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Three-dimensional medical image analysis of the heart by the revised GMDH-type neural network self-selecting optimum neural network architecture

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***Abstract*:** In this study, a revised GMDH-type neural network algorithm self-selecting the optimum neural network architecture is applied to 3-dimensional medical image analysis of the heart. The GMDH-type neural network can automatically organize the neural network architecture by using the heuristic self-organization method which is the basic theory of the GMDH algorism. The heuristic self-organization method is a kind of the evolutional computation methods. In this revised GMDH-type neural network algorithm, the optimum neural network architecture was automatically organized using the polynomial and sigmoid function neurons. Furthermore, the structural parameters such as the number of layers, the number of neurons in the hidden layers and the useful input variables are automatically selected so as to minimize the prediction error criterion defined as Prediction Sum of Squares (PSS).

***Keywords*:** GMDH, Neural network, Medical image recognition

I. INTRODUCTION

In this study, 3-dimensional medical image analysis of the heart by a revised Group Method of Data Handling (GMDH)-type neural network self-selecting optimum neural network architecture [1] is developed. In the medical image recognition, there are many kinds of medical images, such as magnetic resonance imaging (MRI) image, X-ray computed tomography (CT) image, X-ray image, mammography and others, whose characteristics are complex and different from each other. Furthermore, in recent years, 3-dimensional medical images generated by multi-detector row computed tomography (MDCT) and MRI are used in clinical diagnosis. The 3-dimensional medical images contain a lot of information and so computer-aided diagnosis (CAD) systems for the 3-dimensional medical images are needed for many kinds of organs. When we apply artificial neural networks to the medical image analysis and CAD , it is very difficult to find the optimum neural network architecture fitting the characteristics of the medical images.

The revised GMDH-type neural network algorithm proposed in our early work [1] is applied to medical image analysis of the heart. The neural network architecture that fits the complexity of the medical images is automatically organized by the revised GMDH-type neural network algorithm so as to minimize the prediction error criterion defined as PSS [2]. The medical images used in this study are MDCT images of the heart. Statistics of image densities in neighboring regions and x and y coordinates of the centers of the neighboring regions are used as the image features. Only useful image features are selected automatically and the optimum neural network architecture are organized using selected useful image features. The 3-dimensional outlines of the heart are recognized using the neural network organized by the revised GMDH-type neural network algorithm and the regions of the heart are extracted. The results are compared with those obtained using GMDH [2] and show that the revised GMDH-type neural network algorithm is useful for the 3-dimensional medical image analysis of the heart and is very easy to apply the practical complex problem because the optimum neural network architecture is automatically organized so as to minimize the prediction error criterion PSS.

II. REVISED GMDH-TYPE NEURAL NETWRK ALGORITHM.

The revised GMDH-type neural network is shown in Fig.1. Here, nonlinear function g_i is described by the following Kolmogorov-Gabor polynomial [3], [4]:

$$g_i\,(x_1,x_2,\cdots,x_p)= a_0+\sum_i a_i x_i+\sum_i\sum_j a_{ij}x_i x_j+\cdots \qquad (1)$$

This nonlinear function is automatically organized by using the polynomial type neuron. In the revised GMDH-type neural network, many kinds of nonlinear combinations of the input variables are generated by using the polynomial type neurons and only useful nonlinear combinations of the input variables are selected. Optimum neural network architectures are organized by using selected useful combinations of the input variables. The architecture of the revised GMDH-type neural network is produced as follows:

1. The first layer

$$u_j=x_j \qquad (j=1,2,\cdots,p) \tag{2}$$

where x_j $(j=1,2,\cdots,p)$ are the input variables of the system, and p is the number of input variables.

