2.75-D ERT: ZIGZAG ELECTRODE ACQUISITION STRATEGY TO IMPROVE 2-D PROFILES

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Abstract

Although 3-D electrical resistivity tomography (ERT) has been available for more than two decades, its widespread use has been limited by higher data acquisition and processing costs compared to standard 2-D ERT. Alternatively, the viable method of processing 2-D profiles with a 2.5-D approach has overwhelming popularity due to ease of data acquisition and processing. However, 2-D profiles do not account for resistivity variations perpendicular to the profile. This limits the retrieval of valuable information and may lead to biased resistivity profiles for subsurface objects that intersect obliquely with the survey line. In principle we could use 3-D processing to calculate a resistivity solution from the 2-D array. Unfortunately, this leads to inversion results that are symmetric with respect to the profile because the sensitivity pattern for each measurement shares this type of symmetry. We propose an acquisition strategy that has the simplicity of a 2-D profile in terms of work in the field and equipment requirements, but overcomes the symmetry issues of classical 2-D profiles. Rather than along a line, we arrange our electrodes in a zigzag pattern of alternating +/- offset along the y-axis. This approach, which we dub “2.75-D ERT” can be implemented by simply shifting the electrodes away from the center profile in an alternating pattern and does therefore not require any additional equipment or setup in the field. The resulting data needs to be processed with 3-D electrical resistivity code. With modern computers and software this does not pose an obstacle anymore even when only moderate computing power is available thanks to free high-performance programs such as BERT or E4D. In a field experiment, we compare the results of a 2-D array to a zigzag array both transecting a known target at an angle. Unlike the solutions for the 2-D array, our zigzag array captured the known target’s asymmetry with respect to the profile.

Introduction

2.5-D ERT inversions with a linear electrode layout have the advantage of easy field implementation, but they consequently enforce symmetry with respect to the profile. Here we test strategies, in the field, that allow for the reconstruction of the 3-D structure in the vicinity of an electrical resistivity profile without the added equipment or time requirements of a full 3-D or roll-along 3-D approach. Instead of placing the electrodes along a profile line, we propose to lay out the electrodes in a zigzag pattern shown in Figure 1(B). For clarity, we distinguish electrode layouts (line, zigzag, 3-D) from electrode arrays (Wenner, dipole-dipole, etc.). Since both line and zigzag layouts require the same field preparation and both aim to reconstruct the electrical resistivity along, or close to a profile, we define them both as “line type” strategies.

Method

To test our layouts, we selected a survey location that transects a subsurface feature of known orientation on Fresno State campus. Recent excavation is visible as a rectangular contrast in the grass, shown in aerial imagery of the site location (Figure 1). The dots show the location of the 28 electrodes and the red lines represent the cable connections between the electrodes for each type of survey: line (A) and zigzag (B). Profiles were intentionally oriented obliquely to the target (light-green grass) in order to test for bias resulting from linear electrode layouts. For each electrode layout (line and zigzag) we measure a combination of Wenner and dipole-dipole data sets. The 2.5-D solution was obtained utilizing BERT (Rücker et al, 2006; Günther et al, 2006), while E4D (Johnson et al, 2010) was used for 3-D inversions. When using BERT for 3-D inversions we obtained similar results as the presented E4D solutions.

