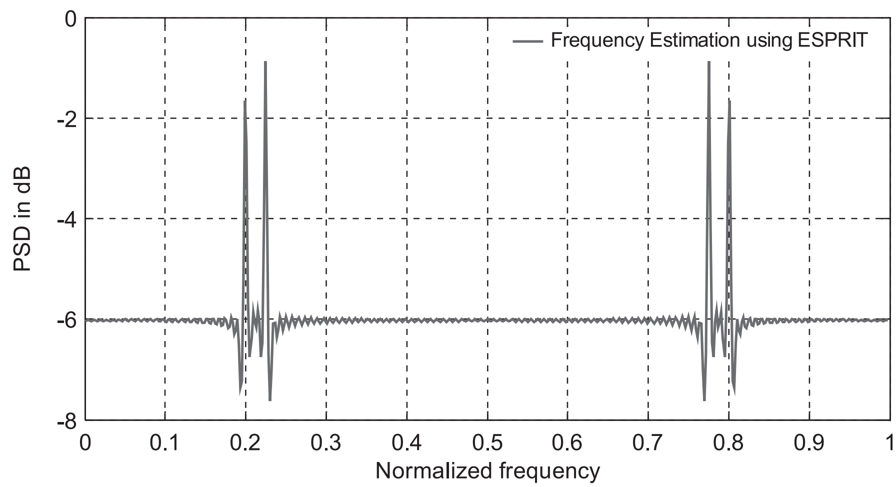

Figure 4: PSD using ESPRIT method

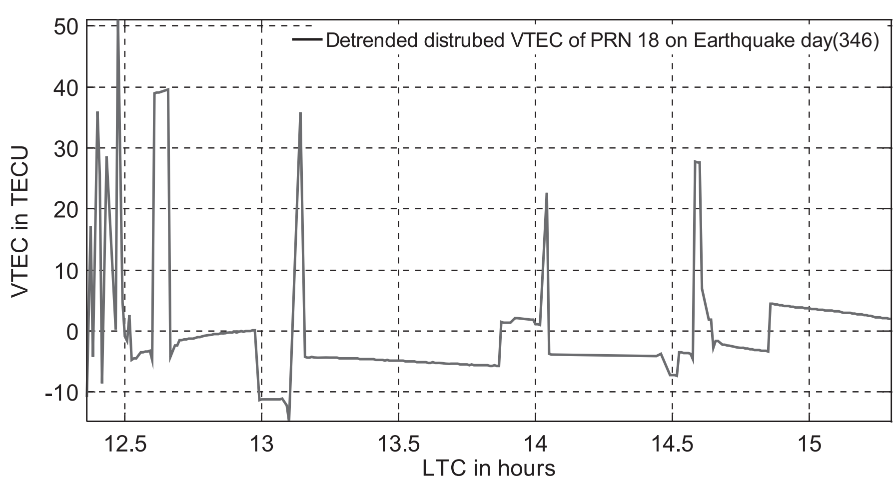

Figure 5: Plot for Disturbed VTEC (detrended)

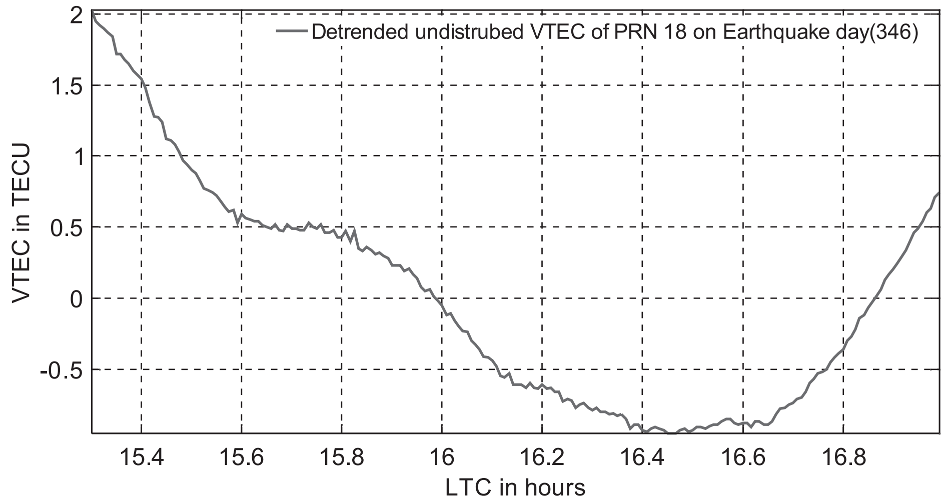

Figure 6: Plot for Undisturbed VTEC (detrended)

