Application of electrical resistivity tomography method in archaeological excavation

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Abstract. Archaeology has always been an important application field of geophysical methods. In this paper, multi-electrode resistivity method is used to detect the sites of Yangshao periods in Xia county, Yuncheng city, Shanxi Province. The inversion principle of multi-electrode resistivity method is introduced, the data are also processed and interpreted in two and three-dimensional inversion. Through this exploration, the resistivity characteristics of the cultural layer of the site and the location and depth of its concentrated distribution are found out, which provides an important basis for further archaeological exploration and excavation.

1. Introduction
Although geophysics has been linked with archaeology for a long time, it was used on a large scale after 1945. Now it has been developed to possess remote sensing, electric method, magnetic method, shallow seismic method, ground penetrating radar exploration and other detection methods, realizing the desire of "non-destructive detection of underground cultural relics" in the field of archaeology. At present, almost all kinds of geophysical exploration methods, including sky, underwater, underground and ground, are increasingly serving for Archaeology abroad. Archaeological work of geophysical method is applied in our country, as can be traced back to 1956 years of Ding Ling Tomb geophysical exploration [1,2]. With the development of reform and opening-up in 1978, the task of salvage cultural relics protection and excavation in various regions is arduous. The application of geophysical methods to the exploration and excavation of cultural relics has achieved good results, especially in some tombs and sites. What's more successful were the electrical surveys of Caosigudui tomb in Hao county, Anhui province, in 1982, and Kaifeng city wall site of in the Song dynasty. The other was the "national high and new technology development research program (863 program)" in 2002, which is the first time that remote sensing and geophysical integrated exploration technology was applied to the mausoleum of the Qinshihuang Mausoleum. It is also the first time to describe the three-dimensional form of the underground palace of Qinshihuang Mausoleum with scientific data by using 8 categories and 22 methods, and a series of new achievements have been made. In a word, geophysical methods are playing a more and more important role in terms of the actual situation of archaeological work at home and abroad.

In archaeological exploration, many sites and their surrounding media often have differences in electrical properties, such as: tomb and surrounding rock, coffin and soil, rammed soil and common soil, etc., which makes electrical method become the main method of archaeological exploration, and electrical method itself is a relatively economical and convenient method.

The location of this exploration and study is 15 km southwest of Xia county, Yuncheng city, Shanxi Province, Southeast of national highway 209, west of Shi village, belonging to Yuncheng basin,
and the salt lake of Yuncheng city is 4 km south. Except for the north and South Mountains, the terrain is inclined from northeast to southwest. The general altitude is 300-600 m. It is an ancient settlement site with the remains of the Yangshao period as the main body. The site is agricultural land, high in the northeast and low in the southwest. There are many pottery pieces from the Yangshao period to Zhou Dynasty on the surface.

2. Inversion principle

2.1. 1D AMT inversion framework based on deep learning

The inversion of multi-electrode resistivity method is to find a reasonable geophysical model to be consistent with some geophysical observations. The core of inversion is the process from planning to optimization, and most geophysical inversion problems are nonlinear problems [3]. Nonlinear geophysical problems are expressed as follows:

\[ \Delta d = J \Delta m \]  

(1)

Where \( \Delta d \) is the difference between the observed value and the theoretical data, that is, the increment of the observed data; \( \Delta m \) is the increment of model parameters; \( J \) is the jacobian matrix. By solving this system, we can obtain the model's correction \( \Delta m \), which contains the error caused by linearization. Therefore, adding \( \Delta m \) to the starting model does not result in the real model vector, but a new vector that may be closer to the real model than the starting model vector. Repeat the steps above and you may end up with a realistic model vector.

In geophysical inverse problems, the number of model parameters \( N \) is rarely equal to the number of observed data \( M \), so there is only a least squares solution. The principle of least square is to regularize the system of equations (1) obtained by linearization into the normal equation:

\[ J^T A \Delta m = J^T \Delta d \]  

(2)

Or construct the target function \( \psi \):

\[ \psi = ||\Delta d - J\Delta m||^2 \]  

(3)

Take the derivative of the above objective function with respect to \( m \) and set it equal to 0, the solution can be obtained as:

\[ \Delta m = (J^T J)^{-1} J^T \Delta d \]  

(4)

In the least square method, multiple or false solutions often occur in geophysical inverse problems. In order to reduce such errors, the smoothing coefficient \( C \) is introduced to constrain its inversion:

\[ r = C \Delta m \]  

(5)

Where, \( C \) is the smoothness operator, and the value is 1/4, 1 or 0. Construct the objective function:

\[ \psi = ||\Delta d - A\Delta m||^2 + \lambda ||r||^2 \]  

(6)

Where, \( \lambda \) is the Lagrange multiplier. Take the derivative of the objective function with respect to \( \Delta m \) and set it equal to 0, the following linear equations can be obtained:

\[ (J^T J + \lambda C^T C) \Delta m = J^T \Delta d \]  

(7)

By solving the above equation, we can obtain the model correction quantity \( \Delta m \), and add this vector to the initial prediction model vector to obtain the new prediction model.

