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EEG SOURCE LOCALIZATION FOR TWO DIPOLES BY NEURAL NETWORKS

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Abstract—**It is reported that neural networks are useful for solving physiological inverse problems such as EEG and MEG source localizations, where a single dipole source is localized in terms of position and direction. This method is developed here to localize two independent sources from EEG. To improve localization accuracy, 36 electrodes for EEG measurement are used and two dipole sources are assumed to be in each restricted region of the brain. As a result, localization accuracy has been about 3 to 9% depending on the region restrictions, which may be useful for real time epileptic diagnoses.**

keyword—**Localization accuracy, Source localization, EEG, Back-propagation, Neural networks**

I. Introduction

Brain source localization is an important inverse problem from the viewpoint of medical diagnoses and brain function analyses. Though many method using convergence calculations are used for this problem[1], BPNN(error Back Propagation Neural Network) is conveniently applied because it has ability to install an inverse function by training using data. It is known that a single dipole source is localized by BPNN from EEG and MEG with high accuracy[2,3], even by using conventional EEG 18 electrodes in hospitals[4]. The neural network method is possible to offer real time localization useful for medical applications, not depending on the complexity of brain models. The neural network method has been applied for diagnoses of epilepsy with a spike source[5]. In this paper, we have developed the neural network method for localizing two independent sources from EEG. The purpose is to examine the usefulness of the method as to localizing accuracy changing network structures, training patterns and training methods, comparing with single source localization.

II. Methods

To apply BPNN to EEG localization for double sources, we have to determine a head model, a source model, an electrode configuration and a network structure. We use a three concentric shell head model as shown in Fig. 1 and a current dipole source model which are the same as used in the previous works[2,3] for EEG single source localization by BPNN because of making comparison easy. Using these models, EEG is easily calculated theoretically by an expression[2], superposing two EEG's from each dipole source.

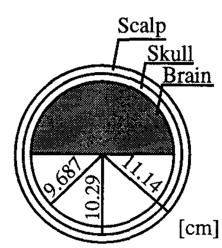

Fig. 1. Three concentric shell model

Two kinds of electrode arrangement are used here, i.e., one composed of 18 electrodes based on the usual 10-20 system as shown in Fig. 2 (a) and the other with 36 electrodes which has additional 18 electrodes for the first case as shown in Fig. 2 (b). We use the average reference of both ear potentials.

Fig. 3 shows the configuration of the neural networks used here, which consists of four layers, i.e., an input layer, two hidden layers and an output layer. Each unit in the hidden and output layers has an input from a bias unit to control threshold. In case of 18 electrodes, the input and each hidden layers have 16 and 73 units respectively, and 34 and 73 units respectively for 36 electrodes.

The output layer is composed of 6 units corresponding to respective positions (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2) of the first and second dipole sources, or corresponding similarly to moments (M_{x1}, M_{y1}, M_{z1}) and (M_{x2}, M_{y2}, M_{z2}). Two specialized network are therefore prepared here. The units in the input layer have a linear input-output function, while other units have a sigmoid function (tanh).

Two dipole sources will appear independently in the whole region of the hemisphere brain model in Fig. 1. In some case, two dipoles may be generated closely in parallel. Then, it will be difficult to discriminate both dipoles each other from EEG. To avoid this situation and make the localization simple, the position of two dipoles are restricted in the region shown in Fig. 4. In case (a), each dipole is restricted in a small partial sphere region, and in case (b), restricted in the left or right almost half region. We have no restriction on the direction of the dipoles.

To train the network, training data should be prepared. At first, two dipoles are put randomly in each region (expanded a little from the each restricted region to reduce localization errors near the boundaries of the region) with random direction and the potentials on electrodes are calculated by the above method. This gives one data pattern, i.e., a pair of EEG data and dipole parameters. We have prepared 30,000 data patterns for training in which the EEG data are supplied to the input units and the dipole parameters to the output units. We have also prepared different 10,000 data patterns for testing of the network, i.e., to examine building up of the desired inverse function.

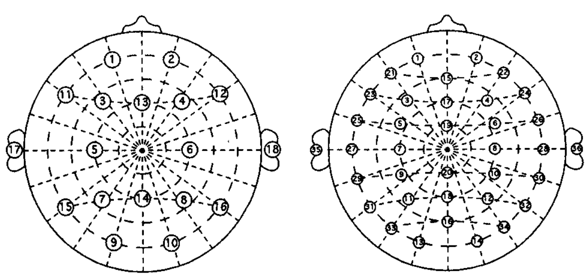

Fig. 2. Arrangements of electrode positions

III. Results and Discussion

The training of the networks has converged after 1,000 iterations of training. Localized position error ε_{pos}[%] is defined by

$$\varepsilon_{pos} = \frac{1}{rN}\sum_{p=1}^{N}\sqrt{\left(x_p - x_p'\right)^2 + \left(y_p - y_p'\right)^2 + \left(z_p - z_p'\right)^2} \qquad (1)$$