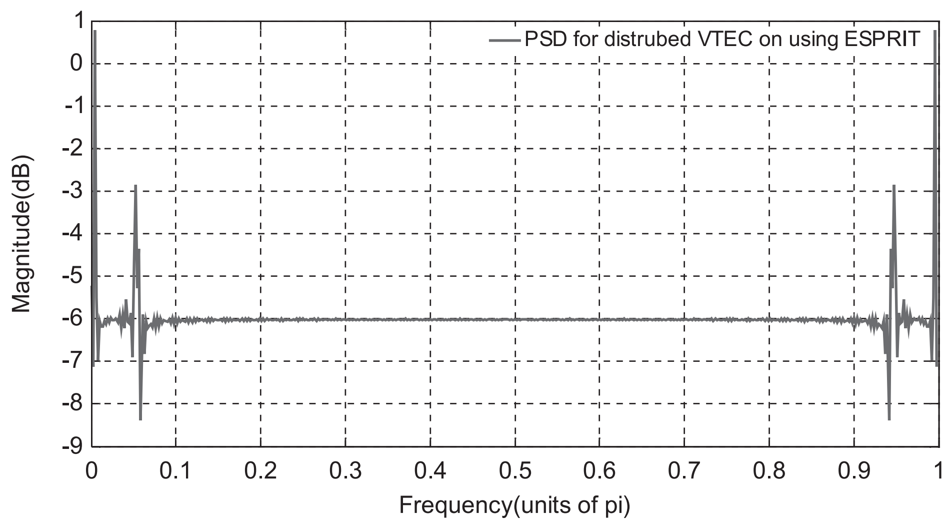

Figure 7: PSD of disturbed VTEC

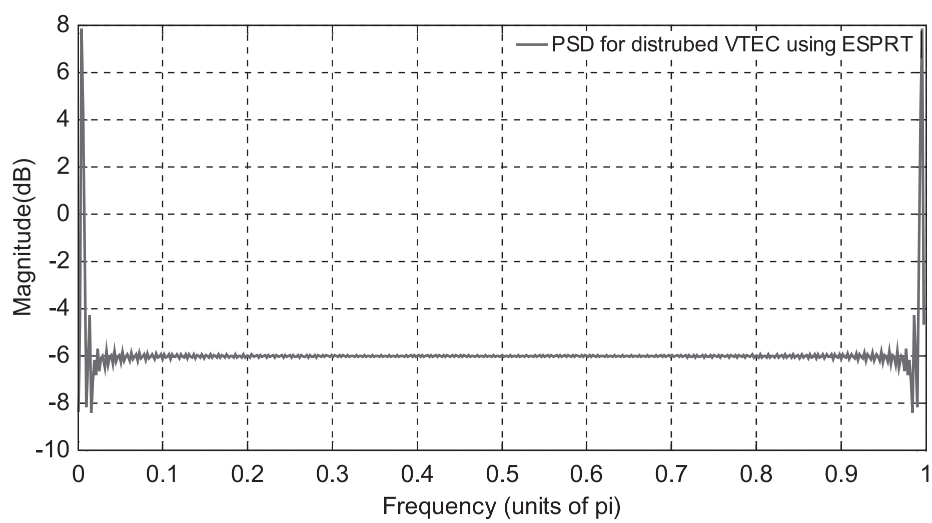

Figure 8: PSD of undisturbed VTEC

The plots of disturbed & undisturbed PSDs are in Figure 7 & Figure 8.

In disturbed plots we have two peaks with frequencies 0.003906 and 0.05273 with PSDs 0.7746 dB and −2.487 dB. In the undisturbed part we got a peak at a frequency of 0.003906 having PSD of 7.841.

It is clearly observed that VTEC data has a dominant frequency of 0.003906. In the presence of disturbance the PSD of the dominant frequency is reduced and a new normalized frequency is observed.

The PSD of the dominant frequency is reduced during the disturbance. The undisturbed data is not having the other normalized frequency because the satellite is looking over a different area where the influence of earthquake is not seen.

