Comparative Analysis of Performance of Earthquake Early Warning System based on Wavelet based Techniques

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***Abstract*-An earthquake may cause injury and loss of life general property damage, road and bridge damage. So efficient and successful seismic event detection is an important and challenging issue in many disciplines.An important and challenging problem in seismic data processing is to design a efficient earthquake early warning magnitude predictor so that loss life can be prevented .Wavelet decomposition method is used for feature extraction and wavelet coefficients are used as features for prediction of early warning magnitude. This paper demonstrates two wavelet decomposition method DWT (Discrete Wavelet Transform) and MODWT (Maximal Overlap Discrete Wavelet Transform) and comparative analysis of their performance has been done for early warning magnitude.**

Keywords— Discrete Wavelet Transform, Maximal Overlap Discrete Wavelet Transform,median absolute deviation.Accelerograms

I. INTRODUCTION

Human lives are badly affected by earthquakes. The size of an earthquake depend on region covered by the fault that ruptures and the distance passed by one another by the rocks on the two sides of the fault of slide. During a large earthquake the deaths occurs mainly due to the collapse of buildings, thus in general we can say that buildings kill people. A proper construction of buildings may be used to reduce earthquake risks. Earthquake early warning systems (EWSs) offer a few seconds to tens of seconds of warning of oncoming hazardous ground shaking, allowing for short-term mitigation. Magnitude of earthquake from the frequency content of the P-wave arrival is estimated using the approach of predominant period by Allen and Kanamori[17] They choose vertical component of velocity sensor to determine the predominant period in real times. Two (smaller magnitude ranging from 3 to 5 and larger magnitude greater than 5. linear relation have been developed between the maximum predominant periods with magnitude. The maximum predominant period was calculated within the 4 second window starting from P-wave onset of earthquake. Simon et al. [18] in 2005 use wavelet multiscale analysis toward the magnitude estimate. The use Discrete Wavelet Transform (DWT) with lifting approach instead of predominant period. They suggest to use multiscale analysis because it frequency resolution is better. They derive two relation between average station threshold wavelet coefficient and earthquake magnitude for low magnitude and for higher magnitude. Tsang et al. [20] in 2007 used a dataset of 59 past earthquakes records(accelerograms) from the region of Southern California with seismic network named as Southern California Seismic Network (SCSN). They used maximum predominant period and peak displacement amplitude from the first $4\,sec$ to derive the relationship to estimate the earthquake magnitude. They found average error of $0.2, 0.3, and\ 0.4$ magnitude units for different range of magnitude.[8][9]

About 60 events with epicentral depth $(0-100\ km)$ and the event magnitude ranges from $(3-8)$ in Hokkaido Japan's is utilized for our analysis. These events are occurred in between $2000\ to\ 2013$ year. All of these earthquakes occurred in the window bounded by $35°\ to\ 45°$ latitude and $135°\ to\ 146°$ longitude. All the seismic event are recorded with $100\ Hz$ sampling frequency.

