MALAYSIAN JOURNAL OF SCIENCE
MJS
ISSN 1394-3065

Regular Issue

Malaysian Journal of Science 45(2): 55-61 (June 2026)

https://mjs.um.edu.my

Examine Horizontal Resolution of Dipole-Dipole Array Using Synthetic Models Of 2D and 3D Tomography Techniques

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Abstract: The horizontal resolution of the array is the most important factor in accurately mapping subsurface features and ensuring reliable geological interpretations in electrical resistivity surveys. Therefore, six two-dimensional (2D) and three-dimensional (3D) synthetic models were used to assess the horizontal resolution of the Dipole-Dipole array. In each synthetic model, two identical structures with a resistivity of 100Ωm are embedded within a medium of 30Ωm. The horizontal distance between the structures is varied between 2m, 3m, and 4m. The results revealed that the Dipole-Dipole array shows difficulties in delineating the exact location and size of the structures. It provides a distorted image of the structures' locations. It shows better resolution with 2D inverse models compared to 3D inverse models when the horizontal distance becomes small. The sensitivity of this array to the horizontal change in resistivity is increased when the distance between the structures is increased. In the 3D inverse models, Dipole-Dipole array generated a distorted image of the structures when the horizontal distance between the structures is small, while it provides reasonable images when the distance between the structures is increased. So, for investigating a subsurface horizontal structure that is separated with small distances, 2D tomography technique is a better approach than 3D tomography technique when using Dipole-Dipole array.

Keywords: *Horizontal Resolution; Dipole-Dipole Array; 2D and 3D Tomography Techniques.*

1. Introduction

At the present time, the 2D and 3D resistivity techniques are considered the most important techniques of the electrical resistivity method that are mainly used for exploration of the shallow underground structures (Kemna *et al*., 2002; Zhou *et al*., 2004; Loke *et al*., 2013; Al-Zubedi and Thabit, 2016, Al-Awsi & Abdulrazzaq, 2022). These techniques are usually carried out using different electrode arrays, for example, Wenner, Wenner-Schlumberger, Dipole-dipole, Pole-dipole, and Gradient arrays. Various factors, including the target depth, the array's sensitivity function, the array's resolution, the sensitivity of the resistivity meter, and the background noise level, influence the selection of the optimal array for 2D and 3D imaging surveys (Roy and Apparao, 1971; Loke, 2012; Al-Zubedi and Abdulrazzaq, 2025). Accordingly, there have been many studies carried out to determine the best array's response in delineating targets within different situations (Zhou *et al.*, 2002; Dahlin and Zhou, 2004; Tamssar, 2013; Al-Hameedawi, 2013; Thabit and Al-Zubedi, 2015; Al-Zubedi, 2016; Al-Khersan, *et al., 2016*). These studies showed that Dipole-Dipole array has the ability to offer the best resolution and highest sensitivity to target details for a shallow investigation compared with other arrays. On contrary, Wenner-Schlumberger is superior than other arrays for deep investigation. In studies conducted in Malaysia, the Enhancing Horizontal Resolution (EHR) technique significantly improves horizontal resolution in 2D resistivity studies by optimizing data acquisition and inversion processes. This technique allows for deeper penetration and more detailed imaging of subsurface structures. The technique has been validated against borehole data, confirming its effectiveness in accurately mapping subsurface structures (Nordiana et al., 2013; Nordiana et al., 2014).

The dipole-dipole is the array that is most commonly utilized for 2D and 3D tomography techniques, as it is easy to apply in fieldwork. The distance between the current and potential electrodes in this array is known as the n-factor, whereas the spacing between the current electrode pair, AB, is provided as (a), which is the same as the distance between the potential electrode pair, MN. The n-factor controls the depth of investigation and noise level, as with a large n-factor, Dipole-Dipole array will gain more noisy data because of low signal strength Alpine (1950; Kunetz (1966); Keller and Frischknecht (1966) ; Look (2020).

Dahlin and Zhou, (2004); Chitea and Georgescu, (2009); and Loke, (2020), indicated that the Dipole-Dipole array is sensitive when lateral resistivity variation is encountered. Therefore, it is the best choice when mapping vertical structures. However, in mapping horizontal structures, such as sedimentary layers, it is relatively poor. This means that the Dipole-Dipole array has a good horizontal resolution compared to vertical resolution, as it is resolution decrease with a depth.

