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Inverse Analysis of Pavement Thickness Based on Improved Particle Swarm Optimization

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Abstract. Core-drilling is the traditional pavement thickness detection method. However, this way is low efficient and destructive. The Ground Penetrating Radar (GPR) is a continuous, high efficient, non-destructive pavement quality testing tool. The dielectric constant, thickness and other information of pavement structure layer are obtained by inverse analysis of GPR echo signal. In this paper, the improved Particle Swarm Optimization (IPSO) is developed to analyze the dielectric constant and thickness of the pavement structure. Compared with inverse analysis results of theoretical model, the inverse precision of IPSO is higher than that of PSO. In addition, the measured echo signal of GPR is analyzed by the IPSO. The errors between inverse results and the actual core-drilling measurements are less than 3%.

Introduction

Pavement layer thickness is an important quality detection indicator, and core-drilling combined with manual measurement is traditional thickness detection method. This test method is slow, inefficient, not representative, and destructs road structure. The GPR, as a fast, continuous, efficient, non-destructive tool, has been widely applied in highway quality detection. The pavement layer thickness, the dielectric constant and other information can be obtained by inverse analysis of GPR echo signal.

Particle Swarm Optimization (PSO), as a global optimization algorithm, was firstly proposed by Dr. Eberbart and Dr. Kennedy[1] based on the study of birds predatory behavior. Because PSO has few parameters to adjust, is easy to implement and has special characteristic of memory, it has been widely applied in function optimization, fuzzy control, neural network training, geotechnical engineering inversion.

To further improve the search efficiency of PSO, Li et.al.[2] give an improved PSO(IPSO) algorithm. The chance finding optimal solution is improved by changing of the fitness value comparison way and the particle motion model. In this paper, the IPSO is developed to inverse analysis of GPR echo signal. The inverse accuracy between the PSO and IPSO is compared by the theoretical model. In addition, the measured GPR signal is analyzed by IPSO, and then core-drilling is used to verify the accuracy of the inverse results.

Improved Particle Swarm Optimization

The basic idea of the standard Particle Swarm Optimization algorithm can be summarized as: a group is composed by M particles generated in the D-dimensional search space randomly, each particle is seen as a feasible solution of optimization problems, and the quality of the particle is determined by a fitness function. The movement direction and distance of particle in the search space are determined by one velocity variable. The current optimal particle is tracked by competition and cooperation, and finally the optimal solution is found after evolved generation by generation. In each generation, the particle will track two extremes, one is the optimal location which the particle searches by itself, and the other is the optimal position which the entire group searches.

Assuming at time t, the position and velocity of particle i are $x_i^t = \left(x_{i1}^t, x_{i2}^t, \cdots, x_{iD}^t\right)^T$ and $v_i^t = \left(v_{i1}^t, v_{i2}^t, \cdots, v_{iD}^t\right)^T$, respectively. $p_i^t = \left(p_{i1}^t, p_{i2}^t, \cdots, p_{iD}^t\right)^T$ represent individual best positions of particle i, $p_g^t = \left(p_{g1}^t, p_{g2}^t, \cdots, p_{gD}^t\right)^T$ represent the global best positions. The fitness value is solved by substituting x_i^t into the fitness function and compared with individual best position and the global best position, if the fitness value less than individual best position and the global best position, individual best positions and the global best positions will be replaced, and at time $t+1$, the position and velocity of particle i are updated using Eq. (1) and Eq. (2).

$$v_{id}^{t+1} = \omega v_{id}^t + c_1 r_1 \left(p_{id}^t - x_{id}^t\right) + c_2 r_2 \left(p_{gd}^t - x_{gd}^t\right) \tag{1}$$

$$x_{id}^{t+1} = x_{id}^t + v_{id}^t \tag{2}$$

where $i = 1, 2, \cdots, M$, ω inertia weight, c_1 and c_2 are non negative coefficients called acceleration factors, r_1 and r_2 are two random numbers different from each other and generally distributed in the range [0,1].

