2D electrical resistivity imaging based on backpropagation artificial neural network

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Abstract. Dipole-dipole is one configuration design survey in electrical resistivity method which is common to interpreted shallow subsurface base on resistivity parameter, and the model can be developed using inversion formula. Otherwise, we developed some model without empirical mathematic formula; it is called Artificial Neural Network (ANN). ANN is a system which has a pattern like the human brain process to solve the complex problems. The research aims to develop a neural network algorithm using Matlab and compare the result 2D model resistivity between ANN and inversion by Res2Dinv (existing procedure) software. The research was done in Taman Rumah Kita (TRK) where located in Faculty of Science and Mathematics, Diponegoro University. A cylinder was buried in the center of TRK and getting the best architecture of the network and the value of Mean Square Error (MSE) of the output network. The backpropagation artificial neural network was built from many layers such as an input layer, hidden layer, and output layer and developed by Matlab programs. The Network train was tested using synthetic data and field data. The synthetic data was made with forwarding modeling method by Res2Mod software, and the field data was obtained by doing the measurement at the measurement site using dipole-dipole resistivity method. The comparing result models are present the best architecture obtained one input layer with three input units, three hidden layers with each layer has 100 neurons and one output layer that obtained by trial and error process. MSE obtained respectively in observation lines are 0.0210 at Line 1, and 0.0345 at Line 2.

1. Introduction

Electrical resistivity method can be used to obtain the 1D, 2D, even 3D model of subsurface through the acquisition process using a different configuration. The potential differences at points below the surface can be detected using an electrical resistance and a cross-sectional area which produced by direct electrical currents, to assess the rock or soil’s ability to conduct electricity [1][2]. There are many applications of electrical resistivity: geotechnical characterization of shallow landslides [3][4], detect the soft clays and to evaluate the soil stabilization [5][6][7][8][9][10][11]. 2D Dipole-dipole configuration commonly used to interpreted shallow subsurface base on resistivity parameter. After the acquisition process, the subsurface model can be developed using the inversion formula. The inversion formula was obtained by developing some or more mathematics equation.

The most important in this research is to develope model based on data information without using empirical mathematics equation. One of the methods is called Artificial Neural Network. This method is fitted for mapping the non liner data, even can be used for complex data. In building the ANN
system, Matlab application designer language was used. The research aims to develop neural network algorithm using Matlab to know the inversion pattern of 2D resistivity data obtained from the acquisition of dipole-dipole array and compare the result of 2D model resistivity between ANN and inversion by Res2Dinv software using Surfer software.

2. Artificial Neural Network System

Artificial Neural Network (ANN) is a data processing method which has the abilities that resemble human neural system\(^\text{[12]}\). Like the human brain, the artificial neural network is like a processor that can store the knowledge in its neuron, and get the knowledge from the learning process\(^\text{[13]}\). The ANN’s work system is like simulate the cognitive process just like a human brain. So, this method can be used to solve complex problems\(^\text{[14]}\).

ANN was formed as a generalization of mathematics model based on followed assumptions. First, processing data occurs at simple elements (neuron), second, the signal is transmitted through neurons via a connection, third, the connection among neurons have weights which can strengthen or lower the information that received, and forth, the output is made by using a system called activation function\(^\text{[1]}\). So, ANN formed by neuron architecture or the pattern of neurons connection, a method to determine the weights, and the activation function. Input and output from non-linear data are mapped by ANN and let the neural network to study and obtain the information about the problems, but also at the same time; it solves the problems\(^\text{[15]}\). ANN needs to be trained so that it can map the non-linear data pattern. There are two kinds of training, first is supervisor training and the second is unsupervised training. Supervisor training has a master to teach the neuron or called the target as a media study that the value will be followed. The result should produce the output value that resembles the data target. While at unsupervised training, there is no such target to teach the neurons, but the neurons will compete to produce the desired output.

ANN can be used to do pattern recognition, signal processing, and also can be used to do forecasting. When ANN is used for pattern recognition purpose, it used to recognition the pattern of written, number, sound, face, signature, also a picture even the pattern has been changed a bit. For signal processing purpose, ANN can be used to lower the noises. And for the forecasting purpose, ANN can be used to predict the future based on the data in the past. Beside of electrical resistivity field, ANN also can be used to solve problems in the medical field, control, etc.

