3D characterization of archaeological remains buried under obstacles using annular array electric resistivity tomography

Zhanjie Shi*,1,2, Tianxiang Yu1 and Liuwei Xu1

1 School of Earth Sciences, Zhejiang University, Hangzhou, PRC
2 School of Art and Archaeology, Zhejiang University, Hangzhou, PRC
Email: shizhanjie@zju.edu.cn

Abstract. When archaeological remains are buried under buildings or other obstacles, it is very difficult to detect them by performing the traditional electric resistivity tomography (ERT) which commonly sets out survey lines right above those remains. We presented an annular array ERT method to solve the above problem. All electrodes were arranged around the obstacles in an annular array form. The apparent resistivity data were acquired through a special electrode shifting design. The electrode moved in the same serial number order with the cross diagonal survey of a 3D rectangular array. ERT apparent resistivity data were inverted by a 3D resistivity inversion package named RESINVM3D. The proposed method was tested using a synthetic model and field data. Synthetic results show that the target buried under obstacles can be imaged through the annular array. The result of field case indicates grave chamber buried under grave mound can be characterized using the proposed method. We conclude that the annular array ERT is an effective and valuable scheme for the detection and characterization of archaeological remains buried under obstacles.

1. Introduction

Geophysical technologies are non-destructive and effective for the investigation of buried archaeological remains and structures. Among them, magnetic method, ground penetrating radar (GPR) and electric resistivity tomography (ERT) are three main geophysical methods and widely used in the archaeological exploration [2,5,6]. Using the above geophysical technologies, we can investigate the ancient city site, big graves, ancient settlement and so on. The plan layout and 3D structure of buried remains can be detected through geophysical explorations.

For traditional geophysical technologies, the survey lines are commonly arranged in the area including those located right above buried archaeological remains. However, when there are some surface obstacles above the detection targets, such as the ancient monuments or modern buildings, the data acquisition cannot be performed on these areas. Then it is unsuitable to use the traditional geophysical measurement mode in such environment. L and CORNER array ERT have been used in such environment [1]. But it need special instrument and is mainly suitable for square obstacles. In order to meet more general needs, in this paper, the annular array was proposed and tested to detect the buried targets under the obstacles.

2. Methodology

Traditional 3D ERT is carried out using the cross diagonal survey [3] whose diagram is shown in Figure 1a. Numbered electrodes are connected one by one in a zigzag form. And green lines indicate that the practical survey lines for one data acquisition. Using the same numbered electrodes, we set out the...
annular array shown in Figure 1b by connecting electrodes along a rectangle. For one data acquisition of the annular array, the electrode serial number and shifting order are the same with those in cross diagonal survey, but electrode positions of the same serial number are different for the two arrays.

For the inversion of ERT data, we use an inversion package developed by Pidlisecky et al. [4] using Matlab code. In the package, finite volume approach is used to calculate electrical potential and inexact Gauss-Newton method is for inversion processing. Before inversion processing, data files containing apparent resistivity and the electrode relevant coordinates are made for the input of the inversion package. The data of annular array were collected using electrode shifting mode of cross diagonal survey, so the electrode positions need to be rearranged according to their practical coordinates.

![Figure 1](image1.png)

**Figure 1.** Different electrode array for 3D ERT. (a) cross diagonal array and (b) annular array. Electrode positions are marked by small circles. The serial number of the electrode is denoted from 1 to 30.

### 2.1. Synthetic examples

In order to evaluate the validity of the annular array survey, firstly, a test on a synthetic model was performed (Figure 2). In the example, the model has the length of 16.5m, width of 17m and thickness of 13.4m. Figure 2a shows the horizontal slice at the depth 4m and Figure 2b shows vertical depth slice through the model center. The anomaly buried depth of 1.35m has the length of 2.5m, width of 3m and thickness of 5.55m. In the center of the anomaly, there is a smaller anomaly with the length of 1m, width of 2m and thickness of 2.875m. We designed the homogenous background with resistivity value of 200Ω·m. The resistivity value of the anomaly and the smaller anomaly are 40 Ω·m and 10 Ω·m, respectively.

