COMPARING GENETIC ALGORITHM AND PARTICLESWARM OPTIMAIZATION APPROACHES IN INVERSION OF SURFACE WAVE DATA

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ABSTRACT

Shear-wave velocity (Vs) is an important parameter for site characterization in geotechnical and earthquake engineering studies.Shear-wave velocity is in situ measured by various methods including borehole tests, shear-wave refraction and reflection studies and surface-wave techniques. In recent years, surface waves have been increasingly used for deriving Vsas a function of depth. But, inversion is the key problem in processing surface wave data for estimating velocity of S-waves. In present study we applied two metaheuristic optimization approaches, Genetic algorithm (GA) and particle swarm optimization (PSO), for inversion of Rayleigh wave dispersion curves. GA and PSO are the global optimization methods that belong to metaheuristic searching algorithms. In geophysical surveys, the application of metaheuristic techniques is novel. After programming the GA and PSO in MATLAB, its efficiency was investigated by a synthetic model. At the end, GA and PSO inversion algorithms were tested on an experimental Rayleigh wave dispersion curve data which was collected for seismic hazard assessment in an area of city of Tabriz in the northwest of Iran. Real datasets were obtained from one stations in south part of Tabriz (near Elgoli Road) that contain Miocene –Pliocene and pyroclastic bedrocks. The results proved applicability of proposed inversion algorithms in Rayleigh wave dispersion curve inversion. Also, assessment of two inversion algorithms showed that PSO inversion algorithm, because of few parameters to adjust, is fast and easy to implement compared to GA inversion algorithm.

INTRODUCTION

Shear-wave velocity (Vs) is an important parameter for site characterization in geotechnical engineering (Renalear et al., 2010). In theory, Vs is a function of ground compactness and rigidity variations (Hunter et al., 2002). Also, Vs imaging techniques allow for the delineation of geologic boundaries in the subsurface. In earthquake engineering, ground motion characteristics including amplitude and duration are amplified in the sites where soft soil layers cover firm bedrock. This issue is in contrast to Vs values that strongly control dynamic site response and the resulting damage(Zarean et al., 2015). Shear-wave velocity (Vs) is in situ measured by various methods including borehole tests, shear-wave refraction and reflection studies and surface-wave techniques (Hunter et al., 2002; Boore, 2006). In recent years, surface waves have been increasingly used for deriving Vs as a function of depth (e.g., Socco and Jongmans, 2004).

The inversion step in the processing of surface wave data is a significant matter for obtaining a reliable near-surface Vs profile because of its nonlinearity and multi-dimensionality. Though, most geophysical inversion methods are based on linearized techniques to estimate the parameters of model in an iterative manner; i.e., using local optimization algorithm to modify a starting model defined by users (Wathelet et al., 2004). The solution is quite often trapped to local minima during the application of local optimization methods. As a result, their success depends on the sufficient closeness of the initial model to the true global-minimum solution. But, global optimization algorithms include the ability of producing solutions which are independent from the initial model to explore the model space in more details and thus a better chance to find the true global minimum solution (Poormirzaee et al., 2014a).

In general, optimization algorithms can be divided into two categories: deterministic and stochastic algorithms. Deterministic algorithms follow a rigorous procedure and its path, values of both design variables, and functions are repeatable. On the other hand, stochastic algorithms which always have some randomness are of two types in general: heuristic and metaheuristic. Further development over heuristic algorithms is the so-called metaheuristic algorithms, which generally perform better than simple heuristics. In addition, all metaheuristic algorithms use the certain tradeoff of randomization and local search (Yang, 2010).

In geophysical surveys, the application of metaheuristic techniques is new. Particle swarm optimaization (PSO) and Genetic algorithm (GA) are global optimization methods that belong to metaheuristic searching algorithms. In the current study, the reabilityof GA and PSO algorithms in the inversion of surface wave data was investigated and then a comparison was made between the proposed inversion algorithms. İn this study refraction microteremor (ReMi) (Louie, 2001) method was used as a passive surface wave data.

In current study, GA and PSO application on Rayleigh wave dispersion curve inversion was demonstrated. To evaluate calculation efficiency and stability of GA and PSO in the inversion of Rayleigh wave dispersion curve, first GA and PSO code was developed in MATLAB; then, one synthetic datasets was inverted. Finally, GA and PSO inversion algorithm in Rayleigh wave dispersion curve datawas investigated in a case study in an area of city of Tabriz in the northwest of Iran. The obtained results from both synthetic and real datasets proved the reliability of GA and PSO approaches for inversion of surface wave data.

GAAND PSO ALGORITHMS

Genetic algorithm has been developed by J. Holland in the 1970s to understand the adaptive processes of natural systems. Then, they have been applied to optimization and machine learning in the 1980s.GAs are a very popular class of evolutionary algorithms (Yang, 2010).

