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Eigen Double Derivative Technique to further improve the seismic image generated by conventional data processing

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ABSTRACT
In conventionally processed seismic image, there is always a possibility of the presence of noise and scope for further improvement. Dealing and suppressing the residual noise, after application of several kinds of filters in conventional data processing, is challenging. Improving seismic image by reducing such noise, strengthens further analysis and interpretations. The Eigen Double Derivative Technique (EDDT) enhances the image by restoring the seismic amplitudes of conventionally processed seismic section, with average of neighbourhood data amplitudes in the low contrast direction. The low contrast orientation is indicated by Eigenvectors of double derivative image. Estimation of derivative images intoduces checkeredboard artefact, which is avoided by up-sampling of seismic amplitudes. In the present study, the efficiency of EDDT for improving seismic image is evaluated, by measuring contrast to noise ratio (CNR). Application of EDDT on seismic section of 3D seismic data from Balol oil field, Cambay basin, India has resulted into improvement of its CNR by 16%. Thus, the EDDT can be used to further improve the conventionally generated seismic image, by reducing inherent residual noise and improving contrast.

Keywords: Seismic image enhancement, Eigen values and vectors, Double derivative image, Up-sampling, Contrast to noise ratio.

INTRODUCTION

An image consists of numerous features. The visualisation of such features, plays an important role in their analysis and interpretation. In that sense, the seismic image can be considered a record of seismic waves, reflected from subsurface geological interfaces underneath. An energy source (dynamite or vibrator) generates a seismic wave, which travel through the subsurface and returns to the receivers on the surface. The receiver converts the variations in the earth's motion to an electrical signal, which is digitally recorded. The recorded seismic waves are then assigned source and receiver coordinates to form a seismic record (Zhou, 2014), which becomes an integral part of various geophysical studies. The recorded seismic data contains several types of noise due to anthropogenic activity at acquisition site, experimental errors (Bahavar et al. 2002) and complex subsurface geological conditions. Several efficient processing techniques (Yilmaz, 2001) exist to improve the signal to noise ratio. The conventional processing attenuates several types of noise, viz. ground roll, airwaves, multiples etc., mostly by using frequency domain filters. Frequency domain filters introduces artefacts, if their parameters are not set properly. A frequently used median filter improves the image quality, however contributes to blurring, thereby limiting interpretation capabilities (Guo et al. 2010). The histogram equalisation to improve the image converts image histogram into a uniform distribution by manipulating seismic amplitudes. It does improve the contrast, however few details invariably disappears (Liu et al. 2010). Similarly, conventional processing improves the signal to noise ratio (SNR) of the traces, but there is always a possibility of residual noise presence and scope to improve it. Any level of seismic image improvement adds strength in successive analysis and interpretation. Such noise suppression in an image results in improved contrast to noise ratio (CNR) and represents the image in a more visibly palatable way by bringing out more visual content which is otherwise not visible for perception and interpretation (Kumar et al. 2009). In medical science, the computed tomography (CT) scan images are improved using double derivative techniques to efficiently monitor dental implants in human (Mendrik et al. 2009). Derivatives do optimise the quality of CT images (Karla et al. 2004) by decreasing noise while maintaining the image contrast.

Present Eigenimage double derivative technique (EDDT), suppresses the noise in low contrast direction by manipulating the seismic amplitudes to improve image visibility. The Eigenvectors computed on double derivative image is used to identify the low contrast direction. In this study, EDDT has been applied on conventionally processed and post-stack migrated seismic section along an inline of seismic data from Balol oil field, Cambay basin, India.

