Study on conical source transient electromagnetic based on AWPSO algorithm

Gang Huang and Haiyan Yang
School of geophysics and measurement and control technology, East China University of Technology, Nanchang, China
E-mail: gangh16@163.com

Abstract. The transient electromagnetic conical field source device can effectively reduce the inductance between the coils and improve the resolution of the small device to detect the shallow underground layer. However, the conventional inversion method requires an initial model and has the disadvantage of low inversion precision. Combined with the results of previous studies, this paper proposed an adaptive weighted particle swarm optimization (AWPSO) algorithm based on Sigmoid function through the analysis and research of PSO, which solved the problem of artificial initial model and low precision of inversion results. By calculating the test function, the algorithm can effectively improve the searching ability of particle swarm optimization algorithm. Several different typical geoelectric models are designed, and the algorithm is applied to data inversion of transient electromagnetic geoelectric model. Combined with the measured data of a hot spring practice area, the inversion calculation and interpretation of the sounding data were carried out, and the inversion calculation results were confirmed by the geological and hydrological data. The results show that the proposed particle swarm optimization algorithm has a high inversion fitting degree to the theoretical model and the measured data, achieves the separation of the apparent resistivity anomalies in the shallow subsurface, and improves the resolution and interpretation accuracy of the measured data in the conical field source transient electromagnetic method.

1. Introduction
In recent years, with the development of geophysical exploration, TEM has been used in engineering tunnels, coal mine roadway, urban and engineering shallow detection and other fields [1,2]. However, in limited space, the application of conventional large-size excitation sources is limited, and small-scale devices have become common working devices [3–5]. Eve and the cone type source device the device while the number of turns coil winding and become, but the circle radius of coil is different, there is also a certain distance between coil and magnetic moment conditions, such as it has been proved in mutual inductance is about 1/9 times turn small loop, about multiple cut-off time turns 1/8 of the small loop, transient electromagnetic method can effectively enhance the small device of shallow detection ability. Therefore, it is necessary to further study the inversion method suitable for this device.

Particle Swarm Optimization (PSO) is an intelligent Swarm nonlinear global Optimization algorithm. In recent years, some scholars have applied it to geophysical inversion and achieved good results [6]. Cheng J L proposed a joint inversion technique of transient electromagnetic and DC method suitable for advanced detection of tunnels and roadways by using particle swarm optimization algorithm [7]. Monteiro used particle swarm optimization to invert the spontaneous potential data of buried abnormal bodies, and pointed out that the particle swarm optimization algorithm was fast and
did not need the initial model [8]. Li M X realized a PSO-DLS combined inversion method suitable for roadway transient electromagnetic detection by using particle swarm optimization algorithm, and solved the problem of the late optimization speed decline of PSO algorithm and the given initial model of DLS algorithm [9,10].

2. Algorithm

2.1. An adaptive weighted particle swarm optimization algorithm based on Sigmoid function

Inspired improvement strategy, based on the above algorithm based on cone type nonlinear inversion problem of source device, combined with neural network algorithm the activation function is monotone increasing and bounded features, the author of the particle swarm algorithm is improved, and proposes a Sigmoid function $F(D)$ based adaptive weighted particle swarm optimization algorithm (AWPSO).

Different from the time-varying update strategy, the acceleration factor varies according to the distance between the particle and the individual $P_{best}$ and global optimal $G_{best}$. If the current particle is far away from and, a relatively large acceleration coefficient is used to accelerate the particle's motion. In order to prevent premature convergence, the value of acceleration coefficient is limited in an appropriate range, that is, speed should be limited to ensure the algorithm's search and optimization ability. From the above point of view, combining with the characteristics of geophysical inversion, the following adaptive rules are proposed.

\begin{align}
C_{gp_{ij}} & = F(gp_{ij}) \quad (1) \\
C_{gg_{ij}} & = F(gg_{ij}) \quad (2) \\
gp_{ij} & = P_{best}X_{i,j} - X_{i,j} \quad (3) \\
gg_{ij} & = G_{best}X_{i,j} - X_{i,j} \quad (4) \\
F(D) & = \frac{b}{1 + e^{-a(D-d)}} + d \quad (5)
\end{align}

$X_{i,j}$, $V_{i,j}$ are the velocity and position of the particle, $W$ is the weight coefficient, $r_1$ and $r_2$ are accelerating factor and and D is the input of the specific problem function.

\begin{align}
X_{i,j}^{k+1} & = X_{i,j}^k + V_{i,j}^{k+1} \quad (6) \\
V_{i,j}^{k+1} & = wV_{i,j}^k + C_{gp_{ij}} \times r_1 \times gp_{ij}^k + C_{gg_{ij}} \times r_2 \times gg_{ij}^k \quad (7)
\end{align}

where $e$ is the base of natural logarithm, $a$ is the steepness of the curve and is a constant, $b$ is the peak of the curve, $c$ is the abscissa value of the center point of the curve, $d$ is a positive constant value, $V_{i,j}^{k+1}$ and $X_{i,j}^k$ are the velocity and position of the particle, $W$ is the weight coefficient, $r_1$ and $r_2$ are accelerating factor and and $D$ is the input of the specific problem function.

