Present a Proper Pattern for Choose Best Electrode Array Based on Geological Structure Investigating in Geoelectrical Tomography, in order to Get the Highest Resolution Image of the Subsurface

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Abstract

Each electrode array applicable for electrical tomography of subsurface has some merits and demerits, and so selection of each array is based on the situation of data acquisition, background noise level, and target geological structure (in other word, electrical specification of structure, and shape of disturbing body), because resolving power and depth of penetration of each electrode array are different in various geological structures. By exact study on behavior and specifications of each array, we can estimate that in each geological structure, which electrode arrays have high accuracy in detection of anomalous bodies, and which one doesn't. By the way, to safe interpretation of data, we require to have complete knowledge on resolving power and noise sensitivity of each individual array. In this research, by numerical modeling we analyzed behavior of seven electrode arrays which are popular in geoelectrical surveys, consisting: Pole-Pole, Pole-Dipole, Dipole-Dipole, Wenner Alpha, Schlumberger, Wenner Beta, and Half Wenner. We investigated these arrays on the four geological models, which simulating buried channel, thin conductive dyke, thin resistive dyke, dipping blocks. These synthetic models represent various kinds of geological structures. Finally the results of this research are as follows in brief: (1) WN, WB arrays have less noise contamination than other arrays, although their low noise rate couldn't produce high resolution image. (2) The sequence of Arrays DD, PD, SC (although Schlumberger has some edge effects) yield best resolution image than others, and consequently these electrode arrays is highly recommended for accomplishing of geoelectrical tomography. However, the final choice of electrode array will be done with considering geology of target structure, field remarks and logistical considerations.

Introduction

Technique of DC electrical resistivity surveying, is a method of investigating of subsurface, that is widely used in groundwater exploration, civil engineering, mining exploration, investigating of Archeology sites , and more other targets. This technique is very popular, because of its simple physical background, using some systems with not very complicated design. Traditional resistivity surveying methods are resistivity sounding method (VES), and resistivity profiling method (HES), which are one- dimensional methods, and they probe the subsurface, in only one dimension, vertical or horizontal. The novel methods of resistivity sounding, is 2d or 3d. In 3d method, we require too many numbers of observed data, in order to get volumetric image of the earth. According to, the 3d method is very time consumer, and

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expensive through the high amount of observed data, so, 2d method, in other words, 2d electrical tomography method, is best choice for having agreement between surveying costs and precision of the information we are gathering. In the past years, good developments have been done in computerized methods of modeling and inversion routines, and have been produced some efficient softwares as well as new developments in data acquisition systems for execute geoelectrical tomography surveys in exact and rapid manner. In the past years several electrode arrays, have been used in geoelectrical surveys, but the arrays we introduced in figure 1, are more commonly used in various aspects of geoelectrical tomography usage. They are Wenner (WN), Wenner beta (WB), Pole-Pole (PP), Pole-Dipole(PD), Dipole-Dipole(DD), Schlumberger (SC), and Half Wenner (HW). WB is a special case of DD and WN is a special case of SC, [1], [2], [3]. Each electrode array, have its own limitations and advantages in field operation and interpretation capabilities. From tomography point of view, there might be different abilities for these arrays, when they are applied to different geological structures, differences in tendency to produce untrue realistic structures in the resultant model. Differences in sensitivity to background noise, signal to noise ratio, and anomaly effect, differences in interpretable maximum depth of investigation, and finally, differences in resolution of the images reconstructed in geoelectrical tomography. There have been some investigations about mentioned differences of the arrays. For example, Sasaki at 1992 synthetically compared the resolution of cross-hole resistivity tomography using PP, PD and DD arrays [4]. He suggested that DD surveying, when the instrument accuracy is high, is more suitable for resolving complex structures than the PP array, and that PD may present a good compromise between resolution and signal strength. Oldenburg and Li at 1999, analyzed the 'depth of investigation', observed the different depths of penetration achieved by PP, PD and DD arrays in the inverted models [5]. Dahlin and Loke at 1998, and Olayinka and Yaramanci at 2000, respectively, examined the imaging resolution and reliability of WN array [6], [7].

