A Simulation Method of Magnetic Treatment to Depressed Brain based on Chaotic Network

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Abstract. Chaotic neural network has a wide range of applications, especially in uncertain time-series prediction. Aihara Neural Network takes refractoriness into consideration and shows superiority in solution to TSP. The inspiration was from peers' work on specifically targeted on deep brain by nanometre materials. We defined a complex system with 16 brain regions related to depression. Based on BOLD signals, we reconstructed the connectivity matrix and the parameters and applied modeled signals as irritation to specific region to provide a model prototype. The comparison between Power Spectral Entropy before and after irritation indicates the relation between physical irritation and curative effect. The results proved the obligation to implement multi-point treatment.

Keywords: chaotic network; simulation; electromagnetic stimulus; brain region.

1. Introduction

Chaos as a normal phenomenon in the biological neurons, its combination with neural network can more real close to the brain neural network. In 1990, Aihara proposed a chaotic neural network model on the basis of biological experiments and added refractoriness as a parameter controlling its dynamic properties.[1][2] The model inherits the parallel processing ability, network learning ability, associative ability of neural network, and it has better nonlinear approximation and self-learning ability [3]. It has been widely applied in areas such as network communication, combinatorial optimization and artificial intelligence.

In this article, we mainly pay attention to the application of Aihara chaotic neural network in the medical field, especially in the therapy of MDD. We utilized bold signals of the patients, weighing the activity of brain regions, to construct the connectivity matrix and then build the network, where controlling parameters have been properly chosen.[4] Modeled signals simulating physical irritation was exerted on the specific brain regions to generate corresponding outputs, which may measure the curative effects. Although the model can only predict transient changes in brain regions receiving stimulus due to, we neglected the dynamical alteration of the connectivity, the achievement uncovered a new chapter of modeling depression and can provide ideas for further studies.

2. Aihara Chaos Model and its Simplification

In 1990, Aihara proposed a kind of chaotic neural network consists of M neurons, dynamic equations of the neuron are defined as follows:

$$x_i(t+1) = f_i\left(\sum_{j=1}^{M} V_{ij} \sum_{d=0}^{t} k_e^d A_j(t-d) + \sum_{j=1}^{N} W_{ij} \sum_{d=0}^{t} k_f^d h_j(x_j(t-d))\right) - \alpha \sum_{d=0}^{t} k_r^d g_i(x_i(t-d) - \theta_i) \tag{1}$$

Where Network external input function $A_j(t)$, via the

i-th neuron connection weight v_{ij} act on $x_i(t)$. Network internal neurons feedback function $h_j(x_j(t))$, via the weight W_{ij} between neurons act on $x_i(t)$, Neurons refractoriness influence function is expressed as $g_i(x_i(t))$. Full or no excitation threshold of neurons is θ_i.

Where: α =refractoriness parameters; k_r^d =external input attenuation coefficient; k_f^α =feedback input attenuation coefficient ; k_r^d =refractoriness influence attenuation coefficient.

This equation can be simplified as the following recursions:

$$\begin{cases} x_i(t+1) = f_i[\xi_i(t+1) + \eta_i(t+1) + \zeta_i(t+1)] \\ \xi_i(t+1) = \sum_{j=1}^{M} V_{ij} A_j(t) - k_e \xi_i(t) \\ \eta_i(t+1) = \sum_{j=1}^{N} W_{ij} h_j(x_j(t)) - k_f \eta_i(t) \\ \zeta_i(t+1) = -\alpha g_i(x_j(t)) + k_r \zeta_i(t) - \theta_i(1-k_r) \end{cases} \tag{2}$$

3. Methods

3.1 Brain Region Selection

We use specified brain region as 'node' defined in Aihara model. Therefore, according to medical research results [5], we selected the following 16 representative brain regions as simulation nodes. These nodes are of high-level relationship to depression. The 16 brain regions and their numbers are showed in Table 1.

Table 1. specified simulating brain regions and numbers.

Number	Name
1	frontal cortex
2	gyrus cinguli
3	Primary Visual Cortex
4	posterior hypothalamic area
5	DMH
6	VMH
7	CA1 - a
8	fascia dentata
9	VTA
10	ventral pallidum
11	amygdaloid nucleus
12	nucleus accumbens septi
13	corpus striatum
14	habenula nucleus
15	thalamic reticular nucleus
16	subthalamic nucleus

3.2 Coefficient of Association

In Aihara model, different neurons require W_{ij} to describe the level of coupling weight. According to the work constructed before [7], we calculate Spearman Coefficient of 16 brain regions' fMRI data to obtain the Matrix W. The data set is from website connectivity.brain-map.org. Thus, the connection matrix is showed in Figure 1.

