Meridian ECG Information Transmission System Modeling Using NARX Neural Network

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***Abstract*—With the increasing death number of cardiovascular disease, it is significant to study ECG signals at meridian acupoints for developing new alternative and complementary therapies for chronic cardiovascular diseases. Therefore, an ECG measuring experiment at acupoints of the human meridian is firstly carried out for obtaining information transmission data of the meridian system. Then according to the nonlinear characteristics of the meridian, a nonlinear autoregressive with exogeneous inputs (NARX) network is established for the modeling of meridian information transmission system. The analysis results of acupoint ECG data of ten subjects show that the NARX model outperforms the autoregressive with exogenous input (ARX) model and autoregressive and moving average model with exogenous input (ARMAX) in the ECG signal prediction at meridian acupoints. The prediction accuracy of the NARX neural network model for meridian ECG signal is larger than 0.98.**

Keywords—ECG signal; information transmission system; modeling; meridian

I. INTRODUCTION

Cardiovascular disease is a leading cause of illness and death in the world according to statistic data[1]. With the growing number of aging people in our society, it is of great significance to develop effective alternative and complementary therapies for chronic cardiovascular diseases. In recent decades Traditional Chinese Medicine (TCM) has been gaining more and more attention as the traditional therapy of complementary and alternative medicine (CAM) due to its simplicity, convenience, efficiency and cheapness [2-5]. Meanwhile, an increasing number of researchers are dedicating in the development of telemedicine systems for cardiovascular diseases through remote electrocardiogram (ECG) monitoring devices[1]. Since most of the therapies of TCM for chronic cardiac diseases are of non-invasive property, it will be a promising research direction to develop a modern telemedicine system with remote ECG information detection based on the TCM.

However, compared with western medicine, the application of TCM is still mainly limited to acupuncture because the underlying medical and physiological mechanism of the human meridians still remain unclear [2-5]. Although there are a growing amount of studies on specificities of meridian acupoints through biophysics[6,7], electro-physiology[8-10] , and infrared imaging [11,12] etc., none of these results have been accepted widely due to the unrepeatable experiment and the lack of scientific and systematic analysis [13,14]. Moreover, most of current acupoint researches mainly focus on the feature variation of acupoints under the external chemical, electrical, or optic stimulation on the meridians [13,14]. There is very few research about ECG signals of meridian acupoints [15].

Besides, it has been verified by lots of experimental results that acupoints have lower electrical impedance and meridians represent the channels with low impedance [8]. The meridian system has architecture with many channels allowing the electrical signals to pass through easily. The acupuncture points distributed in the meridian system offer some distinctive ways of transferring signals and processing information including electrical information[10]. Nevertheless, up till now, there is only few research on the modeling of meridian system from the point of view of the electronic information transmission. Furthermore, these research mainly focus on explore the hysteresis feature of meridian systems with the electronic stimulation signals on acupoint, rather than ECG signals on acupoint [10,16]. The modeling of information transmission of meridian system based on ECG signals is still a novel topic.

Therefore, a new measuring experiment of ECG signals on the meridian was firstly built in this paper for identifying the inherent transmission features of ECG signals of meridian systems. Moreover, a mathematic model based on nonlinear autoregressive with exogeneous inputs (NARX) network was devised to simulate the meridian ECG transmission system. The results not only theoretically interpret the transmission mechanism of information of meridian system, but provide a scientific basis for the development of remote ECG information detecting system based on the TCM.