In order to obtain a reliable high-resolution image, the electrode array used, should ideally give data with the maximum anomaly information, reasonable data coverage and a high signal-to-noise ratio. From figure 1, we can see that, except for WN, WB and PP, the arrays have many combinations of the parameters *a,* and *n* which can be adapted depending on the required spatial resolution, penetration depth and background noise at a field site. Parameter *a,* is minimum electrode spacing, and parameter *n*, is array expanding factor, [8]. In general, a larger spacing *a,* and larger *n* gives relatively information about the deeper parts of earth's structure, while a small spacing *a,* or small *n* may offer relatively good horizontal resolution for the shallower sections of the ground.

We investigated behavior of mentioned electrode arrays by numerical modeling and inversion scheme, via getting geoelectrical images from four structure models, which simulate various geological situations in practice. Also we compared level of noise contamination between mentioned electrode arrays.

Simulated Geological Structures

We designed four geological models (see fig. 2), in order to investigate the behavior of electrode arrays. These models represent various geological situations in real works. The first model simulates a buried channel of coarse-grained sediments, and geologically, this model simulating an old river in clayed environment with covering of sediments (fig. 2a). That consists of a 2.5 m thick upper layer of resistivity 70 Ωm which is decreases its diameter in the right hand. This upper layer overlaid on the main layer of resistivity 30 Ωm, which is implanted a trapezoidal structure of resistivity 200 Ωm inside it, with maximum depth of 11 meters. The second model is a narrow resistive dyke with an overburden (fig. 3b). It consists of 2 meter wide vertical dyke of resistivity 300 Ωm in a low resistivity environment (50 Ωm) with a 2.5 meters thick overburden of resistivity 200 Ωm. This model geologically, simulates a resistive intrusive dyke in sedimentary rocks, with cover of sediments. The third model is a narrow conductive dyke with an overburden (fig. 3b). It consists of 2 meter wide vertical dyke of resistivity 50 Ωm in a high resistivity environment (1000 Ωm) with a 2.5 meters thick overburden of resistivity 200 Ωm. This model simulates a fractured or weathered zone in crystalline rocks, with cover of sediments. The last model (fig. 3c) is some dipping blocks of different width, under a covering layer of 200 Ωm. Resistivity of sequence of dipping blocks are 100 , 300 Ωm alternatively. This model simulates a tilted sequence of sedimentary rocks under a layer of till or coarse-grained sediments.

Noise Sensitivity of electrode arrays

The actual errors that our data encounter with them in a real geoelectrical work are combination of observation errors, as well as modeling errors due to 2d modeling of 3d earth, anisotropy, limitations of forward modeling, and non-linearity of inverse problem. Among mentioned forms of errors, we analyzed observational errors which are produced when we are observing electrical potential because background noise is in same kind of observing potential. As each array has different sensitivity to potential, so noise sensitivity of each array will be different, and each groups of data that every array is producing, will be contaminated by different noise level. After study on behavior of potential observing errors, it has been realized that as observed potential amplitude decrease, degree of noise contamination of data will increase by a power, as follows: $\beta = (c_1 / U)^{c_2}$ where β denotes percentage of absolute relative error of observed potential; U is potential readings; and c_1 , c_2 are positive constants that depends on data acquisition place and time. Consequently, resulted noisy data will be as follows: *Noisy data* $= U(1+R)\beta/100$ where U denote potential readings; R is a random number. By assigning different values for c_1, c_2 we can simulate different noise levels, [9]. Figure 3 is an instant for different levels of noise contamination of each array data which has been simulated over conductive dyke model. We can see that, as potential amplitudes decrease, noise value increases. Also from this example, from point of view of noise contamination, we can categorize the arrays in a descending order of being noisy, as follows: DD, PD, WB, HW, SC, PP, and WN. At this study, we added 20 percent synthetic random noise to raw potential data which has been produced with forward modeling package was developed in MATLAB.