The resolution of electrical arrays is the ability to distinguish variations in electrical resistivity. This is based on electrode

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Received: April, 2025
Accepted: June, 2025
Published: June, 2026

DOI:https//doi.org/10.22452/mjs.vol45no2.6
Malaysian Journal of Science 45(2):55-61 (June 2026)

spacing and spatial locations, so that the two targets can be separately recognized instead of being one target. Further, the resolution can be classified into two kinds, vertical and horizontal resolution. Vertical resolution is the ability of the array to distinguish two targets located at different depth levels. Conversely, horizontal resolution describes how two neighboring targets can be positioned horizontally and still be distinguished as two distinct targets as opposed to one (Kallweit and Wood, 1982).

This study will evaluate the Dipole-Dipole array's horizontal resolution through synthetic models to examine its ability in defining shallow buried structures that are separated horizontally using 2D and 3D tomography techniques.

2. Materials and Methods

Horizontal resolution of arrays is a critical parameter in geophysical surveys. The purpose of the present research is to estimate the resolution of dipole-dipole arrays related to the horizontal discontinuity based on the synthetic models using two-dimensional and three-dimensional tomography techniques. The models used were built with contrast rectangles representing an anomalous body in a uniformly layered Earth model. The middle depth position of the rectangle is taken as the level of the array setup called the observation position. A somewhat different approach related to the array position was chosen for the presentation of a different electrical nature. Synthetic models are an integral part of advances in different fields. These models help to understand and interpret the data and methodologies. Tomography is an ill-posed inverse problem that retrieves subsurface geophysical parameters using the observed data. Different tomography techniques use different mathematical approaches. Hence, one can use different synthetic models to test the behavior and capability of these techniques. Various models such as 1D, 2D, 2.5D, and 3D setups are used in the tomography technique based on the availability of data. The effect of the complexity of the model on the desired resolution can be calculated easily by testing the technique on these synthetic models.

In order to determine the horizontal resolution of Dipole-Dipole array in 2D and 3D tomography techniques. Six synthetic models are prepared to represent two buried structures. The synthetic models were created using the 2D and 3D forward modeling software RES2DMOD and RES3DMOD (Al-Zubedi and Thabit, 2015).

Three 2D resistivity synthetic models were designed with a survey line of 35 m long and minimum electrode spacing of 1 m. In these synthetic models, two identical structures were built. The width and the height for each one are 2m, while their resistivity value is set to be 100 Ωm. These structures are embedded within a host medium characterized by a resistivity of 30 Ωm (Fig. 1). In this case, this host medium may represent sand materials. For the 2D synthetic model, the horizontal distance between the two structures is set to be 2 m, 3 m, and 4m. Figure (1), shows the 2D synthetic model of the two structures when the horizontal distance is 2 m.

As shown in the 2D synthetic models, the same resistivity values for the structures and the host medium are used to create the 3D synthetic models. Further, the same horizontal distances of 2m, 3m, and 4m between the structures are used for the 3D synthetic models. To build the 3D synthetic models, the distances between the structures are changed in the x-direction to be 2m, 3m, and 4m, while the distance in the y-direction remains fixed. Figure (2) shows a 3D synthetic model of the horizontal structures when the distance between them equals 2m, and they are 1.6 m thick.

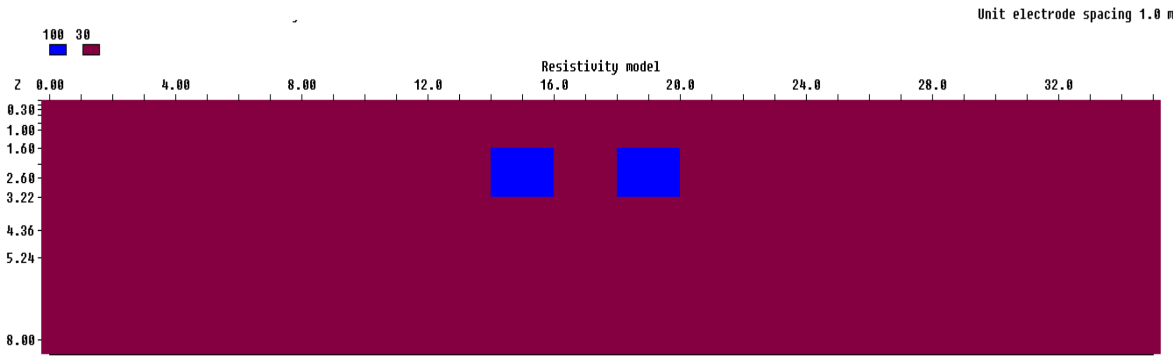

Figure 1. The 2D synthetic model of the two structures when the horizontal distance is 2 m.