METHODOLOGY

Eigen double derivative technique (EDDT) involves computations of Eigen-values and Eigen-vectors of double

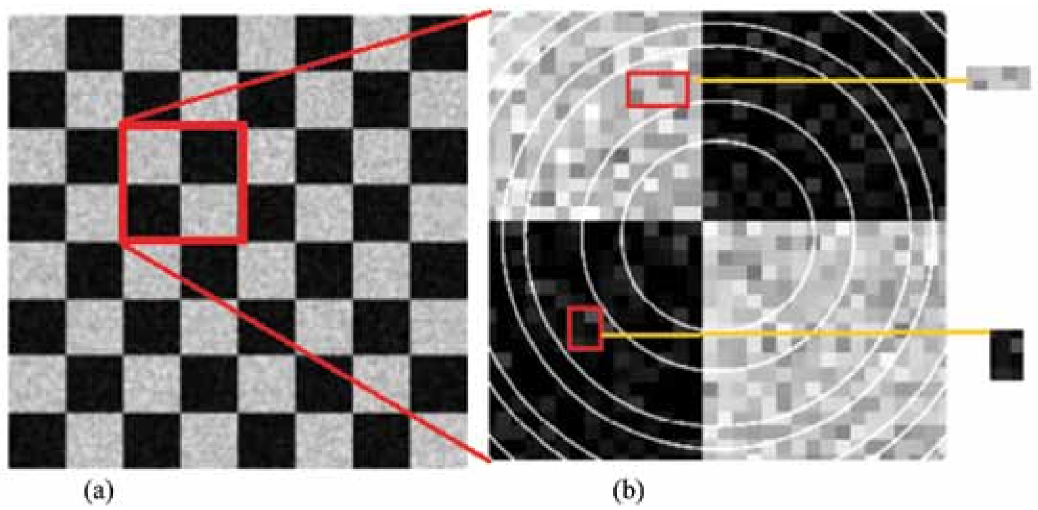

Figure 1. Noisy chess board enhancement through derivatives with resulted checkerboard artefact.

derivative image, to identify data amplitudes corresponding to lower contrast. The data amplitudes corresponding to low contrast in the conventionally processed input image are replaced by average of neighbouring amplitudes. The derivative of an image is computed both in horizontal (X-direction) and vertical (Y-direction) using data amplitudes. The derivative in the x-direction at data point P1 is estimated by computing the difference between Po and P2, which are the data values to the left and right of P1 and similar procedure is adopted in vertical direction also. The image, thus formed, is called first-order derivative image. Repetition of same computational process on the first order derivative image, produces a double derivative image. Image noise results in data amplitudes that look very different from their neighbours. The larger the noise, the more difference among neighbour data amplitudes. Computation of image derivative is nothing but application of difference filters, which smoothens the image and suppresses the noise.

In EDDT, input image is convolved with Gaussian function $G(x,y) = \frac{1}{2\pi\sigma^2} e^{\frac{-(x^2+y^2)}{2\sigma^2}}$, where x, y represents the position of seismic data points. This procedure acts as low pass Gaussian filtering. The width of Gaussian filter is adjusted with variance parameter. Increased variance parameter involves more data amplitudes in the computations and more effectively suppresses the noise. The Gaussian function is nonzero everywhere, but approaches to zero at about three standard deviations from the mean. Thus, the width of Gaussian filter is optimized to 3σ, accounting to about 99.7% of Gaussian curve. Derivative based noise removal techniques, always contribute to checkerboard artefact, which deteriorates image quality at the micro visual level. The standard procedure to avoid checkerboard artefact is up-sampling data amplitudes before the computation of image derivatives. The derivative scheme applied on noisy chess board image, without up-sampling, has resulted in checkerboard artefact as illustrated in Figure 1 (Shapiro and Stockman, 2000).

Checkerboard artefact is a break in picture elements leading to poor visible quality, especially in frequent zooming applications, such as seismic images. Up-sampling is done before calculating derivative images to avoid checker board artefact. In EDDT, the seismic data amplitudes are up-sampled at a rate of ↑10 and ↑4, i.e., after every ten data amplitudes, average of preceding ten seismic data amplitudes is inserted and after every four seismic data amplitudes, average of preceding four data values is inserted in Xand Y-direction respectively. It is a trial and error procedure, however the rate of up-sampling is decided based on computational overload and required visible quality.