From the above model we calculated synthetic apparent resistivity data using the finite volume approach [4]. To examine the influence of loop number, we designed three annular arrays whose loop number are one, two and three. And their electrode number are 30, 68, and 114, respectively. The electrode distributions of different loop number are shown in Figure 3. Data point positions for three arrays are shown in Figure 4, Figure 5, and Figure 6. The number of data point for three arrays is 69, 558, and 1909, respectively. These synthetic data without noise were used as the observed data for inversion experiment.
Figure 2. A plot of true synthetic model. (a) Resistivity images of horizontal slice at the depth of 4m; (b) Resistivity images of vertical depth slice through the center of the anomaly.

Figure 3. Three annular arrays for synthetic test. (a) One loop; (b) two loops; (c) three loops. Black points indicate the position of electrode and the red number mark the serial number of electrode. The boundary of the obstacle is shown in blue rectangle.

Figure 4. Data point distribution for one loop array. (a) 3D view and (b) vertical profile.
Figure 5. Data point distribution for two loop array. (a) 3D view and (b) vertical profile.

Figure 6. Data point distribution for three loop array. (a) 3D view and (b) vertical profile.

Figure 7 shows the inversion result for one loop. The horizontal slices at the depth of 4 m and the vertical depth slices through the model center are shown in Figure 7a and Figure 7b, respectively. From Figure 7, we cannot almost see the anomaly shape in the inversion image of one loop array. The main reason is that there are few data point in this kind of annular array. Figure 8 shows the inversion result for two loops. The horizontal slices at the depth of 4 m and the vertical depth slices through the model center are shown in Figure 8a and Figure 8b, respectively. From Figure 8, we can see that the low resistivity anomaly shape is recovered through inversion. And the planform is similar with that of the true model. From the comparison between Figure 4 and Figure 5, we can see that there are more data points for two loops and the distribution of these points is relatively uniform. So data collected from the two loops has a better inversion image. Figure 9 shows the inversion result for three loops. The horizontal slices at the depth of 4 m and the vertical depth slices through the model center are shown in Figure 9a and Figure 9b, respectively. Compared with Figure 8, in Figure 9, the anomaly shape and position recovered have more difference with the true model. From Figure 6, we can see that the data point number is the most for the three loops, but some points become more intensive and probably overlap together. So it is possible the overlap that increase inversion uncertainty. And then the inversion accuracy is reduced.
2.2. Field example

The field data were collected from Yue State Royal mausoleum site in Shaoxing, Zhejiang of China. We chose a grave and carried out annular array ERT around the grave mound. The length of the grave mound is 45m and the width is 20m. Because the number limit of electrodes we have, we only set out ‘U’ shape array around the grave mound using 189 electrodes (Figure 10). The color scale of Figure 10
is for the relative elevation.

Figure 11 shows the horizontal slice of the inversion model at the depth of 3m. From Figure 11, we can see the shape and boundary of the grave chamber corresponding to the low resistivity anomalies. Through drilling, the true boundary of the chamber was acquired and marked by the red dashed line, and the black dashed line indicates the boundary of the grave path. We can see the structure recovered through annular ERT is nearly close to true position of the chamber.

Figure 10. ‘U’ shape array for field data acquisition. Figure 11. Horizontal slice of inversion model.

3. Conclusions

It is concluded that the buried archaeological remains under obstacles can be detected and characterized using the annular array ERT. Through the comparison of the results from different number of loops in synthetic examples, we find that the data point distribution has an important influence on final effect. In order to acquire the better result, the enough data points are needed. Also, the distribution of data point should be as uniform as possible. For the primary application in field case, the grave chamber boundary recovered from annular array ERT is nearly close to the true position. So the annular array ERT is an effective technology for the characterization of buried targets under surface obstacles.

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