Electrical tomography surveys over defined geological models

We produced observed data for every electrode arrays over four defined geological structure models, via adding random noise to raw data which had been obtained by forwards modeling package. Then all of data inverted by RES2DINV inversion package and used smoothness-constraint least square inversion method to invert data, [10]. Figure 4 represents models of **buried channel** (first structure), that obtained from inversion of synthetic data gathered over mentioned structure. Data of each individual array has different rate of noise contamination as, it varies from 10.6 % noise level for WN, up to 19.4% noise level for DD array. Relatively, we can categorize arrays in terms of their yielded resolution of image gathered from buried channel model in descending order, as follows: PD, HW, DD, SC, WN, PP, and WB, where end of sequence has very low resolution. It can be seen that, although relatively low noise contamination of WN and SC, but they yield relative low resolution image than PD, DD and HW. Also in DD, because of its very high level of noise, appears some low resistive zone in the bottom of inverted model. Figure 5 shows inverted models for **thin resistive dyke** (second structure) obtained via our seven arrays. At this group of models, noise contamination rate is lower than other structures also similar to last group, WN array owns minimum noise level of 4.8%, and DD has maximum noise level 8.6%. PP and HW arrays have poorly resolved the geometry of the dyke, than other arrays. Maximum resolution of image is for DD and PD arrays. WN, SC and WB have mediocre resolution. Consequently, we can categorize these arrays in terms of their resolution in descending order: DD, PD, SC, WN, WB, HW, and PP. In figure 6 we see inversion results for each seven array data over thin conductive dyke. In this structure, noise level is higher than resistive dyke. Same as other structures, WN has minimum noise (12.8%), and DD has maximum noise level (24.4%). PP has failed because it has very low resolution, and it cannot show width of the dyke correctly as well as upper layer. Also SC and WN have relatively poor resolution at showing upper layer. DD, PD and WB have good resolution in resolving both of dyke and upper layer. So we can categorize arrays in following sequence, that the array at end of list has poor resolution: DD, PD, HW, WB, SC, WN, and PP. Inverted models of last structure (dipping blocks of sedimentary rocks), has been shown in figure 6. Arrays of DD and PD although have high noise level, but they represent good resolution, that dipping of blocks can be recognized in image. Also there are some artifacts in their image, that they can be result of high noise degree. SC and WN have lower resolution than DD and PD, also resolution of SC is better than WN; however SC has some edge distortion. WB array didn’t give good image, that dipping blocks could not be identified. Also PP array give poor resolution, as resistivity of blocks was poorly identified, but there are very little artifacts in the image instead. HW is better than SC, WN and WB. We can categorize the arrays in descending order as follows: DD, PD, HW, SC, WN, PP, and WB.

Conclusion

As we see in this research, every electrode arrays has different sensitivity to measure potential. Naturally, each one that is more sensitive will be more contaminated with potential dependent noise. In other word, electrode arrays noise contamination is born of their sensitivity to potential measuring power. Also, we see that in some arrays such as WN and SC, vertical resolution is dominated to lateral resolution. In some other arrays such as DD and PD, vertical resolution is dominated to lateral resolution. Consequently we must consider this fact before choosing electrode array, depends on geological target of geoelectrical survey. By the way, every array have differences in resolving power, anomaly effect and level of noise contamination (in other words signal to noise ratio). So we must truly know each electrode array in order to choose best array according to geological target and field site considerations. At this research we realized that low degree of noise, or high anomaly effect of some arrays, necessarily doesn’t coincide with high resolution image. Majorly, DD and PD arrays are most contaminated with noise than others, and WN and WB are least contaminated than other arrays. Finally, we recommend in sequent DD, PD and SC arrays for using in 2d geoelectrical tomography surveys because of their good resolution of image, however DD and PP have high noise level, and SC has some edge effects. But we must attention that final choice of electrode arrays must be with regarding of target geological structure, type of information we look for, background noise, and our facilities and field situation and logistics.

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Appendixes:Figures

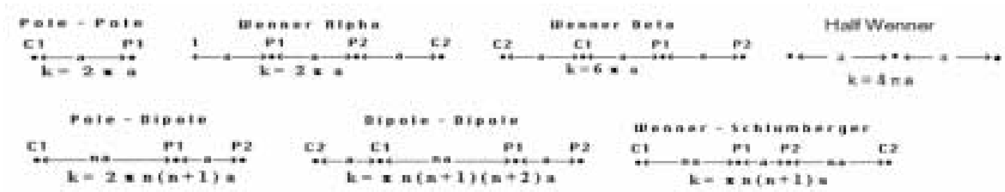

Figure 1: Common electrode arrays used in geoelectrical surveys, and their geometric factors. *a* is minimum electrode spacing (dipole length), *n* is dipole separation factor (array expansion factor). C1, C2 are positive and negative current electrodes, P1, P2 are potential electrodes.

Figure 2: Synthetic geological structures consist of buried channel, conductive and resistive dyke, and sequence of dipping blocks.

