Particle Swarm and Differential Evolution –Global Optimization for Geophysical Inversion

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Abstract:

Inversion of pre- and post-stack seismic data for acoustic and shear impedance is highly non-linear and ill-posed. A deterministic inversion of band-limited seismic data produces smooth models which are devoid of high frequency variations observed in well logs. Stochastic inversion methods often based on Gaussian priors can produce high frequencies in the desired model. In this paper we report on the application of two new global optimization schemes, namely, Particle Swarm Optimization (PSO) and Differential Evolution (DE) to the problem of stochastic inversion of post-stack seismic data. A starting model is drawn from a fractional Gaussian distribution (based on a fractal model) and a suitably defined objective function is optimized in search of acceptable models using PSO and DE. Our investigations reveal that both the methods have nice convergence properties. However, the DE converges at least 10 times faster than PSO. We demonstrate the performance of these methods with application to synthetic and field seismic data.

Introduction

Inversion of seismic data plays a vital role in reservoir characterization. High resolution inversion methods add significant value to the inversion results and increase the confidence level in interpretation of seismic data. Well logs present most accurate information about the petrophysical properties of a subsurface reservoir. However, spatially continuous description of a reservoir at the well log scale is not available due to limited well data. Results from seismic inversion are usually integrated with well log data to derive reservoir models in 3D. A typical deterministic seismic inversion derives blocky or coarse subsurface model well below the resolution of the well logs. A stochastic inversion that combines well logs with seismic inversion has the potential to estimate subsurface models at the well log resolution in 3D. It is well recognized that the low and high frequency part of the subsurface model reside in the null space of the seismic data and can only be incorporated through a priori information. Common stochastic inversion methods employ Gaussian probability density function to describe prior impedance models. Most recently Srivastava and Sen (2009 a, b) made use of fractal based a priori model for acoustic impedance in post- and prestack seismic inversion. They showed that geologically realistic acoustic impedance models can indeed be estimated by this approach. Srivastava and Sen (2009a, b) employed very fast simulated annealing, VFSA (Sen and Stoffa 1995) in the search for optimal models. Our approach is very similar to that used in Srivastava and Sen (2009 a, b). However, we employ two new global optimization methods, namely, particle swarm optimization (PSO) and differential evolution (DE) in stochastic inversion of post-stack seismic data. To the best of our knowledge, this is the first application of DE to geophysical inversion. We demonstrate performance of our approach with application to field data.

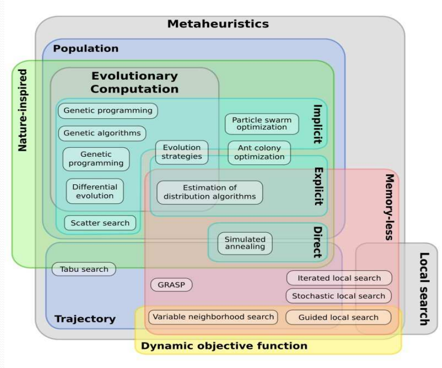
Theory/Methodology

Before, inversion, spectral analysis of seismic traces at different well locations in 3D data volume has been carried out to ascertain the reliable spectral bandwidth, signal to noise ratio and phase variations. Statistical analysis of well log data has been carried out for understanding the relation among log derived seismic parameters, i.e., acoustic impedance, velocity and density which provide a solid base for prediction of lithology. Synthetic seismograms generated using sonic, density logs and VSP surveys are used to calibrate geologic picks of different wells to seismic reflections. A composite full wavelet has been estimated using both seismic and several well logs available in the 3-D study areas. Initial 3D impedance models were generated using seismic,well log and picked horizons. Different techniques of inversion are being used by the industry to perform stratigraphic inversion from post stack seismic data.
The methods involved are as follows

1. definition of an objective function
2. choice of a starting model and
3. choice of optimization methods

Objective function:

We consider an error function based on the median properties of the Observed and Computed seismogram Let:
F1=(Observed-Computed)
F2=(Observed+Computed)
Thus we use the following function for minimization
F=F1/(F1+F2)



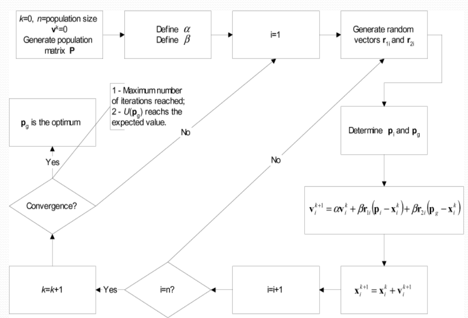
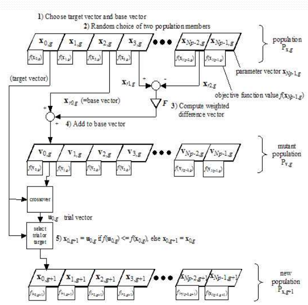


Figure 6. Iterative procedure for the Particle Swarm Method.