The size of the model correction \( \Delta m \) is measured by the root mean square (RMS). When the root mean square error reaches the target, the inversion converges and the iteration stops. In order to reduce errors, when fitting the measured apparent resistivity data with the calculated resistivity data, both groups of data are calculated in logarithmic form, and the formula is as follows:
\[ \delta = \sqrt{\frac{1}{N} \sum_{j=1}^{N} \left( \ln[\rho_0(j)] - \ln[\rho_i(j)] \right)^2} \]  

(8)

Where, \(N\) is the number of measuring points, \(\rho_0(j)\) is the measured apparent resistivity of the \(j\)TH measuring point, and \(\rho_i(j)\) is the calculated resistivity value of the \(j\)TH point after the \(i\)TH iteration.

3. Data processing and analysis and achievement recognition

3.1. Field construction scheme

Through the field survey in the early stage, the site was roughly defined as a wheat field in the northwest of Shicun village. We divided the wheat field into a rectangle of 150 m×140 m, and explored the wheat field with a point distance of 1 m, a line distance of 2.5 m and a survey line of parallel arrangement (as shown in Figure 1), so as to understand the distribution of underground media in the wheat field.

![Figure 1. Map of survey area.](image)

3.2. Achievement cognition

Based on the geological survey of the area, this paper makes the following interpretation through two or three-dimensional inversion of the data obtained:

(1) After the preliminary survey and sample section excavation, it is found that a large number of pottery chips (as shown in Figure 2) are unearthed at the excavation depth of about 0.9-1.8 m, that is, the target culture layer. Although there are also pottery chips unearthed at other layers, the number and concentration are far less than this layer. Therefore, a survey line (line 14) is arranged at the excavated section to check whether the culture has resistivity characteristics, and the results are shown in Figure 3: The obvious layered medium appears at the depth of 1-2 m. The location of the excavation section
basically corresponds to the inversion result of line 14. It shows that the cultural layer of the site has different resistivity characteristics from the surrounding medium, and the variation range of the resistivity of the cultural layer is about $5-10 \, \Omega \cdot m$;

![Figure 2. Excavation profile of sample point (red line refers to boundary of culture layer).](image)

(2) The soil in the abnormal area can be roughly divided into three major electrical properties from top to bottom: high resistance layer, low resistance layer and medium low resistance layer. The electric properties of each layer are basically uniform and stable. The upper high resistivity layer corresponds to relatively loose light yellow sandy clay with a thickness of about 1 m, which is arable soil layer and contains modern tombs locally, causing the resistivity to fluctuate in the range of $20-100 \, \Omega \cdot m$; the middle low resistivity layer is light yellow gray sandy clay with a thickness of 0.5-2.8 m, which is the cultural layer with concentrated distribution of traces, with a resistivity variation range of about $5-10\Omega \cdot m$; the lower middle and low resistivity layers are similar to The variation range of resistivity of dense light yellow sandy clay is about $10 \, \Omega \cdot m$;

![Figure 3. 2D inversion results of resistivity of line 14.](image)

(3) Figure. 4 is the three-dimensional inversion slice map at the depth of 0.25 m (a), 0.5 m (b), 1 m (c) and 1.4 m (d) in the survey area, In Figure. 4a, the black frame is the distribution area of modern tombs, and the orange red high resistance is the reflection of high resistivity of modern tombs; In Figure. 4a, the orange frame is a depression with low resistivity; The range (1, 2, 3) of red frame in Figure. 4a is the same as the resistivity of the known cultural layer. Its depth is shallower than the cultural layer of the known section, and it begins to appear at the depth of 0.25 m. Until 1.4m, it can still be seen that there is a difference with the surrounding medium, so it is speculated that it is the concentrated distribution area of the site; In Figure. 4b, the band resistivity of 2 and 3 areas is about $5 \, \Omega \cdot m$. It is speculated that the wall foundation site is located at the depth of 0.5 m in area 2 and 3. It
has been verified by traditional exploration and actual excavation that No. 2 and No. 3 areas are indeed concentrated sites. A large number of Dongzhou and Yangshao period pottery chips were unearthed at a depth of about 0.2-0.4 m, and wall foundation sites were found at a depth of about 0.5-1 m.

(4) The blue spot in Figure 5a is the key discovery area of archaeological excavation. The excavation is shown in Figure 5c, which corresponds to the 2 and 3 areas in the resistivity inversion results (Figure 4). A large number of remains of Yangshao period, Dongzhou period and Song Jin period are found.

(5) Multi-electrode resistivity method has successfully detected the location and depth of the site distribution, but it is unable to make a more detailed and accurate division. For example, the tombs buried in soil, circular and square house sites can't be reflected in the resistivity inversion results, and the modern high resistance tombs will have low resistance false anomalies in the depth (the location surrounded by the black frame in Figure 4d).

![Figure 4. 3D inversion slice of resistivity with depth of 0.25 m (a), 0.5 m (b), 1 m (c) and 1.4 m (d).](image)
4. Conclusion
Through this geophysical exploration work, it can be confirmed that multi-electrode resistivity method has a good effect on the clay sites (ceramic chips and wall bases) in the Middle East and Yangshao periods. It is mainly due to the existence of a large number of ceramic chips and wall bases that the resistivity of this layer is relatively small. The soil in this area belongs to Q_2 clay, and its resistivity is generally 10-20 Ω·m, while the resistivity of surface backfill or arable soil is generally greater than 20 Ω·m, or even up to 200 Ω·m. The resistivity of cultural layer containing traces shows a low resistivity of 5-10 Ω·m. Geophysical prospecting can be used to detect cultural relics quickly and undamaged, provide a means for the search, structure detection and current situation evaluation of ancient tombs and other cultural relics, and provide a basis for the work plan of cultural relics protection, rescue and excavation.

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