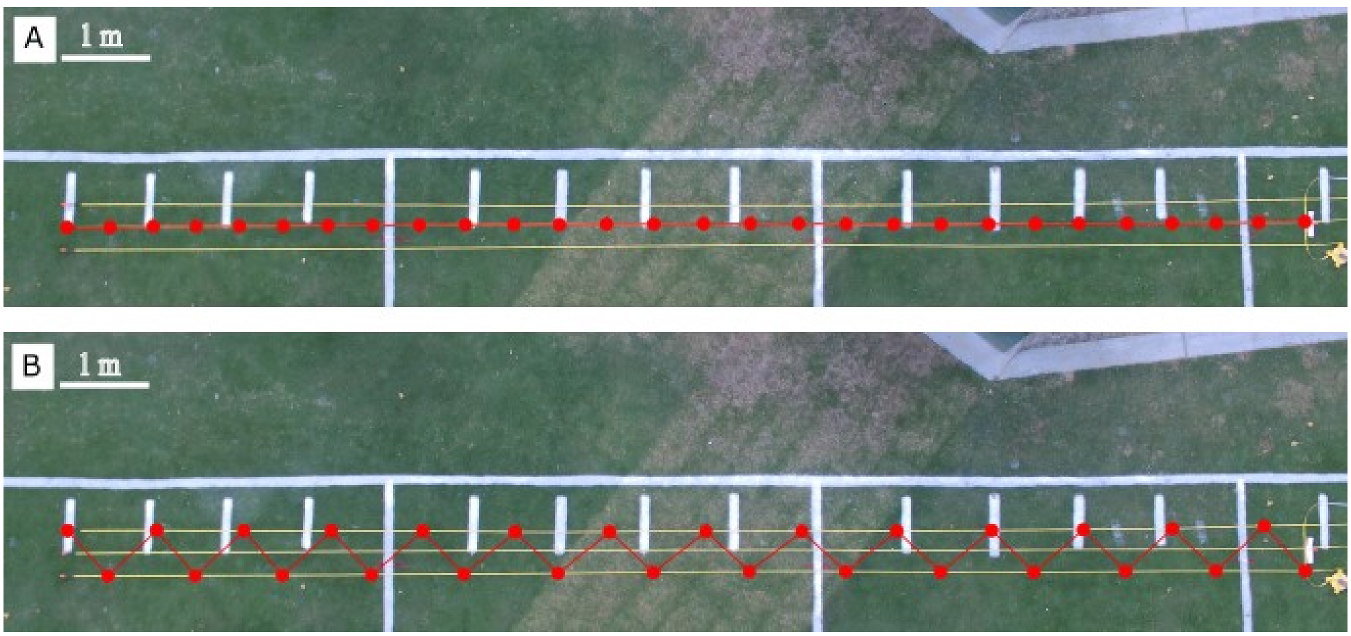

Figure 1: Aerial photograph with drawn electrode layout strategies (red line and dots) at survey location on California State University, Fresno campus. (A) Line with electrode spacing 0.5 m. (B) Zigzag layout achieved by moving each electrode away from the profile in an alternating fashion. Electrode offset distance from profile is 25 cm, distance between electrodes is (0.5^2+0.5^2)^(1/2). The light-green strip cutting across our profile between the 7-th hash mark and the 10-th hash mark resulted from recent excavation and reburial with fresh soil.

Results

In Figure 2 we present the profile resulting from a 2.5-D inversion of the combined Wenner and dipole-dipole data collected using the line electrode layout illustrated in Figure 1(A). In this profile we observe distinct resistivity contrasts between 6.4 m and 7.6 m (conductive) and 10.8 m and 11.7 m (resistive), both at a depth of 0.5 m. Since the excavation crosses the profile near 5.6 m and 8.6 m, we interpret the conductive feature as backfilled soil from recent construction. The resistive region near 11 m coincides with the increasing proximity to various surficial structures including an electrical utility box and a parking lot.

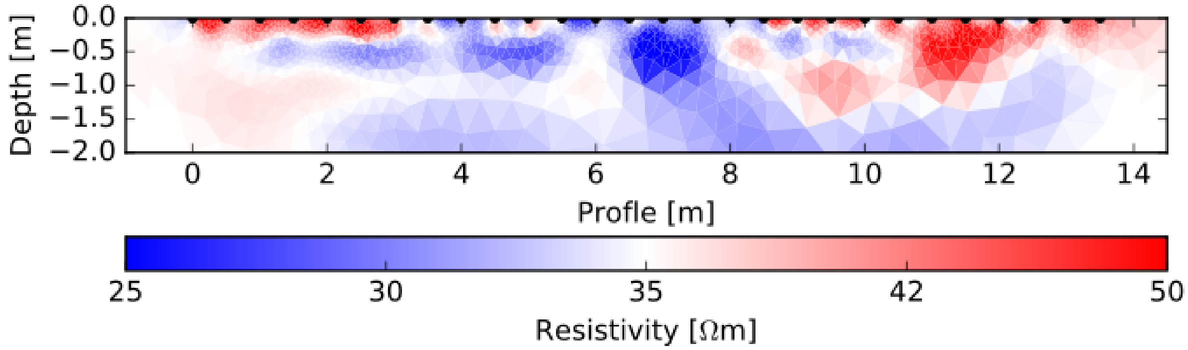

Figure 2: 2.5-D inversion result of the combined data using Wenner and dipole-dipole electrode arrays for the line electrode layout (Figure 1A). Inversion performed using standard inversion settings in BERT (Rücker et al, 2006; Günther et al, 2006).

The 2.5-D approach succeeds in determining the location at which the subsurface object intersects the profile line, but, due to its 2-D nature, fails to reconstruct the angle of intersection. For this, we would require 3-D inversions. In Figure 3, we present the 3-D results for the two electrode layout strategies shown in Figure 1: “line” (A) and “zigzag” (B). The sections overlying the aerial photographs of the survey site show the resistivity results at 0.5 m depth. As in Figure 2, the resulting resistivity shows a conductive region near 7 m along the profile and a resistive feature near 11 m. We interpret these as the same structures identified in Figure 2. The difference between Figure 3(A) and Figure 3(B) is that, while in Figure 3(A) all features are symmetric with respect to the profile, the conductive and resistive features discussed earlier show asymmetry with respect to the profile line in Figure 3(B). We observe that the conductive feature in Figure 3(B) is aligned with the light-green strip in the aerial photograph. They are both directed in a top-right to bottom-left orientation. The resistive feature in Figure 3(B) concentrates closer to the parking lot and electrical utility box.