DERIVATIVE SCHEME FOR SEISMIC IMAGE IMPROVEMENT

The EDDT is applied on digital seismic section from Balol oil field, Cambay basin, India and reproduced in Figure 2. The double derivative image uniformly distributes seismic amplitudes concentration as a function of virtual time (τ). The successive smoothing of the seismic image at different virtual times is calculated by using following mathematical expressions.

$$\frac{\partial I}{\partial \tau} = \nabla.(D.\nabla I) \quad \text{-- (1)}$$

Where I- represent seismic amplitude, Divergence Operator ∇I – seismic image gradient, D – square matrix known as diffusion tensor, and $\frac{\partial I}{\partial \tau}$ - is rate of change in seismic amplitude with virtual time (τ).

The diffusion matrix, which gives local orientation of data values is computed using structure tensor *J*:

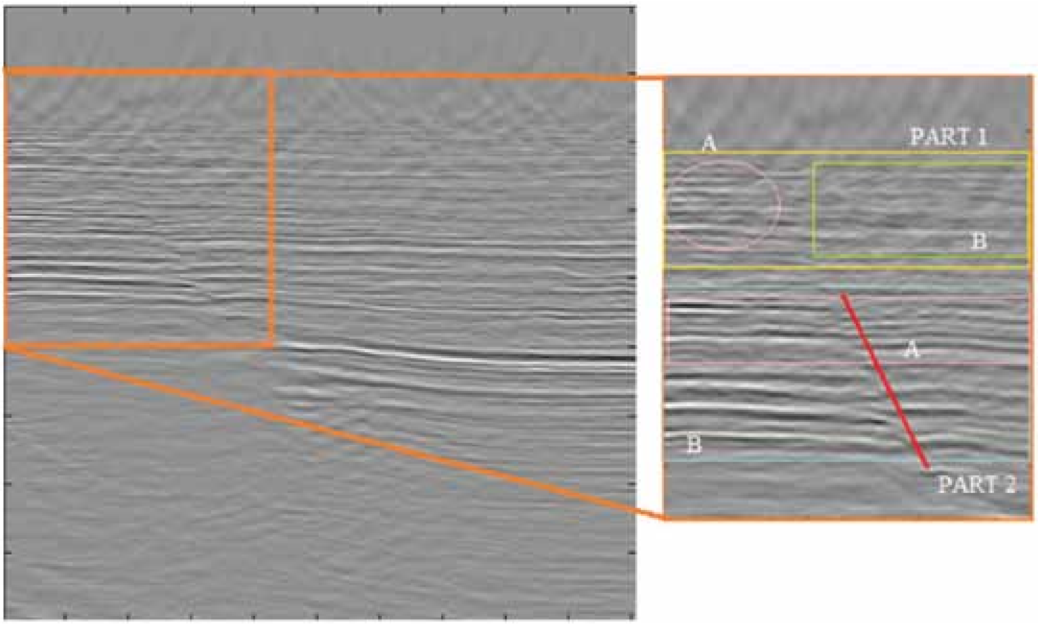

Figure 2. Conventionally processed seismic section along an inline of 3D seismic data from Balol oil field, Cambay basin, India (Data Source: ONGC India).

$$J(\nabla I) = \nabla I . \nabla I^T = \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \quad \text{-- (2)}$$

Where $I_x = \frac{\partial I}{\partial x}, I_y = \frac{\partial I}{\partial y}$ – first order derivative images in x and y directions respectively

$I_x^2 = \frac{\partial^2 I}{\partial x^2}, I_y^2 = \frac{\partial^2 I}{\partial y^2}$ – second order derivative images in x and y direction respectively

$I_{xy} = \frac{\partial^2 I}{\partial x \partial y}$ Second order derivative image in xy direction

The diffusion matrix is redefined in terms of Eigen-values and Eigen-vectors of double derivative image as

$$J(\nabla I) = [V_1 V_2] . \begin{bmatrix} \mu_1 & 0 \\ 0 & \mu_2 \end{bmatrix} . [V_1 V_2]^T \quad \text{-- (3)}$$

Where, V_1, V_2 – Orthogonal Eigenvectors corresponding to Eigen values - μ_1, μ_2.