5. CONCLUSION

The results represents that perturbations due to earthquake can be identified by using ESPRIT method. The perturbations in ionosphere are observes before earthquake was occurred. If we had sufficient data sets are provided, we may give short time early warning using this analysis. It is clearly observed that VTEC data has a dominant frequency of 0.003906. In the presence of disturbance the PSD of the dominant frequency is reduced and a new normalized frequency is observed.

References

1. Ali Alp Akyol[1], Orhan Arikan[2], Feza Arikan[3], M. Necat Deviren[4], "Investigation on the Reliability of Earthquake Prediction Based on Ionospheric Electron Content Variation", *16th IEEE International Conference on Information Fusion (FUSION)*, 2013, from 9-12 July 2013, pp: 1658 – 1663, ISBN number: 978-605 -86311-1-3.
2. Komjathy, A. (1997). Global Ionospheric Total Electron Content Mapping Using the Global Positioning System. Ph.D. dissertation, Department of Geodesy and Geomatics Engineering Technical Report No. 188, University of New Brunswick, Fredericton, New Brunswick, Canada, 248 pp.
3. Pulinets. Sergey [1], "Ionospheric Precursors of Earthquakes; Recent Advances in Theory and Practical Applications", TAO, Vol. 15, No. 3, 413-435, September 2004.
4. Thanassoulas. C[a] and Tselentis. G[b], "Periodic variations in the Earth's electric field as earthquake precursors: results from recent experiments in Greece", Tectonophysics, 224 (1993) 103-111, Elsevier Science Publishers B.V., Amsterdam.
5. Freund, F. (2005). Cracking the Code of Pre-Earthquake Signals. National Information Service for Earthquake Engineering, University of California, Berkeley (Found at: http://solar-center.stanford.edu/SID/educators/earthquakes.html).
6. Gosh. D, and Midy. S.K, "Associating an ionospheric parameter with major earthquake occurrence throughout the world", *Journal of Earth Systems and Science*, 123, No. 1, Februrary, pp. 63-71.
7. Prathap Mishra, "Global Positioning Systems", Second edition, Ganga-Jamuna Press.
8. Dimitar Ouzounov, et. al., "Atmosphere-Ionosphere Response to the M9 Tohoku Earthquake Revealed by Joined Satellite and Ground Observations. Preliminary results", Ref: arxiv.org/abs/1105.2841, DOI: 10.1007/s11589-011-0817-z.
9. Molchanov. O, et. al., "Lithosphere-Atmosphere-Ionosphere Coupling as Governing Mechanism for Pre-seismic Short Term Events in Atmosphere and Ionosphere" , *Natural Hazards and Earth System Sciences* (2004) 4: 757–767.
10. Contadakis, M.E, et. al., "TEC Variations over the Mediterranean During the Seismic Activity Period of the Last Quarter of 2005 in the Area of Greece", Nat. Hazards Earth Sys., 8, 1267-1276.
11. Michael E. Contadakis, Dimitrios N. Arabelos, Christos Pikridas, Spyrous D. Spatalas1, "Total electron content variations over southern Europe before and during the M 6.3 Abruzzo earthquake of April 6, 2009", *Special Issue: earthquake precursors., Annals of Geophysics*, 55, 1, 2012; doi: 10.4401/ag-5322.
12. Su. Y. C, Liu. J. Y, Chen. S. P, Tsai. H.F, and Chen. M.Q, "Temporal and spatial precursors in ionospheric total electron content of the 16 October 1999 Mw7.1 Hector Mine earthquake", *Journal of Geophysical Research, Space Physics*, Vol. 118, 6511–6517, Doi:10.1002/Jgra.50586, 2013.
13. He. M, et. al., "Is there a One-to-One Correspondence Between Ionospheric Anomalies and Large Earthquakes along Longmenshan Faults?", Ann. Geophys., 32, 187–196, 2014, www.ann-geophys.net/32=/187/2014/, doi:10.5194/angeo-32-187-2014.
14. Omkar Lakshmi Jagan[*], Koteswara Rao. S, Jawahar. A, Karishma S.K.B, "Application of Particle Filter using Bearing Measurements", *Indian Journal of Science and Technology*, Vol. 9(7), DOI: 10.17485/ijst/2016/v9i7/85557, February 2016.
15. Jawahar. A[*], Koteswara Rao. S, "Recursive Multistage Estimator for Bearings only Passive Target Tracking in ESM EW Systems", *Indian Journal of Science and Technology*, Vol. 8(26), 74932, October 2015.