II. FEATURE EXTRACTION OF SEISMIC SIGNALUSING WAVELET BASED METHODS

A. *Discrete Wavelet Transform Based Feature Extraction*

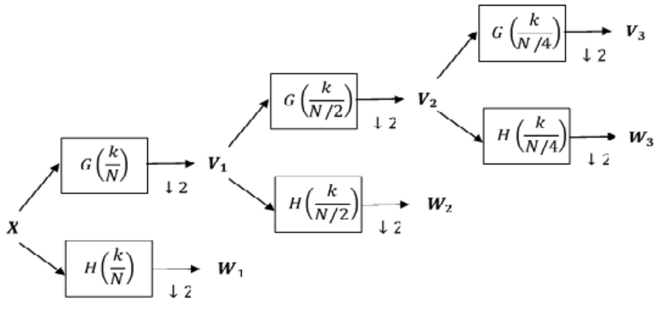

Fig.1 Flow diagram illustrating the 3 level DWT decomposition

Discrete wavelet transform decomposed the seismic signal in terms of discrete wavelet coefficients and same process can be repeated into multilevel DWT decomposition as shown in Fig.1a real valued time series $\{X_t: t = 0, \dots, N-1\}$ with N observations and defined by$\boldsymbol{X}$,a N dimensional vector, the discrete wavelet transform (DWT) of $\boldsymbol{X}$will produces N new values. The DWT coefficient can be determined by using a set of structured filtering process. Consider $\{W_n : n = 0, \dots, N-1\}$ are the DWT coefficients as shown in Fig.2. Then there is relation $\boldsymbol{W} = \mathcal{W}\boldsymbol{X}$,where $\boldsymbol{W}$ *and* $\boldsymbol{X}$ are the column vectors of length $N = 2^J$, $\mathcal{W}$ a matrix of size $N \times N$ defining DWT and satisfies the properties $\mathcal{W}^T\mathcal{W} = I_N$.Now consider the j^{th} level wavelet detail coefficient $\mathcal{D}_j \equiv \mathcal{W}_j^T\boldsymbol{W}_j\, for j = 1, \dots, J$, a N dimensional column vector. The element of this matrix defines the change in scale in $\boldsymbol{X}$ at scaleτ_j. Where $\boldsymbol{W}_j = \mathcal{W}_j\boldsymbol{X}$ denote the portion of the analysis $\boldsymbol{W} = \mathcal{W}\boldsymbol{X}$ at scaleτ_j. And $\mathcal{W}_j^T\boldsymbol{W}_j$ denote the portion of the synthesis at scaleτ_j . Suppose $\mathcal{S}_J = \mathcal{V}_J^T\boldsymbol{V}_J$ has all of its elements equal to the sample mean$\bar{\boldsymbol{X}}$. So we can write

$$\boldsymbol{X} = \sum_{j=1}^{J} \mathcal{D}_j + \mathcal{S}_J \qquad (1)$$

This defines the multiresolution analysis (MRA) for$\boldsymbol{X}$. As shown in equation (1)The first stage detail $\mathcal{D}_{1,t}$ and approximation $S_{1,t}$coefficient are given in equation(2).

$$\mathcal{D}_{1,t} = \sum_{l=0}^{N-1} h_l W_{1,t+l \bmod N} ,$$

$$and\ S_{1,t} = \sum_{l=0}^{N-1} g_l V_{1,t+l \bmod N} , \qquad (2)$$

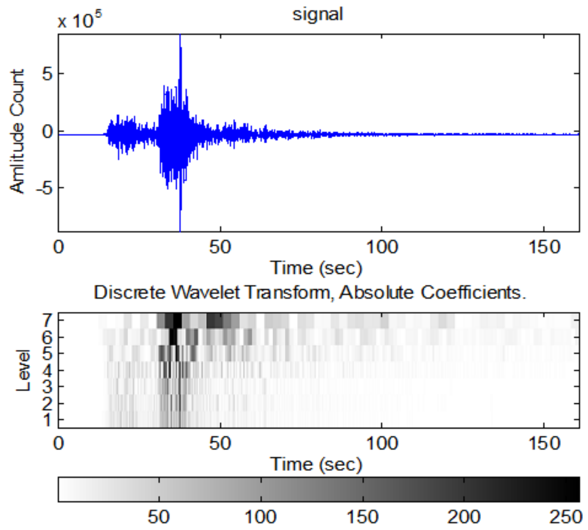

Fig.2 seismogram and its time scale analysis with DWT

The wavelet coefficient after wavelet filtering and scale filtering, then down sample by 2 is known as detailed coefficient and approximation coefficient respectively. The orthogonal DWT have two serious drawbacks first one it requires the input vector size must be divisible by 2^J and second the wavelet and scaling filter are not shift invariant to circular shifting. Extracted DWT coefficients are used for regression analysis which is useful for modelling earthquake early magnitude warning system.