Eigen-values indicate average contrast and corresponding Eigen-vector points towards low contrast.

The EDDT comprises following computational steps,

I. The input seismic image is convolved with Gaussian function for minimal noise removal.
II. The seismic data amplitudes are up-sampled.
III. The first order derivative image is calculated using central difference at each input image data points and similarly using first derivative double derivative image is calculated.
IV. Eigenvalues and orthogonal Eigenvectors are estimated on each data matrix of sizes 5x5, 7×7 and 9×9. The data matrix is shifted towards low contrast as indicated by Eigen-vectors.
V. In low contrast direction,the data amplitudes of input seismic image are replaced with average of neighbourhood data matrices. This procedure is repeated on entireinput image.
VI. Compute Contrast to Noise Ratio (CNR) of the seismic image generated by EDDT.
VII. Stop the computational process, if estimated CNR of the output seismic image is less than 0.05% of previous two successive estimations,without distorting the visible quality.
VIII. If the condition in step IV is not satisfied repeat the steps IV to VII with set increased data matrix sizes.

The flow chart for application of EDDT is illustrated in Figure 3.

IMAGE ENHANCEMENT METRICS

The qualitative and quantitative assessment is performed to check improvement in the output seismic image. Qualitative evaluation is looking for visual quality improvement of the seismic image generated by EDDT, against the seismic image generated by conventional data processing. Quantitative evaluation is carried out by estimation of performance metrics, CNR (Bechar et al., 2012). The mathematical formulations for estimation of CNR are as follows

$$CNR = \frac{\mu_I - \mu_E}{\sigma_E} \quad \text{-- (4)}$$

Where

$$\mu_I = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} I(i,j) \quad \text{-- (5)}$$

$$\mu_E = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} n(i,j) \quad \text{-- (6)}$$

$$n(i,j) = I(i,j) - E(i,j) \quad \text{-- (7)}$$

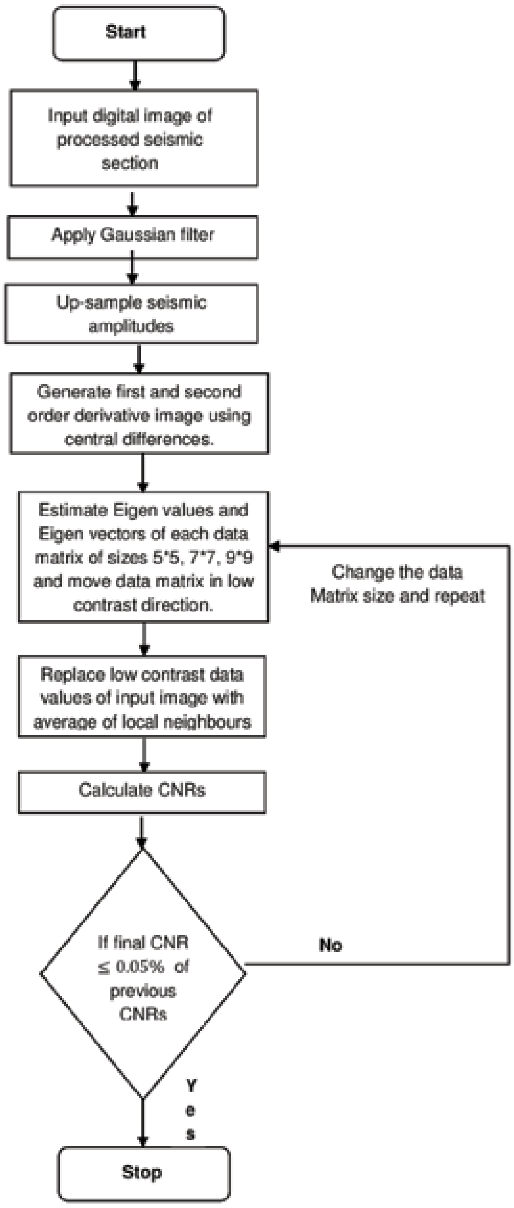

Figure 3. Flowchart of Eigen double derivative Technique.