2.2. Principle of algorithm

This algorithm is divided into eight basic steps:

1. Initialize the particle swarm and set relevant parameters
2. Calculate the fitness of each particle
3. Update individual and global optimal values of particles
4. The distance between the particle and the individual optimal value and the global optimal value when calculating the current iteration times
5. Update the acceleration coefficient
6. Update particle velocity and position
7. Judge whether the convergence condition is met, otherwise return to step 2
8. Output the optimal solution
2.3. The improved algorithm optimizes the test function

In order to verify the effectiveness of the improved particle swarm optimization (AWPSO) algorithm in this paper, Ackley function, a standard test function, was used to compare several previously improved particle swarm optimization (PSO) algorithms introduced in this paper with the adaptive weighted particle swarm optimization (AWPSO) algorithm proposed in this paper. The improvement of Shi X M is M2.PSO, the improvement of Cheng J L is NP.PSO, and the improvement of Li M X et al is MN.PSO [11,12]. The improvement strategy proposed in this paper is denoted as AW.PSO.

![Figure 1](image)

**Figure 1.** The fitness change curve of the test function with different improved strategies.

It can be concluded from figure 1 that in Ackley test function, with the same number of iterations, the fitness value of test function proposed in this paper is the smallest among the four methods, indicating that compared with the other three methods, the improved method proposed in this paper improves the optimization ability of particle swarm optimization algorithm.

3. Model inversion trial calculation

In order to test the effectiveness of AWPSO algorithm in the inversion of TEM data of conical field sources, the AWPSO inversion program was used to invert the transient electromagnetic sounding data of the five-layer (KHK type) geoelectric model.

![Figure 2](image)

**Figure 2.** Comparison of inversion results and forward response of the theoretical model.
Figure 3. Fitting errors in the inversion calculation process.

As can be seen from figure 2 and figure 3, the inversion results obtained by using AWPSO inversion program are basically consistent with the real values, with small inversion error and good inversion stability. Moreover, the magnetic field intensity fitting degree of the two is still very good, proving the effectiveness of the inversion algorithm.

4. Conclusion
For the cone type field source transient electromagnetic device, this paper proposes a Sigmoid function based adaptive weighted particle swarm optimization algorithm, through the test function of the trial, the results show that under the same premise, the improved adaptive weighted particle swarm optimization algorithm (AWPSO) on the convergence speed and optimal results were significantly better than that of other several improved particle swarm optimization algorithm, the improved particle swarm optimization algorithm is used to search optimization ability.

Acknowledgements
This work was supported by the National Natural Science Foundation of China under Grant 41564001 and 41974086.

References
[1] Hu W Y and Tian G 2010 Types of Coal Mine Water Damage and Its Prevention and Control Measures in China Coal Science and Technology 38 (01) 92-96
[2] Li F P 2017 Theoretical study on response characteristics of conical field source by TEM East China University of Technology
[3] Yang H Y, Li F P and Yue J H 2017 Cone-shaped source characteristics and inductance effect of transient electromagnetic method Applied Geophysics 14(1) 165-174
[4] Yang H Y, Li F P and Chen S E 2018 An inversion of transient electromagnetic data from a conical source Applied Geophysics 15(3-4) 545-555
[5] Yang H Y, Chen S E and Yue J H 2019 Transient electromagnetic response with a ramp current excitation using conical source IEEE Access 7 63829-63836
[6] Kennedy J and Eberhart R 1995 Particle swarm optimization Proceedings of IEEE International Conference on Neural Networks, Perth, WA:IEEE, 1942-1948
[7] Ceng J L, LI M X and Xiao Y L 2014 Study on particle swarm optimization inversion of mine transient electromagnetic method in whole-space Chinese Journal of Geophysics 57(10) 3478-3484
[8] Monteiro S F 2010 Inversion of self-potential of idealized bodies’ anomalies using particle swarm optimization Computers&Geosciences 36(9) 1185-1190
[9] Li M X 2019 Study on mine transient electromagnetic method inversion based on PSO-DLS combination algorithm Coal Science and Technology 47(9) 268-272
[10] Li M X, Cheng J Y and Wang P 2019 Transient electromagnetic 1D inversion based on the
PSO–DLS combination algorithm *Exploration Geophysics* **162** 71-72

[11] Shi X M, Xiao M and Fan J K 2009 The damped PSO algorithm and its application for magnetotelluric sounding data inversion *Chinese Journal of Geophysics* **52(4)** 1114-1120

[12] Jiulong Cheng, Fei Li and Suping Peng 2015 Joint inversion of tem and dc in roadway advanced detection based on particle swarm optimization *Journal of Applied Geophysics* **12(123)** 30–35