Backpropagation Neural Network (BPNN) was used to process the data. BPNN is one kind of supervisor training and often be used at technical majority. BPNN’s neurons architecture has more than one layer so that it will solve the complex problems. The neurons architecture are the input layer, one or more hidden layer, and an output layer. The architecture of BPNN is shown in figure 1.

![Figure 1. Backpropagation architecture](image)

Beside layer, the artificial neural network also has weights and bias that effect the value of each layer. This weights and bias also connect the neuron and others neuron and their value always change.
and given randomly by the Matlab program. So, they are responsible for the value that produced by ANN. Another part in building ANN is an Activation function. At BPNN, activation function used to determine the neuron output. The activation function is a combination between input and their weights. If net = \( \sum x_i w_i \), then the activation function is \( f(\text{net}) = f( \sum x_i w_i ) \). The requirements of an activation function are continuous, easy to differentiate, and not a down function.

3. Resistivity Electrical resistivity Method Dipole – dipole Array

The principle of resistivity electrical resistivity method is injection the current through the subsurface to obtain the potential value of the rocks. The Law of Ohm said that potential (V) of a material is depended on the current (I) that through it and the resistance (R) which in the material itself. Ohm also assumed that the resistance (R) is not depended on current (I) (R is constant) but the condition where R is not constant is called as non-linear element and formulated by the equation 1:

\[ V = IR \]  

Dipole – dipole array is shown as figure 2.

![Figure 2. Dipole-dipole array](image)

\( r_1 \) is \( C_1 P_1 \) or \( na \), \( r_2 \) is \( C_2 P_1 \) or \( na + a \), \( r_3 \) is \( C_1 P_2 \) or \( na + a \), \( r_4 \) is \( C_2 P_2 \) oe \( na + 2a \). The geometry factor for this array is using equation 2.

\[ k = \pi n (n+1)(n+2)a \]

Where k is dipole – dipole array, \( a \) is the distance of two electrodes, \( na \) is the space between potential electrode and current electrode, and n is a rounded number.

4. Matlab Programming Language

Matlab programming language can be used to calculate, doing visualization, and programming. Moreover, Matlab is a friendly user because it uses the familiar mathematics notations. Another advantage of using Matlab is Matlab element data is an array that doesn’t need a dimension. An artificial neural network was built using Matlab. Matlab provides some codes to build the artificial neural network. In this research, a backpropagation neural network was built with code newff. Matlab also used to train the ANN to get the best mean square error.

5. Method

Research is divided into three steps, first is data gathering, the second is created the artificial neural network, and the last is test the new artificial neural network. In the first step, there are two kinds of data which used. One is synthetic data, and the other is observation data. Synthetic data is needed to modify the neuron’s weights. This data is made using forward modeling software; it is Res2Mod software. Res2Mod will create the target model with desire resistivity value. The model is built with resistivity 50 \( \Omega m \) buried in 3 meters lengths with the background resistivity 20 \( \Omega m \). When the forward modeling is succeeded, it will be extracted to get the needed value like the apparent resistivity, mid point, space and the number of N. Those parameters then will be processed using Res2Dinv software.
Another data that have been used is observation data. This observation data is obtained from field acquisition using 2D electrical resistivity method dipole-dipole array at Taman Rumah Kita (TRK) Diponegoro University. The target was an anomalies cylinder with 3 m lengths and 1 m diameter that buried at TRK. Figure 3 shown the geology model of TRK with the survey design shown in figure 4.

![Figure 3. Geology model of buried cylinder](image1)

![Figure 4. The survey design of measurement point](image2)

The second step is created the artificial neural network using Matlab programming language. The artificial neural network is made with 3000 epoch, 0.2 learning rate and sigmoid biner activation function are chosen. When using the sigmoid biner, the input data should be transformed into the value which can be processed by the activation function. The value should have ranged from 0 to 1. For the amounts of neuron and the hidden layer will adjust to the most efficiency and the most effective.

The last step is to test the artificial neural network. Before the test start, the artificial neural network should be trained using the combination of synthetic data and half of observations data. The input data are mid point position from the dipole-dipole array (X), targeted depth depends on the number of N (Z), and the apparent resistivity. The output value is true resistivity from a measurement point. After trained, ANN will be tested using the other half observations data which has been initiated.