II. MERIDIAN ECG MEASURING EXPERIMENT

A. Selection of meridian and acupoints

In order to explore the ECG transmission characteristics of human meridians, the meridian to be measured should be closely related to the heart. Furthermore, all the measuring acupoints must selected from the same meridian and be common acupoints used for cardiovascular disease diagnosis

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based on the TCM. Additionally, both the meridian and acupoints should be easy to measure so as to avoid the measuring deviation brought by undesirable conditions. In terms of the TCM, the Pericardium Meridian of Hand-Jueyin (PC) consists of nine acupoints that are mainly used to treat the diseases of the heat, chest and the stomach[2]. Hence, the Pericardium Meridian of Hand-Jueyin was chosen as the measuring meridian and its seven acupoints, i.e. Tianchi (PC1), Tianquan (PC2), Quze (PC3), Ximen (PC4), Neiguan (PC6), Laogong (PC8) and Zhongchong (PC9), were measured for identifying the ECG information transmission feature of the meridian. As shown in Fig. 1, seven acupoints to be measured are evenly distributed on the PC.

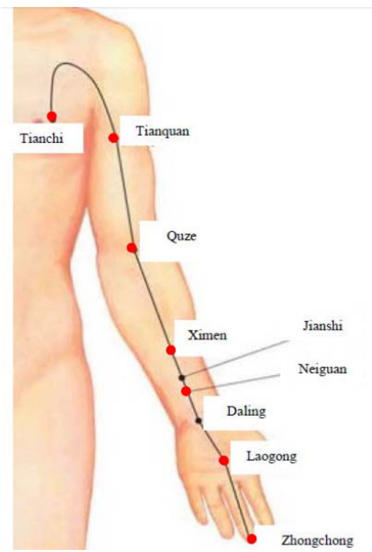

Fig. 1. Measured acupoints of Pericardium Meridian of Hand-Jueyin

B. *Measuring Procedure of ECG signals at meridian acupoints*

In the experiment, a physiological signal acquisition instrument (RM6280C) was used to measure acupoint ECG signals of subjects. Silver electrodes were employed for the signal detection at measured acupoints. Besides, based on the measuring method of Bipolar Limb Leads Standard I , the measurement of ECG signals was implemented. Since human meridians are symmetrical, the left hand of a subject was measured, while Zhongchong (PC9) of right hand was regarded as a reference acupoint. The acupoint Taixi on left leg was used as the grounding point. The sampling frequency of RM6280C was 1k*Hz*. Scanning speed was 200ms/div. The measured ECG signals respectively passed through a 50 *Hz* notch filter for removing the powerline interference, a high-pass filter with 0.05 cut-off frequency for the baseline wondering and a low-pass filter with 150 Hz cut-off frequency for myoelectric interference. Ten healthy volunteers (20 to 30 years old) involved as subjects in this research. Before measuring experiment, all subjects had declared they were free from excitant food, drugs, alcohol, medicines, or the other stimulating factors that may affect the ECG measurement. Each subject was measured only one hour after or before having foods or fierce sport. During the measuring procedure, the subject was required to keep quiet, turn off all the telecommunication devices and take all metal items off the body.Each subject was measured for five times. In every experiment, seven acupoints of the PC of the same subject had been simultaneously measured for 20 seconds by seven channels of RM6280C. As a result, totally 350 ECG records of ten subjects were obtained in the experiment.

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III. Modeling of meridian ECG information transmission system

A. *Preprocessing of ECG signals at meridian acupoints*

The ECG signal is a non-stationary physiological signal with amplitude usually from 10 μV to 5 mV, and with frequencies of interest in the range 0.05–150 Hz. Due to its small amplitude, the ECG signal is easily contaminated by various noises[17]. Hence, the ECG signals on acupoints were further filtered by the discrete wavelet decomposition after the experiment. In order to obtain legible data for the meridian modeling, each sampled ECG signal was decomposed by the wavelet base sym8 with eight decomposition levels. Then the reconstructed ECG signals at acupoints were utilized as the original signals for the meridian modeling.