The fitness value comparison method in the PSO shows that the fitness value of each particle at the new position can appear only two cases, one is the new value f_i^t is less than the particle best position f_{pi} and the global best positions f_g. f_{pi} and f_g are replaced, the other is that f_i^t is larger than f_{pi} and f_g, f_{pi} and f_g are not replaced. Obviously, this value comparison means is too strict, because f_i^t is likely larger than f_{pi} and f_g, but less than the fitness value f_i^{t-1} at previous position, i.e. sub-optimal state. These particles also move towards direction of fitness value reducing, and should be utilized to search continuously. In fact, the updated particles in every generation are major in sub-optimal state. Due to the fitness value comparison mode the potential role of suboptimal particles has been ignored, the chance to find better solutions is reduced.

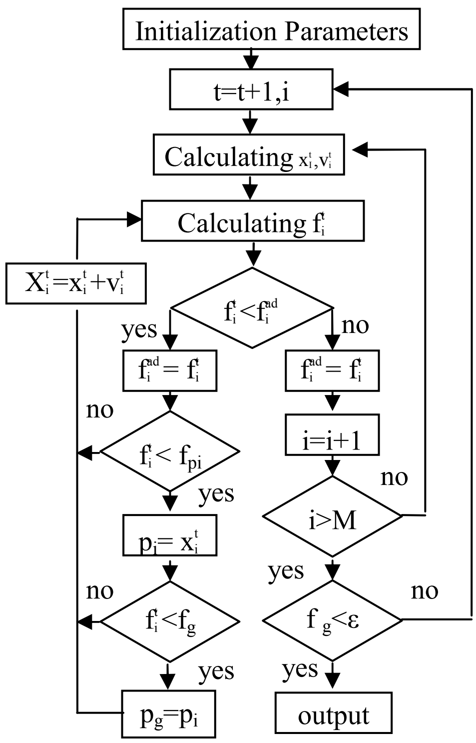

Fig.1 The flow chart of the IPSO program.

Therefore, a new fitness value comparison method is applied. First, the new fitness value f_i^t is compared with the fitness value f_i^{t-1} at the previous position to observe the trend of particle movement, if $f_i^t > f_i^{t-1}$, it is shown that particles moving away from the optimal solution, the operation of the particles will be stopped and the next particles in the population start to move; if $f_i^t < f_i^{t-1}$, it is shown that particles moving towards the optimal solution, the particles should be allowed to search in this direction continuously, and compared with two optimal value until the fitness value is no longer reduced. Correspondingly, the particle motion manner is adjusted similarly. The particles are no longer limited to move one time in each iteration, but can continue to move in that direction until the fitness value is no longer reduced. The IPSO program flow chart is shown in Fig. 1.

The Inverse Process of Pavement Thickness

In inversion process of pavement thickness, the fitness function is established based on the output of the real pavement structure and numerical model, and the IPSO is used to optimize objective function. The parameters set in numerical model are the real parameters of pavement structure when the objective function reaches minimum value. The principle is shown in Fig. 2, where the simulated waveform is calculated by Symplectic method [3].

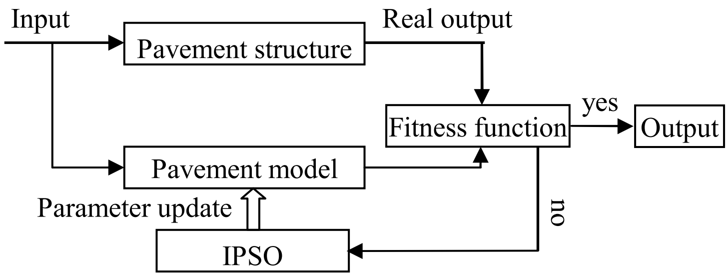

Fig. 2 The flow chart of pavement structure inversion

In this paper, the fitness function is chosen as the mean square deviation between the simulated amplitude and the measured amplitude. The specific parameters values are chosen as: the population size: $M = 50$; the max iteration number: $\max step = 50$; learning factor: $c_1 = 0.5$, $c_2 = 0.5$; the linear-weight: $w = (\max step - step) * 1.0 / \max step$, where step is the current iteration step; iteration termination condition: in this paper, two iterative termination conditions are applied, the first is the fitness function achieves convergence precision, and the second is iterations iteration step reaches the maximum number.