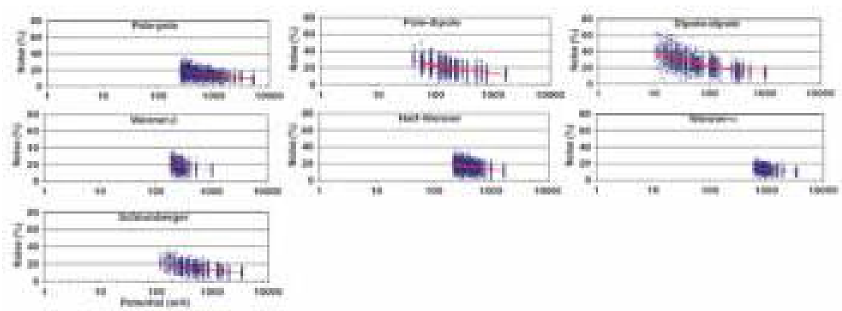

Figure 3: Level of noise contamination of each electrode array data over conductive dyke model.

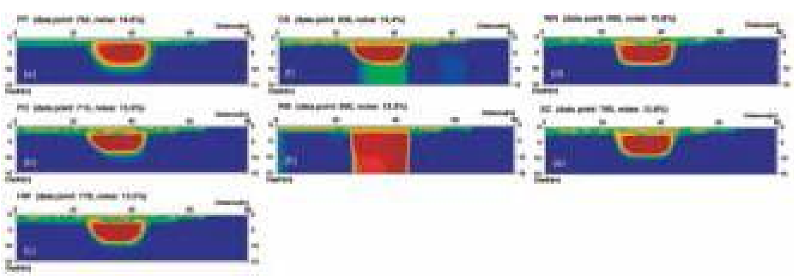

Figure 4: inverted models obtained from inversion of synthetic data gathered over buried channel structure.

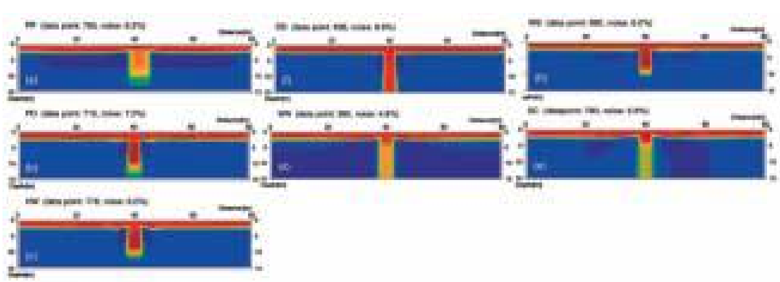

Figure 5: inverted models produced for thin resistive dyke, through inversion of data of each array.

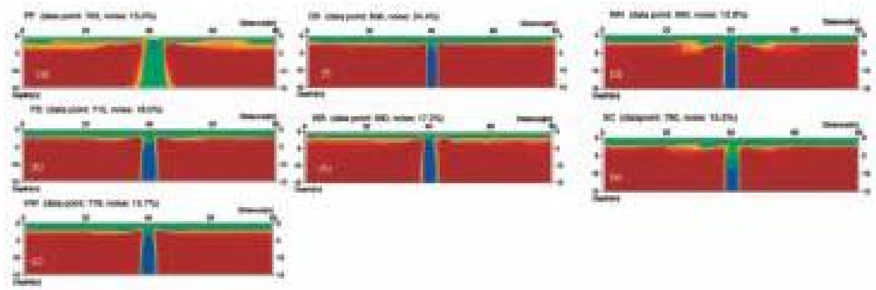

Figure 6: inversion results of seven electrode arrays data gathered on conductive dyke model.

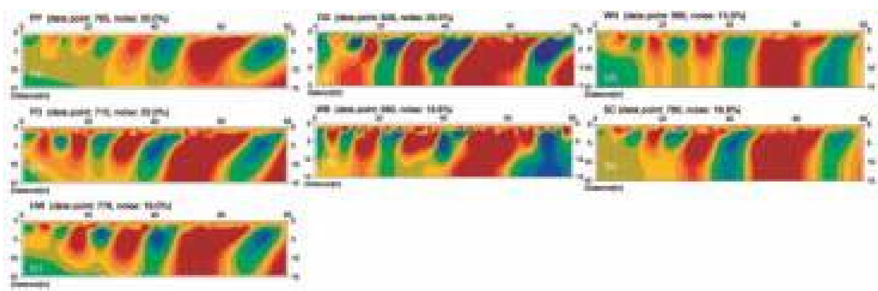

Figure 7: inversion results of used arrays data over model of dipping blocks.