B. *Non-linear characteristics of meridian ECG information transimission system*

According to the theory of Traditional Chinese Medicine, human meridians are channels and collaterals that circulate energy and blood to warm and nourish the tissues and organs and make them as a structural and functional integrity. The Pericardium Meridian of Hand-Jueyin originates from the acupoint Tianchi of the chest, then in turn passes through seven acoupoints and finally ends at the acupoint Zhongchong of the palm[2]. Therefore, without any external stimulation implemented on human body, the heart can be regarded as the sole activity source on meridians. Supposing the ECG signal at the acupoint is the information energy of Pericardium Meridian of Hand-Jueyin, the start acupoint Tianchi can be considered as the input point of information energy, and the other six measured acupoints, i.e. Tianquan, Quze, Ximen, Neiguan, Laogong and Zhongchong, can be regarded as the output of meridian ECG transmission system. As shown in Fig. 2, the measured ECG at each acupoint represents the information energy E_i (i=1,2,...,7) transmitted from Tianchi. All ECG signals at seven acupoints indicate information transmission characteristic of the meridian PC. Hence, the model of ECG information transmission between any two acupoints of the meridian can be developed through taking the ECG signal at the upper acupoint as the input $u(k)$, and that at the lower acupoint as the output $y(k)$, as shown in Fig.3. The noise $n(k)$ can be ignored after signal filtering.

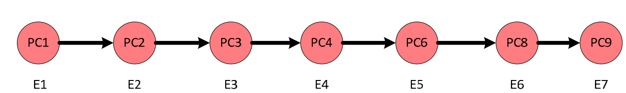

Fig. 2. Informtion energy transimission of Pericardium Meridian of Hand-Jueyin

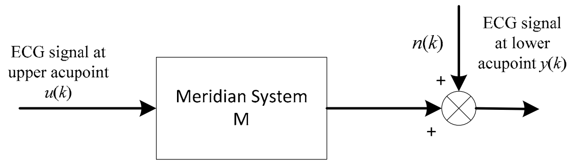

Fig. 3. Model of meridian ECG information transmission system

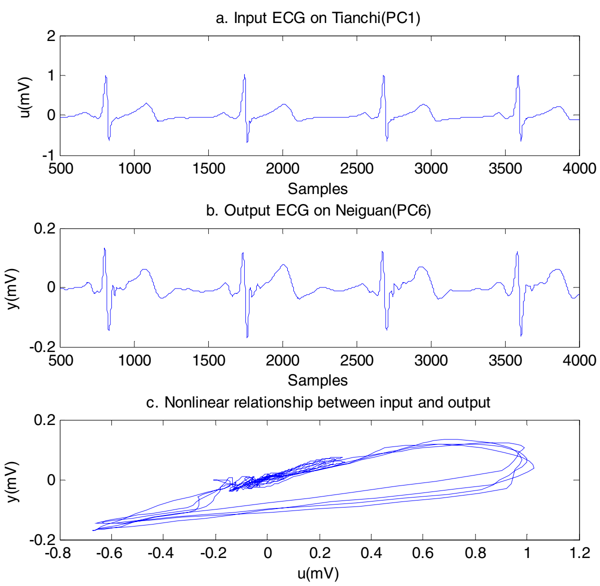

Fig. 4. Nonlinear feature of the meridian

Some research results of electronic stimulation experiments have illustrated that the human meridian system is a dynamic system with some nonlinear behavior, especially hysteretic behavior [10,16]. On the basis of ECG signals measured at acupoints, we found that there is the nonlinearity in the meridian ECG information transmission system. To investigate the information transmission characteristics of the meridian, we took the measuring data of subject 3 as an example. Suppose the ECG signal on Tianchi of Subject 3 as the input $u(k)$ and that on Neiguan as the output $y(k)$. $u(k)$, $y(k)$ and their relationship during four ECG beats were depicted respectively in Fig. 4 a,b and c. It can be clearly seen that the amplitude of $y(k)$ decreases as $u(k)$ is transmitting through the human meridian. Moreover, the ECG input and output of the meridian exists the prominent nonlinear hysteresis. Therefore, the features of ECG information transmission of the meridian should be identified by a nonlinear model.