B. Maximal Discrete Wavelet Transform Based Feature Extraction

This is second technique for feature extraction we have used In this paper. DWT suffers from the problem of sensitivity due to its down sampling after the wavelet and scaling filtering operation at each stage of pyramid algorithm. A change in starting point of a sample vector gives different results. An undecimated version of wavelet transform called maximal overlap discrete wavelet transform (MODWT) is an attempt to get away from these serious problem.The wavelet filter $\{\tilde{h}\}$ and scaling filter $\{\tilde{g}\}$ for MODWT related with DWT filters as $\tilde{h} = h/\sqrt{2}$and $\tilde{g} = g/\sqrt{2}$. Simply these are rescaled version of DFT filters. The quadratic mirror relationship also followed by the MODWT filter as like DWT filter given below[1][2][5][7]

$$\tilde{g}_l = (-1)^{l+1}\tilde{h}_{L-1-l}$$

$$and,\ \tilde{h}_l = (-1)^l \tilde{g}_{L-1-l} \qquad (3)$$

The wavelet coefficients at first stage of scale is:

$$\tilde{W}_{1,t} = \sum_{l=0}^{L-1} \tilde{h}_l X_{t-l \bmod N},$$

$$and\ \tilde{V}_{1,t} = \sum_{l=0}^{L-1} \tilde{g}_l X_{t-l \bmod N}, \qquad (4)$$

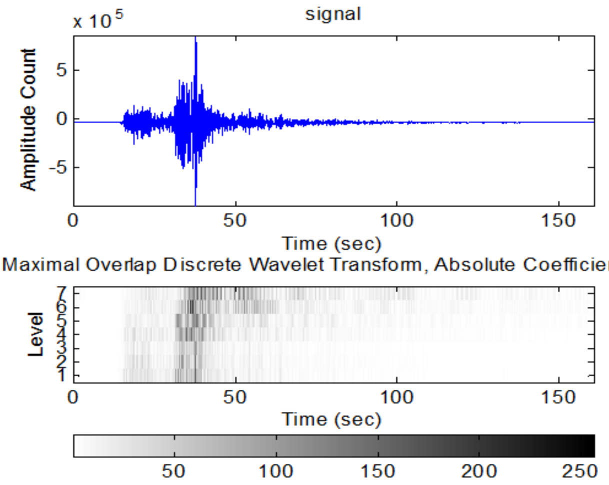

Fig. 3. Seismogram and its time scale analysis with MODWT

The first stage approximation (smooth) S_j and detail $\mathcal{D}_1$ can be obtained by

$$\widetilde{\mathcal{D}}_{1,t} = \sum_{l=0}^{N-1} \tilde{h}_l \widetilde{W}_{1,t+l \bmod N} = \sum_{l=0}^{N-1} \tilde{h}_l^{\circ} \widetilde{W}_{1,t+l \bmod N}, \quad t = 0, \dots, N-1, \qquad (5)$$

$$\tilde{S}_{1,t} = \sum_{l=0}^{N-1} \tilde{g}_l \tilde{V}_{1,t+l \bmod N} = \sum_{l=0}^{N-1} \tilde{g}_l^{\circ} \tilde{V}_{1,t+l \bmod N}, t = 0, \dots, N-1, \qquad (6)$$

Where $\tilde{h}_l^{\circ}$ and $\tilde{g}_l^{\circ}$ are periodized.By summing the detail and smooth one can construct the original signal X from relation, $X = \widetilde{\mathcal{D}}_{1,t} + \tilde{S}_{1,t}$ .By applying the same order as like DWT we can determine the jth wavelet and scaling coefficient.[10][11]

The original time series signal can de decompose from the MRA of MODWT as[12][13]

$$X = \sum_{j=1}^{J} \mathcal{D}_j + S_j \qquad (7)$$

III. DETERMINATION OF WAVELET THRESHOLD COEFFICIENTS

In order to predict earthquake hazardous magnitude, the historical database is used and the dataset contain $4\ sec$ window of seismograms from the P-wave onset point. A scale dependent threshold value is defined to assign zero value for insignificant wavelet coefficient. The wavelet threshold coefficient T_j at scale j is related with spread estimate $\hat{\sigma}_j$ and the number of coefficients at that scale N_j as[15]

$$T_j = \hat{\sigma}_j \sqrt{2lnN_j} \qquad (8)$$

Where $\hat{\sigma}_j = \frac{\text{median absolute deviation(MAD)}}{0.6745}$,

The average of wavelet threshold coefficients over all stations of an event will be used to derive the regression equation for predicting the magnitude for both type of wavelet analysis. The linear regression is done with least square best fit line between average threshold wavelet coefficient and earthquake magnitude information provided by JMA, Japan. In the result section we have evaluate the performance for early warning magnitude based on DWT and MODWT methods.