2. The second layer

Many combinations of two variables (u_i,u_j) are generated. For each combination, the neuron architecture is described by the following equations:

Σ: (Nonlinear function)

$$z_k= w_1u_i+w_2u_j+w_3u_iu_j+w_4u_i^2+w_5u_j^2+w_6u_i^3+w_7u_i^2u_j +w_8u_iu_j^2+w_9u_j^3 - w_0\theta_1 \tag{3}$$

f : (Linear function)

$$y_k= z_k \tag{4}$$

where $\theta_1 =1$ and w_i $(i=0,1,2,\cdots,9)$ are weights between the first and second layer. The weights w_i $(i=0,1,2,\cdots,9)$ are estimated by using the revised regression analysis [5]. This procedure is as follows:

First, the values of z_k are calculated by using the following equation:

$$z_k=\log_e(\phi'/(1-\phi')) \tag{5}$$

where ϕ' is the normalized output variable. Then the weights w_i $(i=0,1,2,\cdots,9)$ are estimated by using the stepwise regression analysis [5] which selects useful input variables by using the PSS [2]. Therefore, only useful terms in (3) are selected and neuron architecture can be organized by these selected useful terms.

From these generated neurons, L neurons which minimize the PSS are selected. The output values (y_k) of L selected neurons are set to the input values of the neurons in the third layer.

3. The third and succeeding layers

In the third and succeeding layers, the same computation of the second layer is continued until the PSS values of L neurons are not decreased. When the iterative computation is terminated, the following calculation of the output layer is carried out.

4. The output layer

In the output layer, the output values of the neural network are calculated from z_k as follows:

$$\phi=1/(1+\exp(-z_k)) \tag{6}$$

So, in the output layer, the neuron architecture becomes as follows:

Σ: (Nonlinear function)

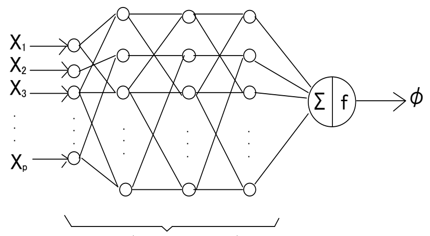
$$z_k= w_1u_i+w_2u_j+w_3u_iu_j+w_4u_i^2+w_5u_j^2+w_6u_i^3+w_7u_i^2u_j +w_8u_iu_j^2+w_9u_j^3 - w_0\theta_1 \tag{7}$$

f : (Nonlinear function)

$$\phi =1/(1+\exp(-z_k)) \tag{8}$$

At last, the complete neural network architecture is produced by selected neuron in each layer.

By using above procedures, the revised GMDH-type neural network can be organized.



$g_i\,(x_1,x_2,\cdots,x_p)$

Σ : (Nonlinear function)

$z = \Sigma\, w_i\, g_i\,(x_1,x_2,\cdots,x_p)$

f : (Nonlinear function)

$\phi =1 / (1+\exp(-z))$

Fig.1 Architecture of revised GMDH-type neural network [1]

III. APPLICATION TO THE MEDICAL IMAGE RECOGNITION.

In the medical image recognition, there are many kinds of medical images, such as MRI image, X-ray CT image, X-ray images, mammography and others, whose characteristics are different each other. So, when we apply neural networks to medical image recognition, it is very difficult to find out the optimum neural network architectures fitting the characteristic of each medical image. The revised GMDH-type neural network can be automatically organized by using the heuristic self-organization method [3],[4]. Furthermore, in the revised GMDH-type neural network, a lot of nonlinear combinations of the input variables are generated and only useful combinations of the input variables are selected so as to minimize the error criterion defined as PSS. Therefore, we can easily apply the revised GMDH-type neural network to medical image recognition. The recognition results obtained by the revised GMDH-type neural network are compared with those obtained by the GMDH.