6. Result and Discussion
The research aim is to create an artificial back propagation neural network algorithm to get the inversion data from observation data field without empirical formulas. Inversion value was obtained from the neurons learning patterns, and then the neuron will determine the output value of the inversion itself. Artificial Neural Network needs a lot of data to get the most accurate value of the target. So, the synthetic data was made with forwarding modeling method while observation data were obtained from field acquisition with four lines measurement which through the target.

The experiments were done until the most accurate result obtained. ANN architecture consists of three-layer input, three hidden layers with 100 neurons in each layer, and one output layer. The weight value is given randomly from Matlab. The architecture is obtained the best after the trial and error process. So, doing some variation to the hidden layer is needed, start from one hidden layer, two hidden layers and three hidden layers have been tried. Also doing some variation to the training method and the number of neurons. Table 1 shown some of the experiments that have been tried.

The yellow block at Table 1 shows the best architecture from the artificial neural network. ANN consists of three hidden layers with 100 neurons in each layer. This architecture was obtained from the trial and error process. Table 1 also told that the regression of the resemblance between ANN and the existing procedure is almost perfect.

Figure 5 is a cross-section of the resistivity which obtained from the results of processing with RES2DINV software (b) and artificial neural networks (a). ANN was tested using the data test. From figure 5 above, it shows the similarity between cross-sectional images (a) and (b) for both lines. Cross-section of the picture an in Line 1 shows that there are two layers. The first layer has a resistivity value
between 20 Ωm to 25 Ωm at a depth of 0 meters to ± 3 m, and it is assumed that this layer is a layer of soil. For the second layer, it has a resistivity range of 0 Ωm to 15 Ωm at a depth of more than 3 meters, and it is suspected that this layer is a sandy clay layer. Then, it can be seen that there are anomalies below the 18th electrode and the 22nd electrode. This anomaly has resistivity value ranging from 40 Ωm to 45 Ωm and is estimated to be the anomaly target.

### Table 1. Variation of artificial neural network (ANN)’s architecture

| Number of hidden layers | Variation of neuron | Regression | MSE Training | MSE Test at Line 1 | MSE Test at Line 2 |
|-------------------------|---------------------|------------|--------------|-------------------|-------------------|
| 1                       | 50                  | 0.894      | 0.0018       | 0.0301            | 0.0404            |
|                         | 100                 | 0.931      | 0.0012       | 0.1043            | 0.2044            |
| 2                       | 10 (lap. 1), 10 (lap. 2) | 0.873       | 0.00216      | 0.029             | 0.0413            |
| 3                       | 100 (lap. 1)        | 0.943      | 0.00099      | 0.021             | 0.0345            |
|                         | 100 (lap. 2)        |            |              |                   |                   |
|                         | 100 (lap. 3)        |            |              |                   |                   |

**Figure 5.** Comparison of ANN modeling (a) versus existing procedure model (b) at Line 1 and Line 2

In Line 2, the picture above also shows that there are two layers exist up to 4 meters in depth. The first layer has a resistivity value between 20 Ωm to 25 Ωm at a depth of 0 meters to ± 3 m, and it is assumed that this layer is a layer of soil. For the second layer, it has a resistivity range of 0 Ωm to 20 Ωm at a depth of more than 3 meters and also it is suspected that this layer is a sandy clay layer. It also can be seen that there are anomalies below the 14th electrode and the 18th electrode. This anomaly has resistivity value ranging from 60 Ωm and is estimated to be the anomaly target.

**7. Conclusion**

Artificial neural network (ANN) has been created and used in the electrical resistivity majority to get the resistivity from a buried cylinder. Based on experiments, the use of ANN is worked well, and when the result is modeled, it showed a resemble with a model that processed with inversion formulas. For ANN, because it needs to learn from its supervisor, so it needs a lot of data to train the ANN. The data was covered with the synthetic data which has known the value of the target.

The best architecture of the ANN consist of three input layer which has three neurons, three hidden layer with each layer has 100 neurons and an output layer. This ANN architecture produce Mean Square Error (MSE) value for line 1, 2, 3, and 4 are 0.000544, 0.0345, 0.0039, 0.0210. This means
that the processing data using the artificial neural network resembles the processing data with Res2Dinv software.

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