A genetic algorithm involves three basic operators corresponding to the biological processes of selection, crossover, and mutation. Selection involves the choice of the individuals for the generation of offspring. Crossover is the method of combining two individuals to produce an offspring. Mutation is the random changing of some individual within the population. Each operator can be implemented in different ways. Choosing the correct combination is vital to the effectiveness of the algorithm (Boschetti et al., 1996).There are many advantages of genetic algorithms over traditional optimization algorithms, and two most noticeable advantages are: the ability of dealing with complex optimization problems and parallelism(Yang, 2010).

Particle swarm optimization (PSO) incorporates swarming behaviors observed in the flocks of birds, schools of fish, swarms of bees and even human social behavior, from which the idea is emerged (Kennedy and Eberhart, 2001). PSO is a population-based optimization tool, which could be easily implemented and applied to solve various function optimization problems. In terms of the algorithm an important feature of PSO is its algorithmic simplicity and fast convergence (Lu et al., 2010).

The particles in PSO are moving towards promising regions of the search space by exploiting information springing from their own experience during the search as well as experiencing other particles. For this purpose, a separate memory is used in which each particle stores the best position (x_i^*) it has ever visited in the search space. The best position of each particle experience comprised to other ones and then the best position, which belongs to minimum of misfit function, selected as the global best (g^*) (Poormirzaee et al., 2014b). This procedure (i.e. finding x_i^* , g^*) is repeated for certain iteration. Finally, the best global g^* is determined as the optimum solution.

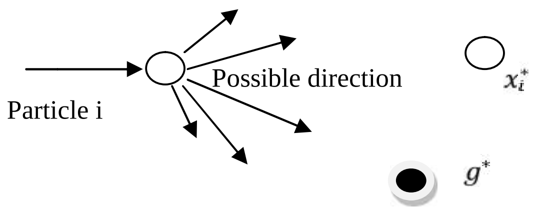

Figure 1. Schematic representation of the motion of a particle in PSO, moving towards the global best$g^*$and the current best x_i^* for each particle i (Yang, 2010)

GA AND PSO ALGORITHMS FOR SURFACE WAVE ANALYSIS

The experiments were tested on an Intel PC with 2.2GHz processor and 4GB memory running MATLAB R2009a in Windows 7. The experiments were carried out on the synthetic model and actual dataset.

In the current study, the focus was on inversion results of fundamental-mode Rayleigh-wave dispersion curve for near-surface S-wave, P-wave velocities and layer thicknesses. Rayleigh-wave dispersion is dominated by S-wave velocity and thicknesses (Xia et al., 1999), but, since in Rayleigh-wave dispersion P-wave plays minor but not completely negligible role, Poisson values are free to vary around a value with the percentage which the user can define (Dal Moro et al., 2011). The inversion was done for S and P-wave velocity by the assumption of 0.2<Poisson's ratio<0.5 and fixing densities to their known values.

The forward modeling of Rayleigh-wave dispersion curves is based on the fast Dunkin's (1965) formulae algorithm developed by Wathelet et al. (2004). Wathelet et al. used an efficient root search based on the Lagrange polynomial which was constructed by iteration with Neville's method (Press et al., 1992). The procedure was designed to find the global minimum of RMS (root-mean-square) error misfit between the measured and predicted phase velocities. The objective function was defined as (Dal Moro et al., 2007):

$$\text{misfit} = \|V_R^{obs} - V_R^{theo}\|_2 / \sqrt{m} \quad (1)$$

where V_R^{obs} is an m×1 vector of the observed Rayleigh-wave phase velocities, V_R^{theo} is an m×1 vector of the theoretical Rayleigh-wave phase velocities and m is the number of dispersion points (phase velocities versus frequency).

SYNTHETIC DATA INVERSION

The GA and PSO inversion algorithms were tested on a synthetic dataset (i.e. A model). Table 1 shows model A; and the search space for the algorithms. Also the obtained mean model and estimated Vs profile are showed in figure 2 and Table 2.

Table 1. Model A and search space

layer	Vp(m/s)	Vs(m/s)	H(m)	search space		
				Vs(m/s)	Vp(m/s)	H(m)
1	400	200	8	100-300	200-600	4-12
2	600	400	half space	200- 600	300- 900	-