1. Results of the medical image recognition by using the revised GMDH-type neural network.

The X-ray CT image shown in Fig.2 are used for organizing the neural network. x and y coordinates and the statistics of the image densities in the neighboring regions of the N×N pixels at the positions of the learning points are used as the input variables of the neural network. The statistics used for the recognition are the mean, the standard deviation, the variance, the median, the minimum, the maximum and the range. Only five input variables which are the mean, the standard deviation, the variance and x and y coordinates are automatically selected as useful input variables by the revised GMDH-type neural network. The output value of the neural network is zero or one. When N×N pixel region is contained in the region of the heart, the neural network set the pixel value at the center of the N×N pixel region to one and this pixel is shown as the white point. The neural networks were organized when the values of N were from 3 to 15. It was determined that when N was equal to 4, the neural network architecture had the smallest recognition error. Five useful neurons were selected in each hidden layer. Figure 3 shows the variation of PSS values. PSS values decreased gradually and small PSS value was obtained. The region of the heart was recognized by using the organized neural network and was extracted automatically. Fig.4 shows the output image of the revised GMDH-type neural network. This output image was processed by the post-processing analysis. In the post-processing, the small isolated regions were eliminated and the outlines of the regions of the heart were expanded outside by N/2 pixels. Fig.5 shows the output image after this processing. In order to check the matching between the original image and the output image of the neural network, the output image was overlapped on the original image of Fig.2. The overlapped image is shown in Fig.6. From Fig.6, we can see that the output image was very accurate.

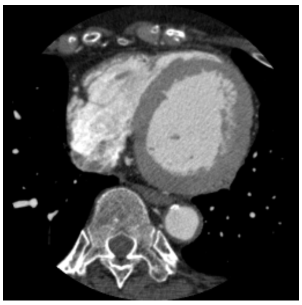


Fig.2 Original image (1)

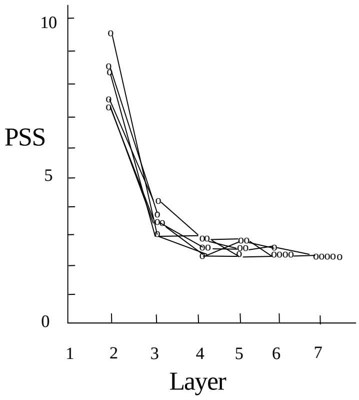


Fig.3 Variation of PSS

Fig.4 Output image of the neural network (1)

Fig.5 Output image after post-processing (1)

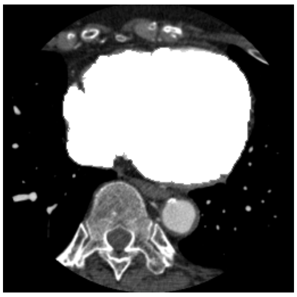


Fig.6 Overlapped image (1)

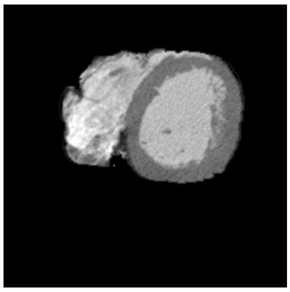
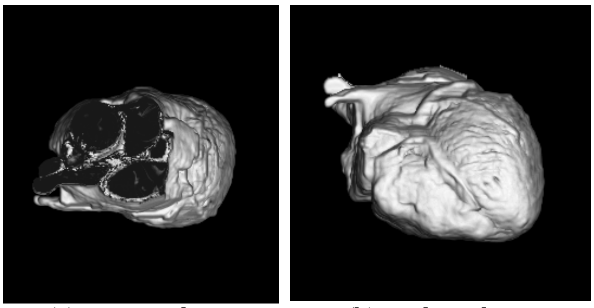


Fig.7 Extracted image (1)

2. Generation of 3-dimensional heart images

Three-dimensional heart images were generated using the following procedures. The heart image shown in Figs. 7 was subtracted from the original images in Fig. 2 using the output images after post-processing in Figs.5. For all MDCT slice images, these image subtractions were conducted and all slice subtracted images of the heart were generated. Then, 3-dimensional heart images were generated from these subtracted images using the rendering software. Figure 8 shows the 3-dimensional heart images generated by the revised GMDH-type neural network.



