JOINT INVERSION OF RAYLEIGH WAVE DISPERSION and H/V CURVE INVERSION BY USING PARTICLE SWARM OPTIMIZATION & GENETIC ALGORITHM

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INTRODUCTION

Joint inversion of surface wave dispersion and ellipticity curves with its highly nonlinear nature has some difficulties using conventional optimization methods due to need and strong dependence to the initial model, possibility of trapping in local minima and evaluation of partial derivatives (G. Dal Moro & Pipan, 2007; Song, Tang, Lv, Fang, & Gu, 2012). There are some modern global optimization methods to overcome these difficulties in surface wave inversion such as Genetic Algorithm (GA) and Particle Swarm Optimizaton (PSO). GA is based on biologic evolution consisting reproduction, crossover and mutation operations have been used for a few surface wave analysis studies such as Gancarlo Dal Moro, Pipan, & Gabrielli, 2007; Pezeski & Zarabi, 2005; Yamakana & Ishida, 1996. Even though PSO and GA processes are similar in appearance, the cross-over operation in GA is not used in PSO and the mutation operation is a stochastic process for changing the genes within chromosomes in GA, but in PSO, this similar process is performed intelligently by sharing information between particles. Unlike GA, the particles in PSO algorithm change their position with logical velocities according to particle’s own experience and swarm’s experience (Gill et al., 2006; Shi & Eberhart, 1998). PSO algorithm developed after GA is inspired from the social behaviour of birds or fish of swarms have just been used one Rayleigh wave dispersion inversion study as Song et al., (2012). In this study, we used PSO and GA optimization technique to determine shear wave velocity structure by using multiojective surface wave dispersion curve and ellipticity curve for which shortest path way was origination. Utility of these multiojective inversion provide reliable results, plausible convergence rate, acceptable relative error and optimal computation cost with global optimization techniques that are important for modelling studies.

OBJECTIVES

In this study, we applied PSO and GA technique to estimate S wave velocities and thicknesses of the layered earth model by using multiojective optimization of the misfit between calculated dispersion & ellipticity curve and observed dispersion and H/V spectral ratios. We emphasize on the advantage of global optimization methods to avoid:

• trapping of local minima/maxima
• dependence to initial model and partial derivatives
• difficulties on taking derivatives

We emphasize on the advantage of PSO modern global optimization algorithm compare with GA which is other global optimization method for geophysical modelling studies considering its:

• rapid convergence
• low misfit error
• computation cost

We also emphasize on the advantage of using multiojective optimization methods

• Reliable results are obtained with different and non-comparable solutions

METHODS

Particle Swarm Optimization

The PSO based on social behaviour of swarms of insects or flocks of birds discovering to the food or reaching to the nest by shortest pathway was traditionally proposed by Kennedy and Eberhart in 1995. Particles distributed randomly in search space denoting the individual parameters changes their own velocity with equation (1) and position with equation (2) using their own intelligence and swarm intelligence for reaching minimum error value/values by using objective function (Figure 1).

v_i(t+1) = v_i(t) + c_1 r_1 (pbest - x_i(t)) + c_2 r_2 (gbest - x_i(t))
(1)

x_i(t+1) = x_i(t) + v_i(t+1)
(2)

where:

• i: particle position at iteration k
• v_i: particle velocity at iteration k
• w: inertial weight, c_1 and c_2: cognitive and social learning factering, rand, and rand).

Genetic Algorithm

GA, invented by Holland (1975), is based on the principles of natural genetics and selections having elements are reproduction, crossover and mutation. Reproduction operator selects the good strings (minimum error values) of the population to form mating pool by using Roulette-wheel selection scheme representing the fitness values which are inverse related with error values (Figure 2). This scheme increases the probability of selection of minimum error values. Crossover operator creates new substrings and new solutions by changing information of strings with other strings. Error values of the new strings are most important to survive in the next reproduction stage. Mutation operator changes the new strings using small mutation percentage number. The use of these 3 operators yield new generation containing new strings with decreased error values.

RESULTS

Synthetic Data

We first used noise free synthetic data to estimate S wave velocity and thickness parameters of each layer by using PSO and GA multiobjective optimization of Rayleigh wave dispersion curve and H/V spectral ratios. ‘grid’ and ‘g excell’ tool developed by Geopsy team is used for comparing Rayleigh wave dispersion and ellipticity curve respectively (Bard et al. 2000). Table 1 shows synthetic data model parameters and estimated model parameters changes their own velocity with equation (3) and position with velocity (A), particles reach minimum error (B).

S Wave

<table>
<thead>
<tr>
<th>Layer No</th>
<th>S Wave Velocity (m/sec)</th>
<th>Thickness (m)</th>
<th>Density (g/cm²)</th>
<th>P Wave Velocity (m/s)</th>
<th>S Wave Thickness (m)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>100 10</td>
<td>1.6106 400</td>
<td>80 120 6 14</td>
<td>203.6 10.7</td>
<td>99.8 9.89</td>
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<tr>
<td>2</td>
<td>200 10</td>
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<td>160 240 6 14</td>
<td>308.3 9.8</td>
<td>98.2 9.82</td>
</tr>
<tr>
<td>3</td>
<td>300 10</td>
<td>1.7202 848</td>
<td>240 360 6 14</td>
<td>396.4 10.6</td>
<td>92.3 9.6</td>
</tr>
<tr>
<td>4</td>
<td>400 10</td>
<td>1.7230 951</td>
<td>320 480 6 14</td>
<td>409.0 10.8</td>
<td>89.3 9.4</td>
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<tr>
<td>5</td>
<td>500 10</td>
<td>1.7329 1000</td>
<td>400 600 6 14</td>
<td>420.5 10.1</td>
<td>86.3 9.2</td>
</tr>
</tbody>
</table>

Estimated Parameters (PSO)

<table>
<thead>
<tr>
<th>S Wave Velocity (m/s)</th>
<th>Thickness (m)</th>
<th>S Wave Velocity (m/s)</th>
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Estimated Parameters (GA)

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<th>S Wave Velocity (m/s)</th>
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Figure 1. Estimation of two parameters (x1) and change position with velocity (A), particles reach minimum error (B).

Figure 2. Roulette - wheel selection scheme (Rao, 2009).

RESULTS

Real Data

We modelled real dispersion data obtained from a site in Bursa region (Bursa project, JUBATK MAM YDBI) to estimate S wave velocity and thickness of each layer fitting the dispersion and H/V ellipticity curve inversion by using multi-objective PSO optimization technique. The objective function that we used is the NRMSE error function same as eq. (3). Normalized number and iteration must be 100 and 200 respectively. Vp/Vs range changes at each layer by exponentially from 4 to 1.7. Figure 5 shows the results of multiobjective PSO technique as the dispersion and H/V curve fitness and their total NRMSE error. This figure also estimated velocity model and the search space. According to results, remarkable fit is provided with the multiobjective PSO technique.

REFERENCES

Global optimization methods such as PSO and GA provide many advantages that they don’t trap any local minima and they don’t depend on initial models and partial derivatives. Compared with GA, PSO also has many advantages which has rapid convergence to minima and less computation time. Solving the PSO method with multi-objective optimization, in which dispersion and ellipticity objective functions are different and non-comparable with each other, provides reliable results. In this study, we normalized the errors getting from dispersion and ellipticity curve objective functions to avoid of contributions of non-comparable errors. Pareto optimality as another method used in the literature for multi-objective solutions is also planned to be used for future works.