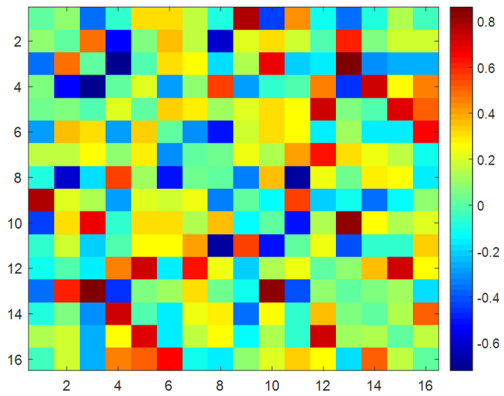


Fig. 1 Coupling Weight Matrix

3.3 Response Without Input

According to previous research work, a combination of parameters can be set as:

$$k_f = 0.3, k_r = 0.7, a_i = 2, \alpha = 10.$$

Let all initial outputs be zeros without stimulus, the simulation sequential of regions is showed as Figure 2. The sequential of different brain region has chaotic characteristics, the chaotic degree can be measured by Lyapunov index [6]. Because of constraints of space, we will not elaborate on those researches on dynamics.

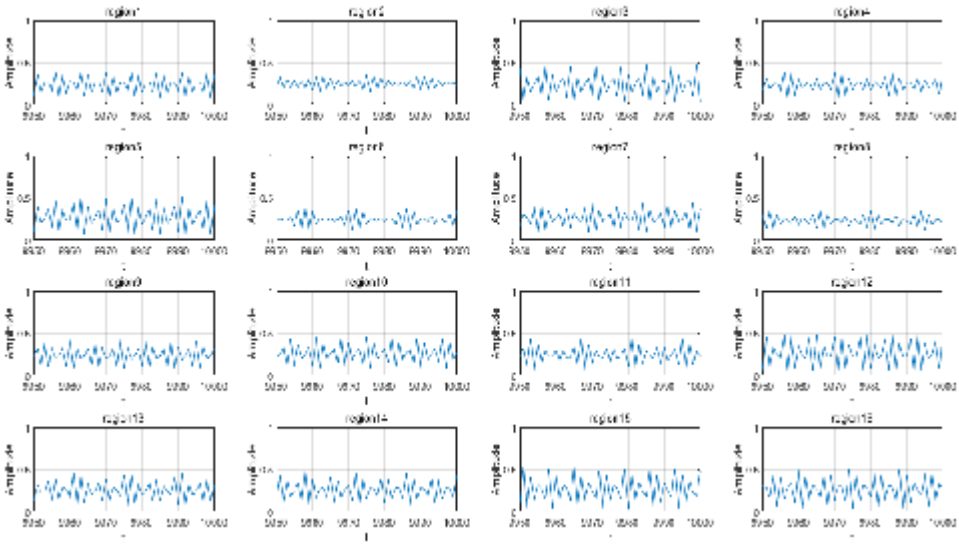


Fig. 2 zero input response

3.4 Introduction of Activity Degree

To describe the effects of specific stimulus, we should measure the activity degree of simulated brain signals. Therefore, we calculate the energy of series in high-frequency spectrum, as the definition of 'activity degree'. By executing different combination of stimulus, we can compare the results before and after our work and then provide some specific curing methods.

Firstly, we gave the activity degree when no stimulus is executed on the model, the result is in correspondent to Figure 2. The activity degree of each region indicates the changing speed of brain signals. As Figure 3 shows, signals of region 2,6,8,13 are relatively 'active' in the group of parameters, while those of region 5,12 are relatively 'inactive'. The result is fundamentally consistent to conclusions in medical research of depression patients [8] and that indicates the rationality of our processing work.