Figure 3 illustrates the advantages of a zigzag approach. The symmetry of the 3-D inversion result in Figure 3(A) does not stem from artificial restrictions, as would be imposed by a 2.5-D inversion approach. Rather, the sensitivity pattern of each single measurement along the profile has the same symmetry. The measurements as a collective can therefore not distinguish on which side of the profile a resistivity contrast resides. The zigzag layout strategy overcomes this problem because each measurement has a different direction of symmetry. By using the zigzag approach, we allow for the 3-D reconstruction of the subsurface resistivity along a narrow band around the profile.

Conclusions

We compared three electrical resistivity tomography field / inversion approaches cutting across a feature with known three-dimensional orientation. Our first investigation comprised 2.5-D electrical resistivity inversion of data collected with electrodes laid out in a linear fashion. Our second investigation used the same data set as the first investigation but instead of 2.5-D inversion we used 3-D inversion. In our third investigation, we again used 3-D inversion but instead of setting up the electrodes along a line we set them up in a zigzag pattern of alternating offset with respect to the profile line. We observed that this simple tweak in the field allowed us to reconstruct, in our inversions, the 3-D orientation of the known feature. Compared to a 3-D "U-shape" electrode layout, the zigzag layout does not reduce the number of electrodes along the profile and does not require a significantly longer cable to map the same profile length as a linear array. Considering that such a zigzag layout only requires minimal change in an electrical resistivity set up and that high-performance 3-D electrical resistivity software is freely available, we see no disadvantages in moving away from traditional profile 2.5-D ERT investigations in favor of zigzag profile 3-D investigations.

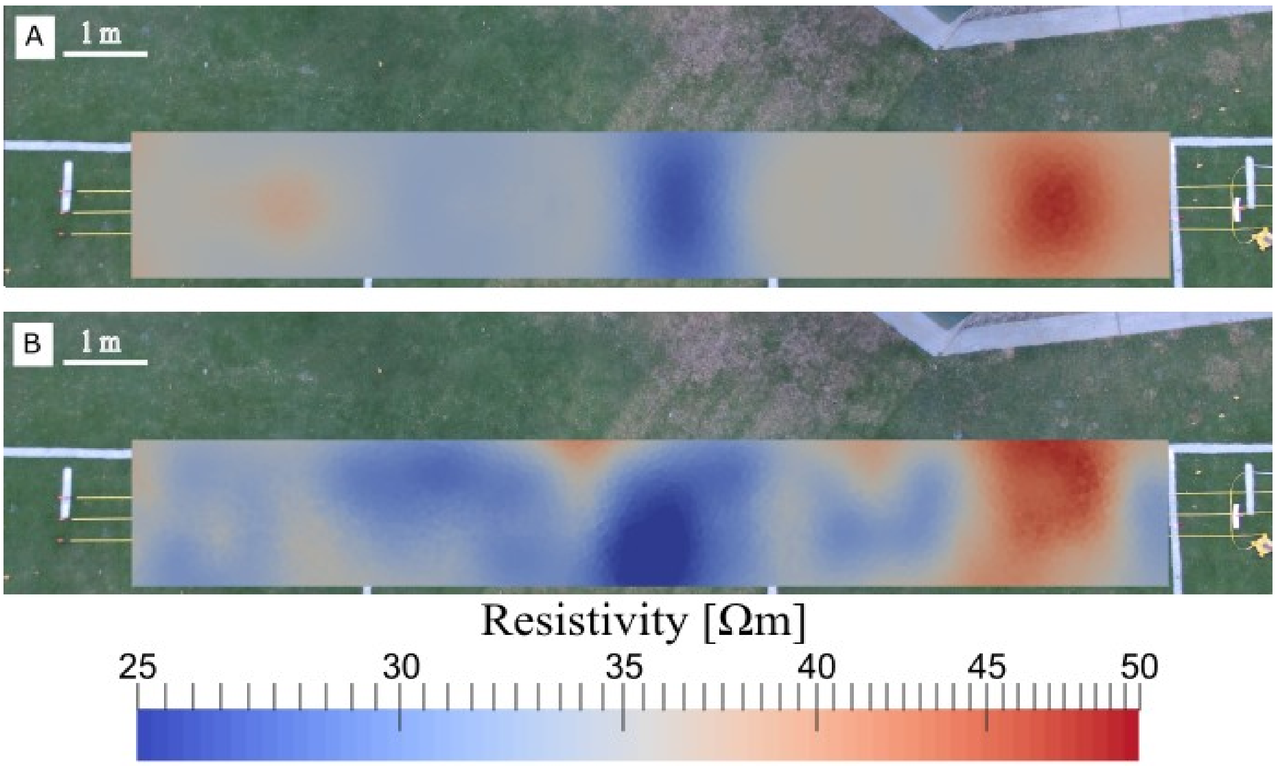

Figure 3: 3-D results of combined Wenner and dipole-dipole datasets using E4D (Johnson et al, 2010). (A) Result using electrodes aligned along a line profile. (B) Result using electrodes set up in a zigzag profile. Both 3-D results are shown as a slice at 0.5 m depth and were trimmed to show the tape measures. Top panel result (line) correctly reconstructs the presence of the known target but not its 3-D structure. Bottom panel result (zigzag) correctly reconstructs presence and orientation of the target.

References

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