(a) Upper side (b) Under side

Fig.8 3-dimensional images of the heart

3. Check of generalization of neural network

In order to check generalization of revised GMDH-type neural network, revised GMDH-type neural network, which was organized by original image of the heart (Fig.2), is applied to another original image of the heart (Fig.9). Revised GMDH-type neural network output the heart image (Fig.10) and post-processing analysis of the heart image was carried out, based on which regions of the heart were extracted. The outline of regions of the heart were expanded outside by N/2 pixels. Fig.11 shows the output image after the post-processing. In order to check matching between the original image and the output image of the neural network, the output image was overlapped on the original image after the post-processing. Overlapped image is shown in Fig.12. From Fig.12, we can see that revised GMDH-type neural network could extract new regions of the heart accurately and it is shown that revised GMDH-type neural network has a good generalization ability. Fig.13 shows the extracted image.

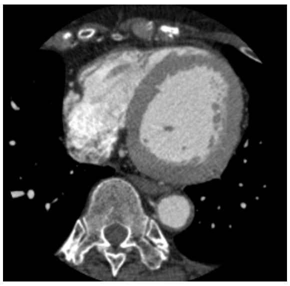


Fig.9 Original image (2)

Fig.10 Output image of the neural network (2)

Fig.11 Output image after post-processing (2)

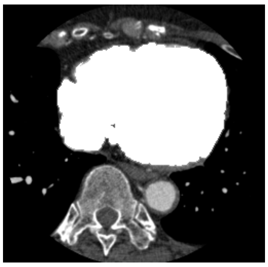


Fig.12 Overlapped image(2)

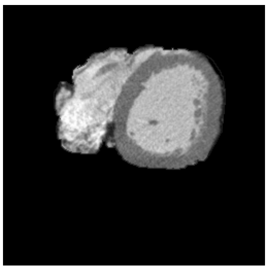


Fig.13 Extracted image (2)

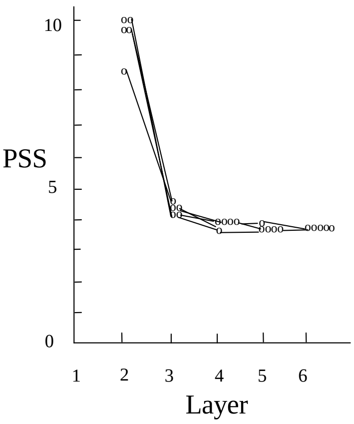


Fig.14 Variation of PSS in GMDH

4. Results of the medical image recognition by using the GMDH [2]

The GMDH was applied to the same recognition problem and the recognition results were compared with the results obtained using the revised GMDH-type neural network. Same five input variables, which were mean, standard deviation and variance, x and y positions were used in the input layer. Figure 14 shows the variation of PSS in the GMDH. The output images are shown in Fig.15 and 16. These images contain more regions not part of the heart than output images obtained using the revised GMDH-type neural network shown in Fig.4 and 10.

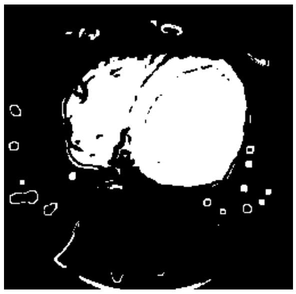


Fig.15 Output image of GMDH (1)

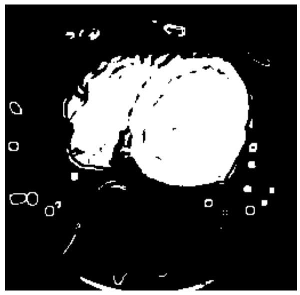


Fig.16 Output image of GMDH (2)

VI. CONCLUSION.

In this study, the revised GMDH-type neural network was applied to the medical image recognition. The revised GMDH-type neural network can automatically organize the optimum neural network architecture fitting the complexity of the medical images. Therefore, we can easily apply the revised GMDH-type neural network to the medical image recognition. It was shown that the revised GMDH-type neural network was very accurate and useful method for the medical image recognition of the heart.

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