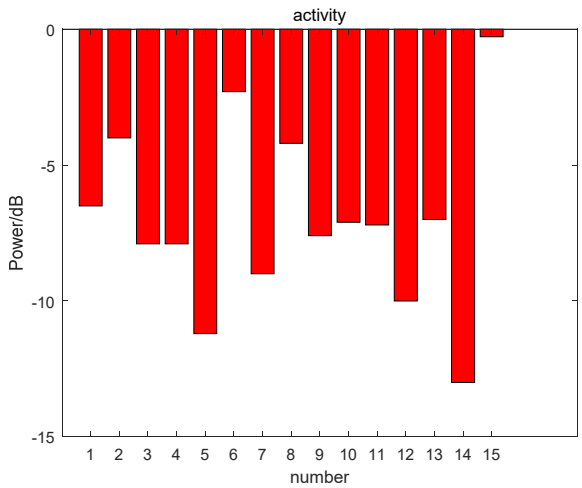


Fig. 3 Activity of brain signals

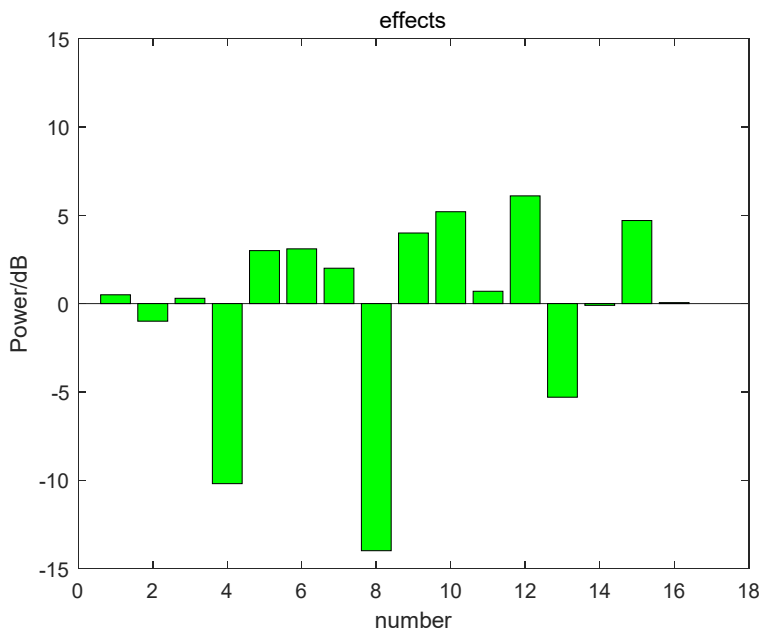
3.5 Stimulus Execution

In practice in medical work, targeted electromagnetic stimulus has superior curing effects. In our simulation, there are 16 regions with 216 possible stimulus combinations. To filter one or more combinations, the condition should be set according to results in medicine. When depression patients turn for better, the activity of some brain signals should change as following rules [9]:

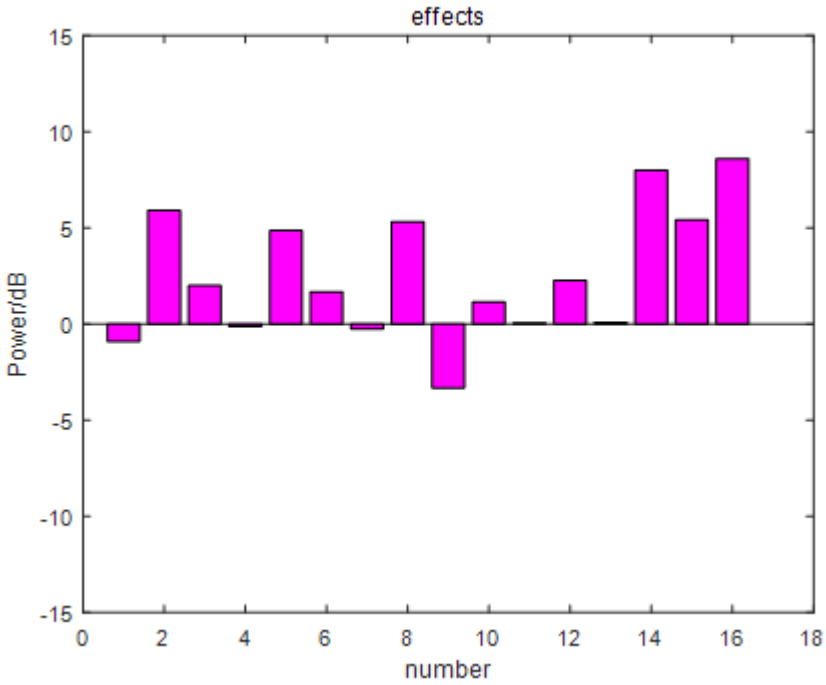
Table 2. Expected changes of brain signals

Region number	Name	Changes expected
1	frontal cortex	↑
7	CA1 - a	↑
14	habenula nucleus	↓

We introduced above 3conditions as constraints. After large-scale computation, we come to only 1 stimulus combination: with a simultaneous stimulation in region 4,5,7,12,15,16. The changes in activity are showed in Figure 4(a).



(a)



(b)

Fig. 4 (a): Changes after specified stimulus.

(b): Changes after stimulus in all regions.

In comparison, traditional treatment like TMS, could be thought as executing stimulation in all brain regions, as Figure 4(b) demonstrates. However, the specified stimulation combination shows much superiority in treatment effects in view of previous conditions.

4. Conclusion

Through research and experiments on Aihara network, we introduced the model to brain signal simulation. While it is acknowledged that nanometer materials could realize targeted stimulus in Psychiatric treatment, our results not only provided a prototype for stimulus effect predication, but also showed the necessity to execute accurate and specified combination to optimize the treatment effects.

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