Table 2. Obtained mean model from the model A

Parameter	true	GA	PSO
Vs1(m/s)	200	197	199
Vs2(m/s)	400	399	407
H1(m)	8	7.8	7.9

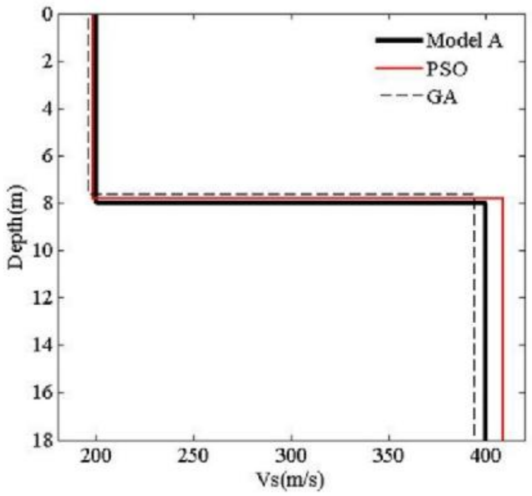

Figure2. Obtained Vs profiles from syntheticdataset by GA and PSO approaches

EXPERIMENTAL DATA INVERSION

At the end, GA and PSO inversion algorithms were tested on a real Rayleigh wave dispersion curvederived from refraction microtremor records data which was collectedfor seismic hazard assesmentinanarea of city of Tabriz in thenorthwest of Iran.The data were collected in a profile line. In this study, the ReMi method was performed using an OYO 12-channal seismograph and 4.5Hz geophones with the receiver spacing of 10m. After obtaining the dispersion curve of field dataset (Figure 3), similar to the inverse strategy of the synthetic case, Vs, Vp and thicknesses (H) of layers were considered as variables (Table 3). After considering the numbers of run and different models, the dispersion curve was taken into account and a 3-layer model was adopted (Figure 4).

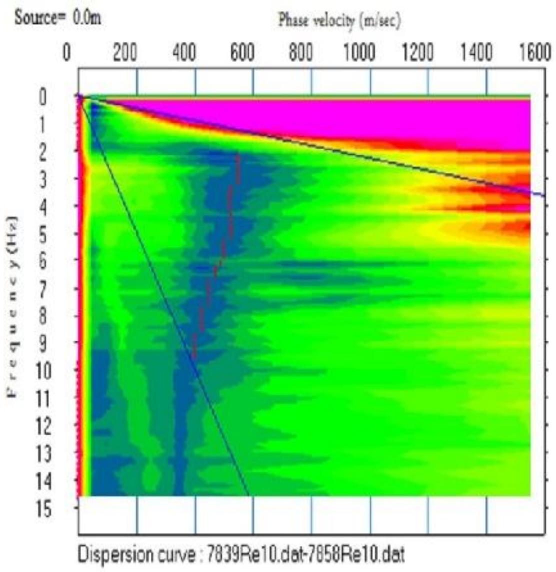

Figure 3. Dispersion curve obtained from field dataset

Table 3.Search space for inversion of field dataset by GA and PSO algorithms

layer	search space		
	Vs(m/s)	Vp (m/s)	*H*(m)
1	200-400	400-600	3-12
2	350- 500	500- 1000	2-9
3	400-650	900-2400	Half-space

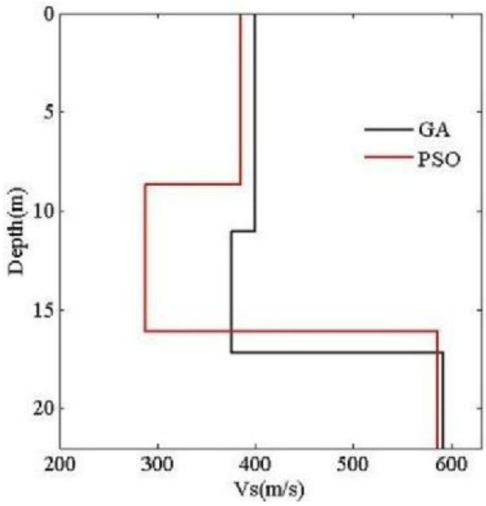

Figure4**.**Obtained Vs profiles from field dataset by using of GA and PSO approaches

CONCLUSIONS

Determination of underground S-wave velocity is a very important issue in geotechnical and earthquake engineering. Surface wave analysis is an accepted tool to estimate shear wave velocity. But, inversion, as a main stage in the processing of surface waves data, is challenging for most of local-search methods due to its high nonlinearity. With the advancement of computer science, optimization algorithms and intelligence strategies, fast and easier techniques can be utilized for the inversion of seismic data. GA and PSO are global non-linear optimization strategies. In this study GA and PSO algorithm was successfully implemented to invert Rayleigh surface waves dispersion curves data. The code for the inversion of surface waves data was written and processed in MATLAB. This code was easy and fast and also allowed the user to include a priori information on different parameters. In this study, one synthetic dataset was inverted. Finally, the GA and PSO inversion algorithm in refraction microtremor data was applied in an area in city of Tabriz in the northwest of Iran. With Using proposed inversion algorithms, a three layer subsurface model was found, which the average estimated shear wave velocity is between 278-592m/s. Also, comparison of two inversion algorithms showed that PSO algorithm, because of few parameters to adjust, is fast and easy to implement compared to GA.nMoreover, results of the field dataset by PSO inversion algorithmwere in good fitting with geological information (Faridi and Khodabande, 2011) of study area.An additional trait of the implemented PSO inversion algorithm code was its more flexibility.

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