C. NARX Neural Network model of meridian

Up till now, there have been some methods proposed for the modeling of meridian systems [10,16]. However, these models are mainly developed for extracting the hysteresis feature of electric stimulation signal on the meridian, rather than the prediction of meridian ECG transmission system. Moreover, the theory of these model become more complex by introducing an expanded input space method to the multi-valued mapping system. Artificial neural networks (ANN) , as a data-driven model, is one of the most significant methods in the modeling of dynamic nonlinear system. It can construct complex non-linear relationships between input and output through learning from actual experimental data, which makes it outperform traditional modeling techniques. Among various ANN models, the nonlinear autoregressive with exogeneous inputs (NARX) network is an important class of discrete-time nonlinear systems due to its powerful computation in theory [18,19] . Besides, it has been reported that gradient-descent learning can be more effective in NARX networks than in other recurrent architectures with ‘‘hidden states’’ [19]. Hence, a NARX model is built in this paper for the meridian ECG information transmission system.

Suppose the ECG series $u(k)$ on the upper acupoint of the meridian as the externally determined input, the ECG seiries $y(k)$ on the lower acupoint as the output variable. Then the next value of the dependent output $y(t)$ can be regressed on previous values of the output and previous values of an independent (exogenous) input . The defining equation of the NARX model is written as follows:

$$y(k) = f(y(k-1),...,y(k-L),u(k-1),...,u(k-R)) \tag{1}$$

where R and L are the maximum lags for input and output, respectively. f is a nonlinear function of its arguments. A NARX model can be implemented by using a feedforward neural network to approximate the function f, as shown in Fig. 5. In a NARX neural network model, each of the input nodes is connected to all the neurons in the hidden layer with the same unity weight. However, each of the hidden layer nodes is connected to the output node through different weights. Each neuron finds the distance, normally applying Euclidean norm, between the input and its center and passes the resulting scalar through a non-linearity. So the output of the mth hidden neuron is given by a nonlinear basis function. Taking the computation complexity into account, the NARX neural network with two input layer nodes, five hidden layer nodes and one hidden layer is used for the modeling of meridian ECG information transmission system.

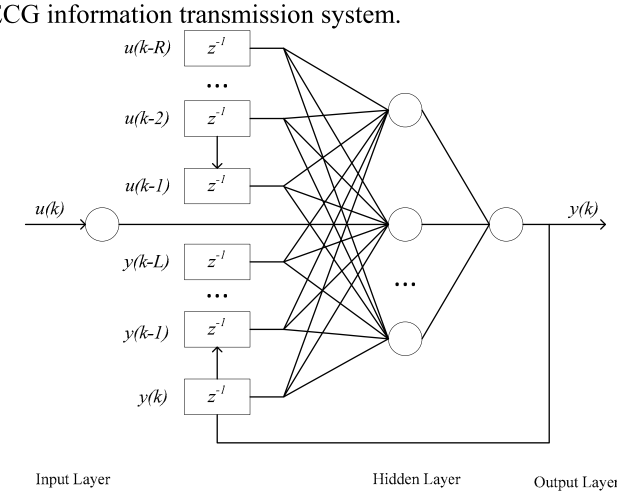

Fig. 5. NARX neural network model

IV. RESULTS AND COMPARISON

In order to evaluate the performance of NARX neural network, the autoregressive with exogenous input (ARX) model and autoregressive and moving average model with exogenous input (ARMAX) were also applied to identify the meridian ECG transmission system. Generally, the ARX model can be expressed as:

$$A(q^{-1})y(k) = B(q^{-1})u(k) + e(k) \tag{2}$$

where $u(k)$ is the input value and $y(k)$ is the output, $e(k)$ is the white noise. $A(q^{-1})$ and $B(q^{-1})$ denote the matrix polynomial matrices constituted by mode and delay operator:

$$\begin{aligned} A(q^{-1}) &= 1 + a_1 q^{-1} + \cdots + a_{n_a} q^{-n_a} \\ B(q^{-1}) &= b_1 q^{-n_k} + b_2 q^{-n_k - 1} + \cdots + b_{n_b} q^{-n_b - n_k + 1} \end{aligned} \tag{3}$$