$$\sigma_E = \sqrt{\frac{1}{MN-1}\sum_{i=1}^{M}\sum_{J=1}^{N}(n(i,j)-\mu_E)^2} \quad \text{- - (8)}$$

$I(i,j)$ - seismic image generated by conventional data processing, $E(i,j)$ - seismic image generated by Eigen double derivative technique and $n(i,j)$ – residual of seismic image is estimated by calculating difference image between images by conventional processing and Eigen double derivative technique.

RESULTS AND DISCUSSIONS

The seismic image enhanced by the application of EDDT is shown in Figure 4, whereas Figure 2 is the input seismic image generated by conventional data processing. On both the Figures, some portions of the seismic image are highlighted by rectangle and circles, to illustrate the efficiency of EDDT for image improvement. The CNR of conventionally processed seismic image and the seismic image enhanced by EDDT is tabulated in Table 1. The CNR of conventionally processed seismic image is 70.235, where as the CNR of output seismic image enhanced by EDDT is 81.335. An increase in CNR by 16% indicates that the image noise has been significantly reduced. Increase in contrast in terms of visual inspection is indicated by enhanced layer and reflector edges/boundaries, as well as smoothing of the layer and fault transition as illustrated in Figure 4.

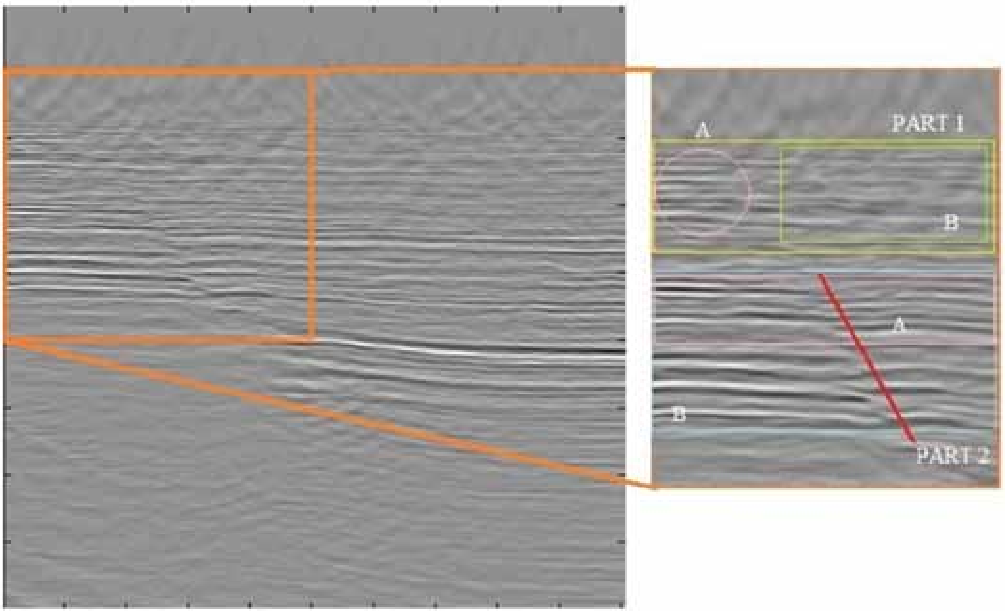

Figure 4. The seismic image enhanced by application of EDDT.