DOI:https//doi.org/10.22452/mjs.vol45no2.6
Malaysian Journal of Science 45(2):55-61 (June 2026)

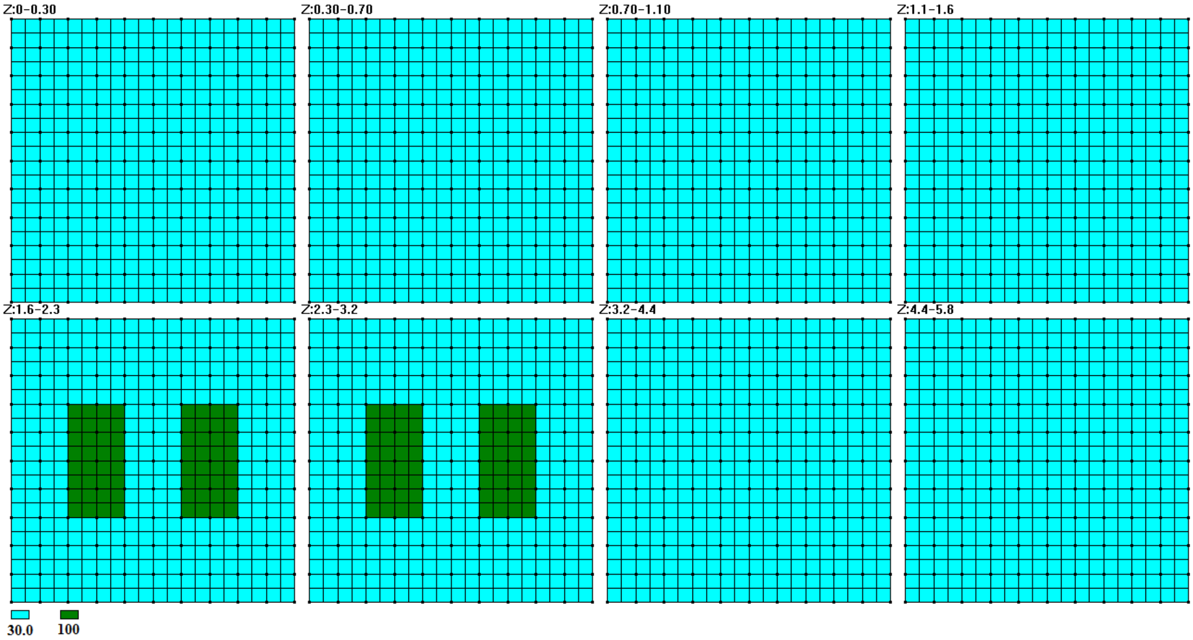

Figure 2. 3D synthetic model of horizontal structures with (2m) distance.

3. Results and Discussion

After synthetic models are created, the apparent resistivity measurements are calculated for each synthetic model. These measurements are carried out on the basis that the n-factor is 8a while the a-spacing is varied between 1a to a maximum spacing of 12a. This procedure allows for performing a higher resolution and a maximum investigation depth. Because of Dipole-Dipole array has a very weak signal strength when the distance between current and potential electrodes becomes very large (Dahlin and Zhou, 2004; Chitea and Georgescu, 2009; Loke, 2020), random noise of 5% is added to the collected data.

The 2D inverse models are created using the RES2DINV ver. 3.59 Software, by the L1 norm (robust) inversion method. This method is useful when there are sharp variations between resistivity values due to sharp boundaries between the buried structures. The inversion reduces the absolute values of the data misfit (Claerbout and Muir, 1973; Olayinka and Yaramanci, 2000 and Loke et al., 2013). Al-Zubedi, (2016) confirmed that the robust inversion method can give the best boundary resolution results for buried walls that have sharp geologic boundaries, while investigated by the Dipole-Dipole array. Therefore, this method will improve the horizontal resolution of the Dipole-Dipole array and help in identifying the buried structures.