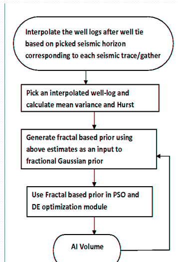


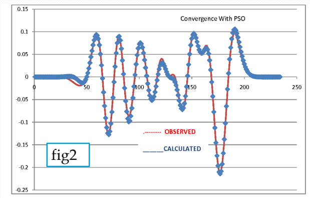
fig1

Results

Synthetic data – we derived random reflectivity using a random generator and convolved it with 30 Hz Ricker wavelet to obtain a synthetic seismogram as our forward model; further we carried out inversion of the same model using PSO and DE in which we generate acoustic Impedance values. The data fit obtained by both the optimization methods is shown in Fig(2) and Fig(3) respectively.

Real Seismic data Inversion:

We also carried out inversion of field data (also used in Sen and Srivastava 2009a). We derived a particular log corresponding to trace number 27 xline number 42 of the seismic data and the acoustic impedance values thus generated were compared with the observed values from well-log data .The plots are shown in the figure 4 and 5. Respectively .Finally we carried out inversion for total of 119 traces using Differential Evolution; the plots are shown in figure 6. 2D Plots of Acoustic Impedance calculated by the inversion of section of seismic field data using PSO and DE are shown in figure 7; note the high resolution estimates



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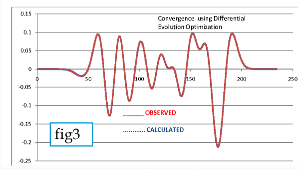

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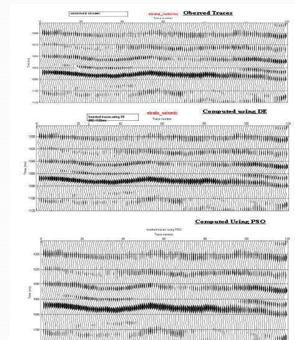

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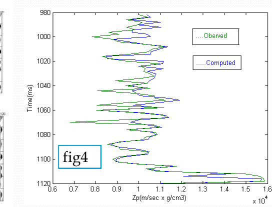

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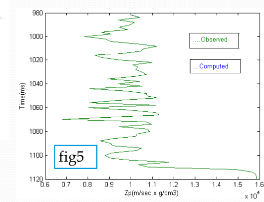

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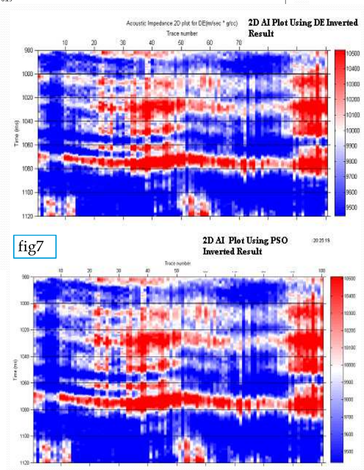

fig7

Conclusions/Discussions

- We presented two new techniques for global optimization for geophysical inversion, namely Particle Swarm Optimization and Differential Evolution Optimization .
- Applied for the inversion of post-stack seismic data and well-log data.
- we generated fractal based a priori model for acoustic impedance values precisely
- PSO has been used previously for geophysical inversion , but to the best of our knowledge, this is the first application of DE fielding Geophysics.
- The objective function used matches seismic data and honors statistic of well-logs. The inversion process is fast - the results were obtained within 1000 iterations. PSO and DE provided good data-fit with very low error approximately to the order of 10e-05 with appropriate time consumption though DE was comparatively faster than PSO with more accuracy and precision.
- PSO and DE can be operated on a wide range of Geophysical problems and data sets with any number of unknowns to be determined accurately .

References:

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