Numerical Examples

Theoretical model. The simulated waveform calculated by the known model are used as the measured signal in the inversion process, and then the dielectric constant of the known model is solved by the PSO and IPSO, Assuming the known model is a three-layer structure, parameters selection are shown in Table 1, in this case, two simulated waveforms are calculated by two groups dielectric constants using Symplectic method. The two group comparison results between the PSO and the IPSO are shown in Table 2.

Table 1 The parameters of theoretical model

layer	dielectric constant			Conductivity	thickness
1	$6\varepsilon_0$	$6.4\varepsilon_0$	$7\varepsilon_0$	0.01	0.2m
2	$16\varepsilon_0$	$16.4\varepsilon_0$	$17\varepsilon_0$	0,05	infinite

where ε_0 is vacuum permittivity

As can be seen from Table 2, the IPSO and the PSO are both converge to the true value, and the errors are less than 6%, but the accuracy of IPSO is higher than the PSO, the errors are less than 2%. In addition, the IPSO convergence speed is faster than the PSO.

Table 2 The comparison of inverse results

	real	IPSO	error	time	PSO	error	time
	6.0	6.07	1.17%		5.71	-6.00%	
1	11.0	11.12	1.09%	184.2s	10.46	-6.00%	242.3s
	16.0	15.72	-1.75%		15.7	-0.13%	
	7.0	7.06	0.86%		6.8	-3.71%	
2	12.0	12.12	1.00%	182.4s	12.8	5.67%	245.7s
	17.0	16.79	-1.24%		16.35	-2.59%	

Project. The parameters of the asphalt concrete pavement design are shown in Fig. 3. Rodar V 1GHz GPR is used to detected, and the accuracy of the inversion results are done by coring at 8 points. The comparison results and the errors are shown in Table 3. As can be seen from Table 3, the accuracy of inverse results is less than 3%.

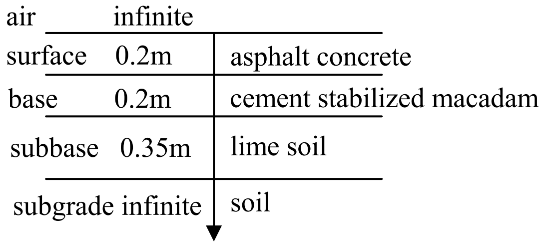

Fig. 3 The schematic diagram of four layered pavement structure

Table 3 The comparison of inverse result and core-drilling

points	1	2	3	4	5	6	7	8
core-drilling	21	20	20.5	19.5	20.5	19.5	22.5	20
inverse	20.65	20.23	20.24	19.78	19.95	19.34	21.96	19.96
error	1.67%	-1.15%	1.27%	-1.44%	2.68%	0.82%	2.40%	0.20%

Conclusions

In this paper, the IPSO inversion analysis combined with symplectic forward calculation are used to identify the pavement layer parameters. By comparing inversion results of the theoretical model, the precision of the IPSO is higher than the PSO. The measured echo signals of asphalt concrete pavement are analyzed by IPSO. Compared with the drill core measurements, it is shown that the inversion results reach the good accuracy. This technology promotes the development of highway nondestructive testing technology

References

[1] J. Kennedy, and R. Eberhart, Particle swarm optimization, Proceeding of the IEEE International Conference on Neural Networks (Perth, Australia, 1995). p.1942-1948.

[2] X.L. Li, F.M. Wang, and X.N. Li, Improved particle swarm optimization for elastoplastic back analysis in geotechnical engineering, Cai Kuang yu An Quan Gong Cheng Xue Bao, Vol. 26 (2009) No.1, p.50-54.

[3] H.Y. Fang, G. Lin, and R.L. Zhang. The first-order Symplectic Euler method for simulation of GPR wave propagation in pavement structure, IEEE Trans. on Geoscience and Remote Sensing, Vol. 51 (2013) No.1, p.93-98.