The ARMAX model is described as :

$$A(q^{-1})y(k) = B(q^{-1})u(k) + C(q^{-1})e(k) \tag{4}$$

where

$$\begin{aligned} A(q^{-1}) &= 1 + a_1 q^{-1} + \cdots + a_n q^{-m} \\ B(q^{-1}) &= b_1 q^{-1} + \cdots + b_n q^{-n} \\ C(q^{-1}) &= 1 + c_1 q^{-1} + \cdots + c_n q^{-r} \end{aligned} \tag{5}$$

In view of the minor prediction error and lower computation complexity, parameters of the models used are set as follows: the ARX model:[n_k n_a n_b] = [0 0 10] ; the ARMAX model: [m n r] = [1 1 10] ;and the NARX model: [R L]=[1 1]. In the modeling experiment, the ECG signal at Tianchi is regarded as the input of the meridian system and that at Neiguan is reagarded as the output. The data in the first measurement of every subject are used as the training data for establishing the transmission model of the meridian. Besides, the data in the other four measurement of every subject are utilized as the model prediction. The root mean square error (RMSE) between the real ECG data and the prediction data was recorded for the analysis and comparison of the model performance. The mean values of prediction errors RMSE of 10 subjects based on these three models are shown in Table 1. It can be seen that the RMSE of the NARX neural network for all subjects are less than 0.01 and smaller than those of the ARX model and ARMAX model. Taking the subject 1 as an example, the prediction RMSEs of ECG output at Neiguan in the second measuring experiment by ARX model, ARMAX model and NARX model are 0.0237,0.0235 and 0.098, respectively. Their corresponding prediction ECG signals at Neiguan of the subject are depicted in Figure 6, 7, and 8. Comparing to the ARX model and ARMAX model, the output ECG signal at Neiguan obtained by the NARX model is closer to the real ECG output at Neiguan.

Furthermore, ECG signals at the other five acupoints of every subject were also analyzed for further verifying the performance of the NARX neural network model of meridian ECG information system. For each subject, the ECG signal at the first acupoint Tianchi is always used as the input u of the model, while the ECG signals at the other six acupoints are regarded as the output signals y_1~y_6 , respectively corresponding to the meridian model M_1~M_6. For each model, the ECG data in the first measurement are used for network training and those in the other four measurement used for model prediction. The mean values of prediction results of model M_1~M_6 are shown in Table 2. Clearly, the NARX neural network model can precisely predict the output of the meridian ECG information transmission system. The prediction accuracy of meridian NARX neural network models for all subjects is larger than 0.98.

TABLE I. MEAN VALUE OF MODEL PREDICTION ERROR RMSE OF ECG INFORMATION TRANSMISSION FROM TIANCHI TO NEIGUAN

Subject No.	ARX	ARMAX	NARX neural network
1	0.0236	0.0247	0.0092
2	0.0338	0.0325	0.0039
3	0.0198	0.0115	0.0019
4	0.0322	0.0225	0.0059
5	0.0499	0.0156	0.0035
6	0.0183	00342	0.0019
7	0.0196	0.0435	0.0044
8	0.0223	0.0176	0.0025
9	0.0214	0.0457	0.0057
10	0.0228	0.0101	0.0045