At a horizontal distance of 2m between the buried structures, the inverse models of the Dipole-Dipole array successfully identify the left-hand buried structure. The right-hand structure is determined also, but its location is less accurate as it appeared under electrodes 19-21 (or the distance 18m-20m). The inverse model shows a misfit error of 3.8%. The Dipole-Dipole array is able to identify the two structures separately instead of being to appear one structure concerning the minimum distance (Fig. 3).

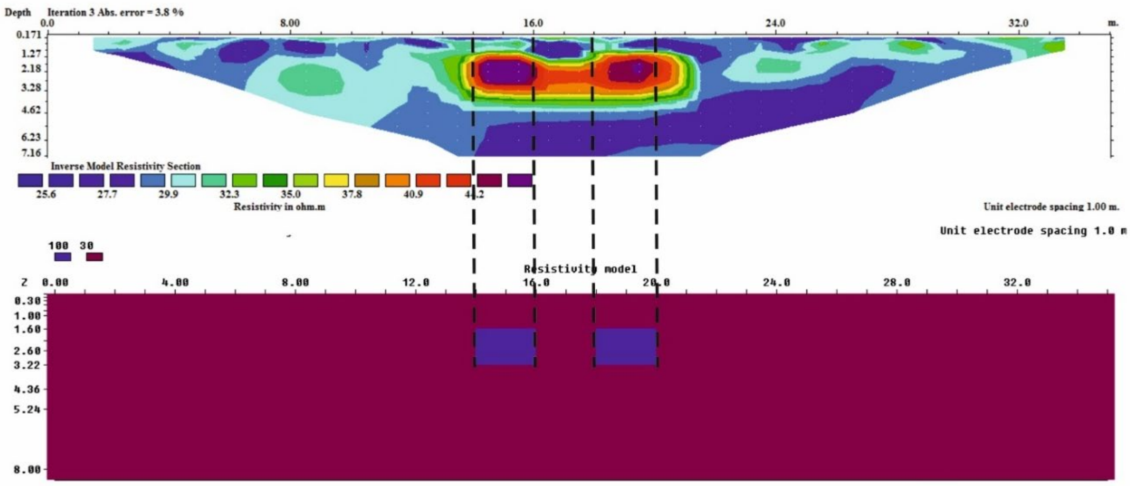

Figure 3. The inverse and the 2D synthetic model of the structures when the horizontal distance is (2m).

DOI:https//doi.org/10.22452/mjs.vol45no2.6
Malaysian Journal of Science 45(2):55-61 (June 2026)

The second and third inverse models, which derived from the second and third synthetic models of 3m and 4m horizontal distance between the buried structures, are not successfully delineating the right-hand structure that occurs under electrodes 19-21 (Fig. 4, and 5 respectively). They provide a distorted image of the location of the right-hand structure. The misfit error of both inverse models is 3.8% after three iterations. This indicated that the Dipole-Dipole array has difficulties in delineating the exact size and location of the buried structures. Accordingly, the Dipole-Dipole array is indeed sensitive to changes in resistivity that occur horizontally. This array still has the ability to identify both structures when the horizontal distance between the buried structures is changed from 2m to 4m.