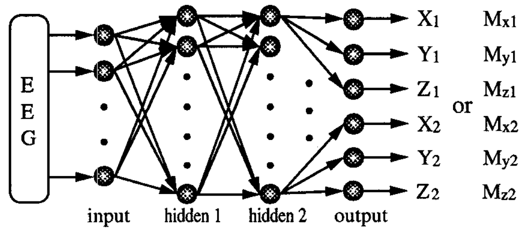

Fig. 3. Configuration of neural network

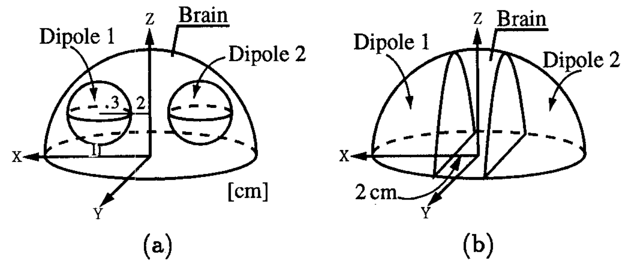

Fig. 4. Restricted regions for source localization

where r = radius of the brain (9.687cm), N = number of dipoles, (x_p, y_p, z_p) and (x_p', y_p', z_p') are the localized position by the neural networks and the actual position of pth dipole respectively. Direction error ε_{ang}(degree) is defined as follows.

$$\varepsilon_{ang} = \frac{1}{N}\sum_{p=1}^{N}\cos^{-1}\left(\frac{(\overrightarrow{m_p}\cdot\overrightarrow{m_p'})}{|\overrightarrow{m_p}||\overrightarrow{m_p'}|}\right) \qquad (2)$$

where m_p and m_p' are the localized and actual dipole moment vectors respectively of pth dipole.

Table 1 shows the average localization error for the case of Fig. 4 (a). When using 18 electrodes, the position accuracy for the test patterns is about 4.7 % which is somewhat larger than that for single dipole localization, about 3.3 % [3]. If 36 electrodes are however used, the position error becomes small to give about 2.6 %. On the other hand, the direction errors are so small as 2 ~ 3 degrees for both electrode arrangements, which may give accuracy high enough for actual use.

Error distribution has been examined for the case of 36 electrodes in Fig. 4 (a). The result is shown in Fig. 5 as a function of the distance between dipole position and the center. It is found that the error increases with decreasing the distance. When the distance is small, two dipoles have high possibility to close each other, which may cause large position error.

Table 2 shows the average localization error for the case of Fig. 4 (b). The error for the test patterns is about 8.9 % though using 36 electrodes, which may be large for practical use. The direction error is also larger than that of the first case. Since these errors are almost the same for training and test patterns, the network is considered to acquire the inverse function with high generalization.

To improve the localized position accuracy, we have to examine the network structure, the number of training data, the number of electrodes, EEG interpolations and revising training algorithm in more detail. It may be however useful to localize by two steps, i.e., global localization first and then precise localization using more specialized networks.

TABLE I
LOCALIZATION ACCURACY 1

	number of electrodes	training pattern right	training pattern left	test pattern right	test pattern left
position error [%]	18	4.22	4.38	4.61	4.79
	36	2.45	2.30	2.63	2.49
direction error [deg]	18	2.70	2.75	2.87	2.90
	36	1.84	1.82	1.97	1.97

TABLE II
LOCALIZATION ACCURACY 2

	number of electrodes	training pattern right	training pattern left	test pattern right	test pattern left
position error [%]	36	8.93	8.40	9.24	8.49
direction error [deg]	36	7.67	7.44	8.08	7.88

IV. CONCLUSIONS

It is found that the neural network method can be applied for two dipole source localization from EEG. Localization accuracy has been about 3 to 9% depending on the region restrictions for dipole positions. If two dipoles are separated with a large distance, localized accuracy is almost the same as that of single source localization, e.g., less than 4 %. Some improvements are however required for two dipoles in vicinity. Developing the neural networks using a realistic head model and its clinical applications will be future works.

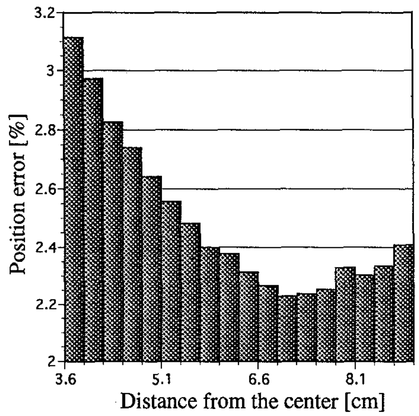

Fig. 5. Distribution of the error

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