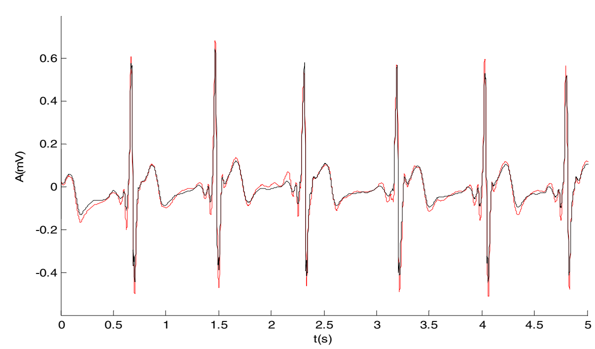

Fig. 6. Meridian ECG transmission model based on ARX model

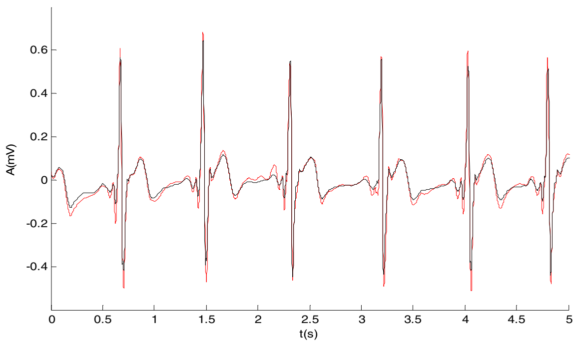

Fig. 7. Meridian ECG transmission model based on ARMAX model

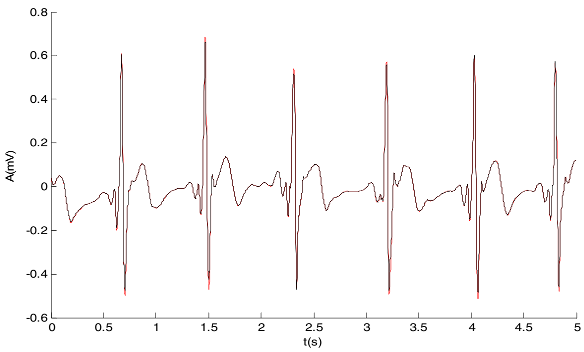

Fig. 8. Meridian ECG transmission model based on NARX network

Note: In Fig. 6,7 and 8, the red line represents the real ECG output of Neiguan; the black line represents the ECG output of the model.

V. CONCLUSIONS

Coronary heart disease is one of leading-rank causes of death in the world. Identifying the characteristics of ECG signals on human meridians is significant in the exploration of new alternative and complementary therapies for chronic cardiovascular diseases. In this paper, an ECG measuring experiment at seven acupoints of the Pericardium Meridian of Hand-Jueyin was developed to achieve the meridian information transmission data. In terms of the nonlinear feature of ECG signal at acupoints, a nonlinear autoregressive with exogeneous inputs (NARX) network is built for the modeling of meridian information transmission system. The analysis results of ten subjects show that the NARX model has better performance than the autoregressive with exogenous input (ARX) model and the autoregressive and moving average model with exogenous input (ARMAX) in ECG signal prediction at meridian acupoints. The prediction accuracy of meridian ECG data by the NARX model is larger than 0.98. The results obtained in this paper also provide a scientific theoretic basis to develop new telemedicine systems for cardiovascular diseases based on TCM theory.

ACKNOWLEDGMENT

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TABLE II. MEAN VALUE OF PREDICTION ERROR RMSE OF NARX NEURAL NETWORK MODEL

Subject No.	M1	M2	M3	M4	M5	M6
001	0.0127	0.0097	0.0097	0.0092	0.0101	0.0101
002	0.0039	0.0039	0.0037	0.0039	0.0039	0.0038
003	0.0020	0.0019	0.0018	0.0019	0.0019	0.0021
004	0.0055	0.0058	0.0058	0.0059	0.0059	0.0059
005	0.0035	0.0035	0.0034	0.0035	0.0036	0.0033
006	0.0019	0.0017	0.0018	0.0019	0.0019	0.0018
007	0.0045	0.0044	0.0043	0.0044	0.0042	0.0044
008	0.0023	0.0027	0.0027	0.0025	0.0026	0.0025
009	0.0056	0.0057	0.0056	0.0057	0.0058	0.0058
010	0.0046	0.0046	0.0043	0.0045	0.0044	0.0044

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