IV. RESULT & DISCUSSION

All the analysis has been done in MATLAB environment.

Wavelet threshold coefficient are correlated with hazardous ground motion magnitude. In this section two wavelet approaches DWT and MODWT are utilized for determination of earthquake early warning magnitude. Further the comparative analysis is done. The result for our analysis are shown in Fig 4, for DWT and Fig5 for MODWT. Total 1254 seismograms recorded at the stations, at the source distance from 30-130 km. 60 events are used for analysis. We plot the wavelet coefficients scale 4 to 7 in function of JMA magnitude. The linear regression is done with least square best fit line between average threshold wavelet coefficient and earthquake magnitude information provided by JMA, Japan.The correlation between DWT coefficient amplitude and ground motion magnitude is derived and the regression equation is found for predicting the early warning magnitude.

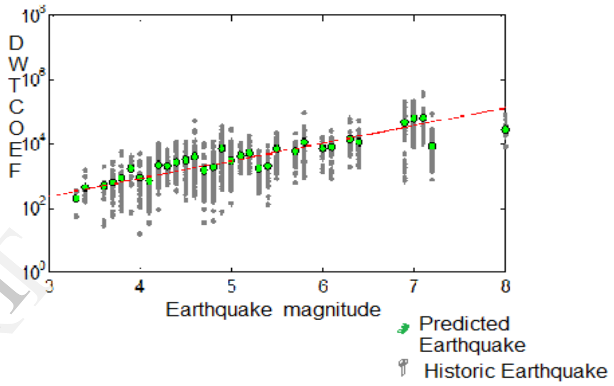

Fig.4 The correlation between DWT coefficient amplitude at level seven and ground motion magnitude

The equation(8) is obtainedfor DWT level 7 for our historic events.

$$M_{DWTE} = 1.817 * log10(DWTCA_7) - 1.308 \qquad (8)$$

Where DWTCA7 is DWT coefficient amplitude at level 7 decomposition. M= predicted magnitude of earthquake

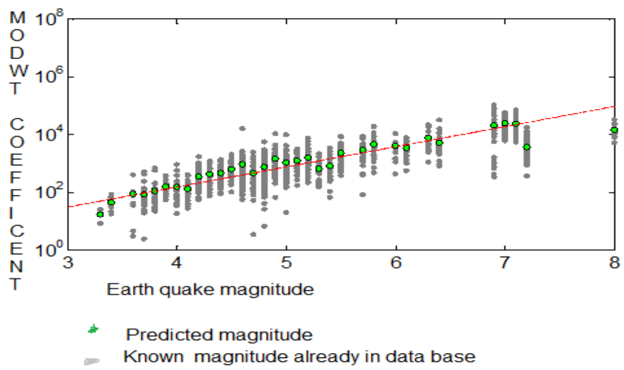

Fig.5 The correlation between MODWT coefficient amplitude at level seven and ground motion magnitude

The equation(9) is obtained for MODWT level 7 for previously considered historic events.

$$M_{MODWTE} = 1.329 * log10(MODWTCA_7) + 1.646 \qquad (9)$$

WhereMO DWTCA7 is MODWT coefficient amplitude at level 7 decomposition andM= predicted magnitude of earthquake

V.CONCLUTION

the mean and standard deviation of prediction error is calculated for DWT and MODWT methods and are shown in Table Ias below. In the both approach of wavelet analysis least square estimation technique is used. The statistics of prediction error shows the better performance for MODWT based technique.

TABLE I. mean and standard deviation of prediction error is calculated for DWT and MODWT

Statistics for prediction error	**Wavelet approach**	
	DWT	**MODWT**
mean	0.7402	0.4869
Standard deviation	0.5987	.4033

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