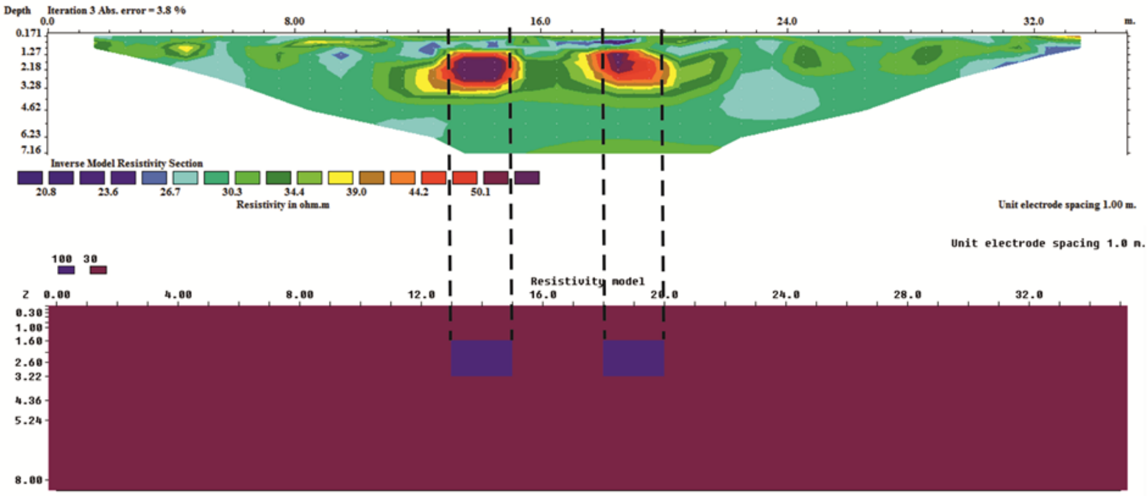

Figure 4. The inverse and the 2D synthetic model of the structures when the horizontal distance is (3m).

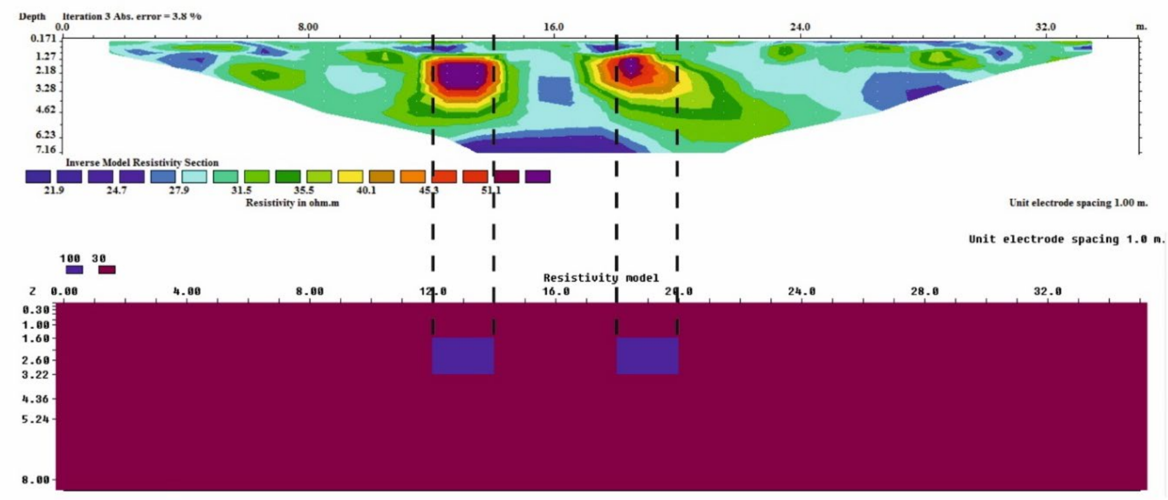

Figure 5. The inverse and the 2D synthetic model of the structures when the horizontal distance is (4m).

For the 3D inverse models, the apparent resistivity measurements are derived from the 3D synthetic models after adding 5% random noise. The 3D inverse models are created using RES3DINV ver. 3.18.2 software. When the horizontal distance between the structures is 2m, the 3D inverse model of the Dipole-Dipole seems incapable of delineating the buried structures. It shows a distorted image of the size and location of these structures. Both are merged and appeared as one structure (Fig. 6). This indicates that the Dipole-Dipole has a lower resolution and incapable of imaging the underground structures when the horizontal distance between the buried structures is small as compared to the electrode spacing used for the survey. Finally, this 3D inverse model shows a misfit error of 3.49% after three iterations.

The 3D inverse model with a 3m horizontal distance between the buried structures does not provide a very obvious image of the two structures. It partially successes in delineating the structures, but it was not able to recognize the shape and the size of the right-hand structure under electrodes (8-10) (Fig. 7). It is relatively delineated by the left-hand structure. Furthermore, it successfully recognizes and separates the buried structures. This inverse model shows a misfit error equals to 3.58%. The 3D inverse model of the Dipole-Dipole array when the horizontal distance between the structures is 4m, successfully determines the two structures, but their sizes and shapes look smeared. The

DOI:https//doi.org/10.22452/mjs.vol45no2.6
Malaysian Journal of Science 45(2):55-61 (June 2026)

right-hand structure is delineated better compared with the previous models (Fig. 8). It is indicated that the resolution of this array is increasing when the horizontal distance between these structures is increasing. This array can provide reasonable images for subsurface structures.