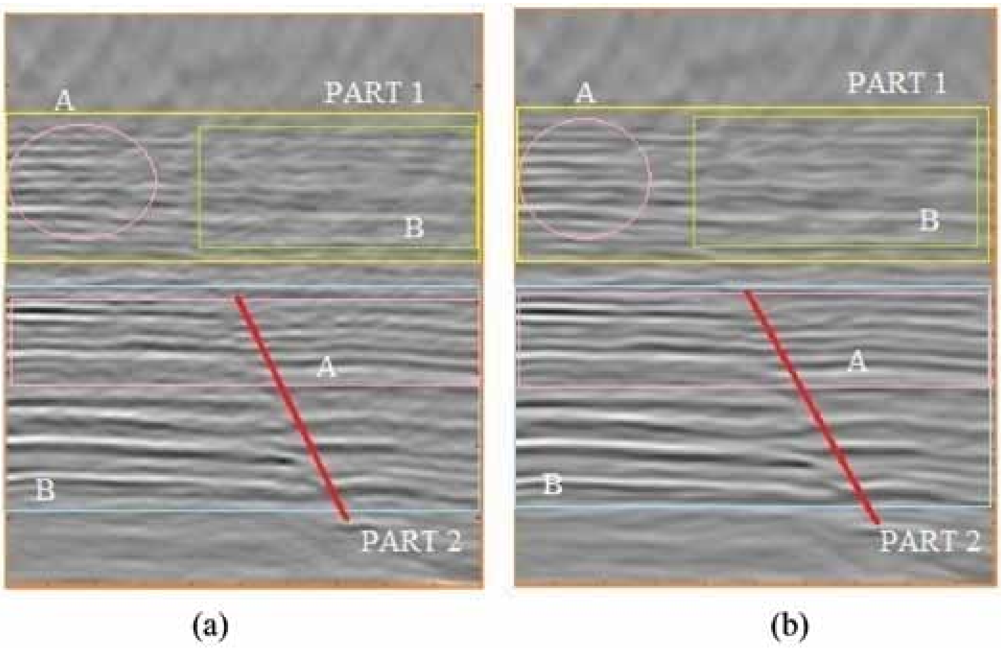

Figure 5. The zoomed version of rectangles highlighted in Figure 2 and Figure 4, (a) Balol seismic image, generated by conventional data processing and (b) The seismic image enhanced by EDDT.

Table 1. Estimated Performance metrics, contrast to noise ratio.

S.No	Description	CNR
1	Seismic Image generated by conventional data processing (Input)	70.235
2	Seismic image enhanced by Eigen double derivative technique (output)	81.335

Seismic images, as shown in Figure 5, are divided into part 1 and part 2. In part 1, both A and B of Figure 5(b) shows enhanced reflector boundaries/edges and smoothened layers. Similarly, in part 2, both A and B of Figure 5(b) shows strong reflector edges, smoothed reflectors and enhanced fault transition (redline). By very close visual inspection of subsections, the enhancement of the output seismic image (Figure 5b) is perceived due to the 16% improvement of CNR over the conventionally well processed seismic image (Figure 5a). This improvement in CNR strengthens the analysis and interpretation. The EDDT generates improved seismic image as a trade-off between CNR and observable visual quality. It appears in Figure 5(b) that fault edges are slightly disturbed, which indicates onset of marginal edge distortion, where tradeoff was made between CNR and visual quality. Even though edges appear to be disturbed, the difference in data concentration around the fault in the residual seismic image is 0.15% which is reasonable for further processing and interpretation of the seismic image. The residual image is generated by calculating the difference between the conventional input image and image produced by EDDT. However, the technique manipulates the seismic amplitudes; thus, the seismic images enhanced by EDDT may limit the application of seismic amplitude analysis techniques.

CONCLUSIONS

The analysis and application Eigen double derivative technique (EDDT) further improves the image quality by reducing the noise of the seismic image, generated by conventional seismic data processing. The use of EDDT has improved the Contrast to Noise Ratio (CNR) to ~81 from ~70, which is approximately ~ 16% image quality improvement. The technique significantly improves contrast of conventionally processed seismic image and thus has the potential to push further interpretation, as the horizons of interest will appear more prominent.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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