The theoretical results showed that the inverse models yield resistivity values lower than the actual ones. All models depicted the resistivity of the structures as less than 100 Ω·m, whereas the true resistivity of each structure is 100 Ω·m. This discrepancy arises from the calculation method used by the software to compute resistivity values within the inverted model. Therefore, the resistivity values in the inverted model do not accurately represent the true resistivity of the underground structures.

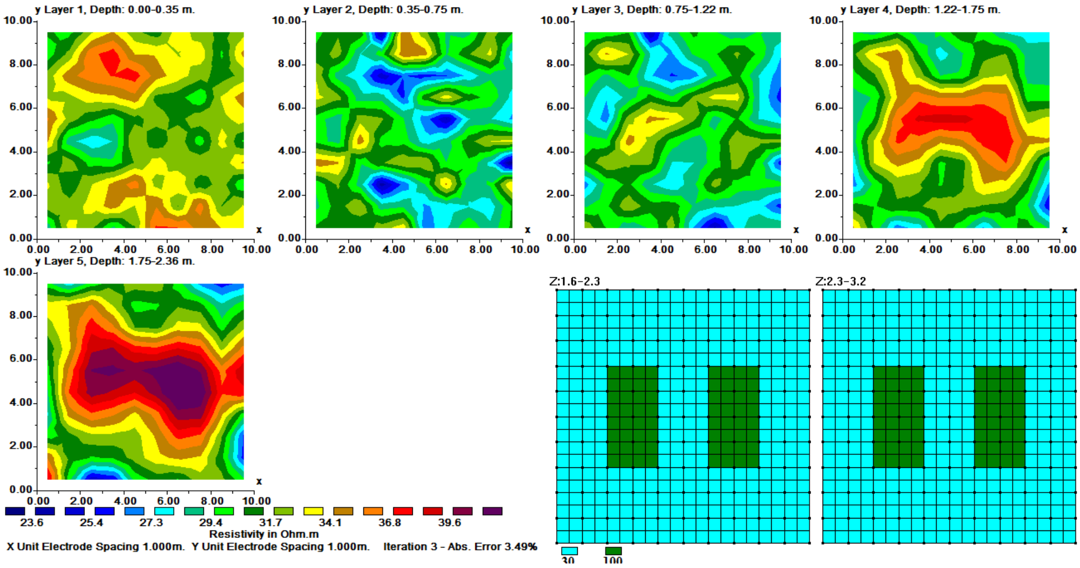

Figure 6. The inverse and synthetic 3D model for structures when separated by (2m).

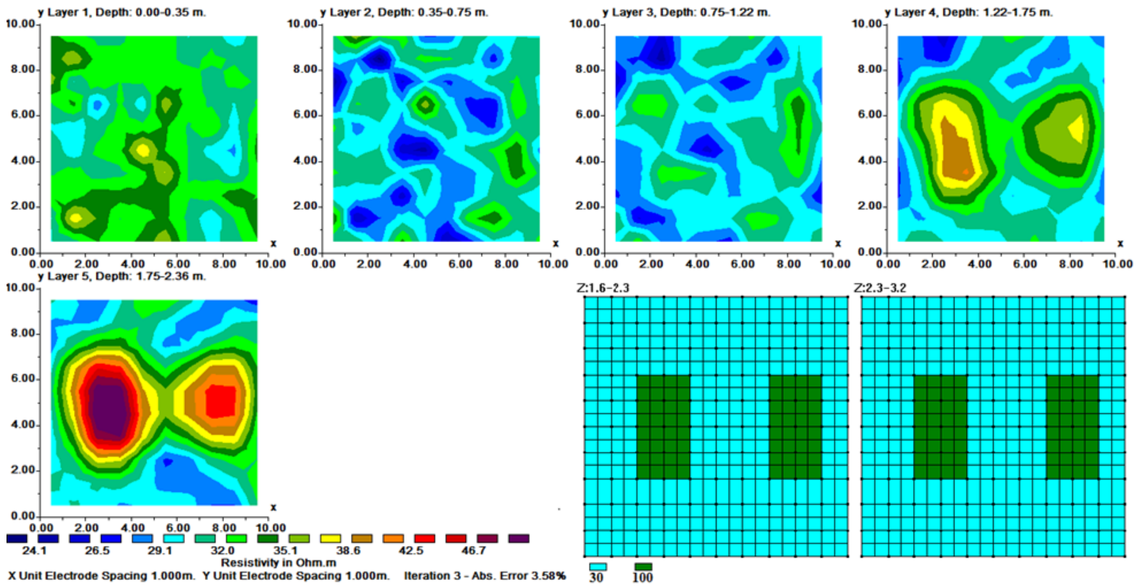

Figure 7. The inverse and synthetic 3D model for structures when separated by (3m).

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Malaysian Journal of Science 45(2):55-61 (June 2026)

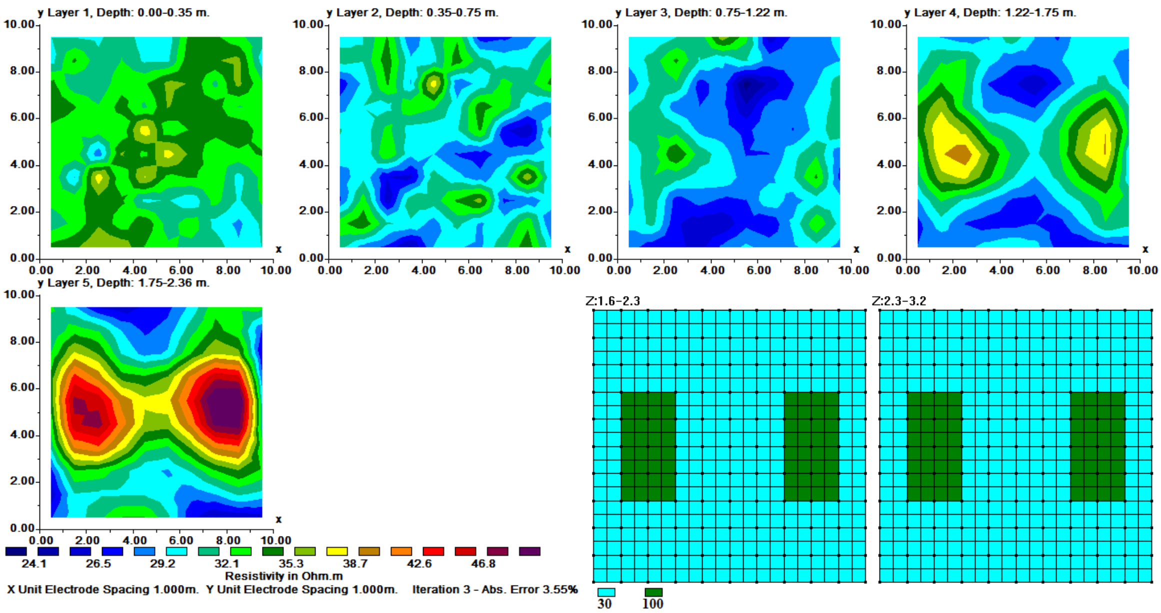

Figure 8. The inverse and synthetic 3D model for structures when separated by (4m).

4. Conclusion

The comparison of horizontal resolution for the Dipole-Dipole array using 2D and 3D tomography techniques on synthetic models show some difficulty in delineating the exact size and location of the structures. Its horizontal resolution within 2D inverse models is slightly better than it in the 3D inverse models, especially when the distance between the structures becomes too small. The Dipole-Dipole's sensitivity to the horizontal change in resistivity is increased when the distance between the structures is increased, with optimal resolution typically achieved when the inter-structure spacing is approximately 1 to 1.5 times their dimensions. In the 3D inverse models, while the Dipole-Dipole array generated a distorted image of the structures when the horizontal distance between the structures is small. It provides reasonable images when the distance between the structures is increased. So, for investigating subsurface horizontal structures that are separated with small distances, 2D tomography technique is a better approach than 3D tomography technique when using the Dipole-Dipole array.

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