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Dynamic properties of feed-forward neural networks and application in contrast enhancement for image[☆]

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ABSTRACT

This paper is concerned with three neurons feed-forward neural network model and more specifically with the study of dynamical behavior of the codimension one nilpotent singularity and 1:1 resonant Hopf bifurcation and outline possible image processing applications. Three neurons dynamical feed-forward neural networks use cross-coupling and feed-forward-coupling to form an nonlinear dynamic neural oscillator with the time delay. The theoretical basis of the pitchfork and 1:1 resonant Hopf bifurcation of feed-forward neural networks with delay is carried out and the analytical formulas are derived to define the various states of the system. The ultimate goal is to understand the dynamics and seek the application in image processing. It is shown that each of these states has a significant impact on the quality of the resulting image contrast enhancement. As application, aiming at the characteristics of remote sensing images with low-contrast and poor resolution textual information, an image enhancement method is presented. We show theoretically and numerically that the gray scale remote sensing image picture contrast is strongly enhanced even if this one is initially very small. The results show that the algorithm can significantly improve the visual impression of the image. Compared with the proposed algorithms in recent years, the information entropy are significantly improved.

1. Introduction

The theories and applications of neural networks have been extensively developed after the works of Cohen [1] and Hopfield [2]. The research of neural network is quite extensive, which reflects the characteristics of the multi discipline cross technology field. Due to the finite propagating speed in the signal switching and transmission between the neurons, time delay is inevitable in the neural network and thus should be incorporated in the mathematical model. Different types of neural network systems with time delays have been proposed and developed. In these models, various types of dynamical behaviors including stability, chaos, Hopf bifurcation, global Hopf bifurcation, pitchfork-Hopf bifurcation, Bogdanov–Takens bifurcation and Hopf-Hopf bifurcation were investigated. See Ref. [3–11]. In 2004, Ruan et al. [12] presented a two-neuron network model with multiple discrete and distributed delays, where the distributed delays describe the neural feedback, and the discrete delays describe the neural interaction history:

$$\begin{cases} \dot{x}_1 = -\mu x_1(t) + a_{11} f_{11}\left(\int_{-\infty}^{t} F(t-s) x_1(s-\tau) ds\right) \\ \quad + \ a_{12} f_{12}(x_2(t-\tau)), \\ \dot{x}_2 = -\mu x_2(t) + a_{22} f_{22}\left(\int_{-\infty}^{t} F(t-s) x_2(s-\tau) ds\right) \\ \quad + \ a_{21} f_{21}(x_1(t-\tau)). \end{cases} \tag{1.1}$$

If the two neurons in the network exhibit the same linear behavior in response to the same outputs, then Equation (1.1) can be rewritten as follows, see Ref. [13]:

$$\begin{cases} \dot{x}_1 = -x_1(t) + af(x_2(t)) + bf(x_3(t-\tau)), \\ \dot{x}_2 = -\alpha x_2(t) + x_1(t-\tau), \\ \dot{x}_3 = -x_3(t) + af(x_4(t)) + bf(x_1(t-\tau)), \\ \dot{x}_4 = -\alpha x_4(t) + x_3(t-\tau), \end{cases} \tag{1.2}$$

which a two-neuron network model with delay feedback.

This paper partly deals with the case of feed-forward systems. We consider the following three-neuron feed-forward neural

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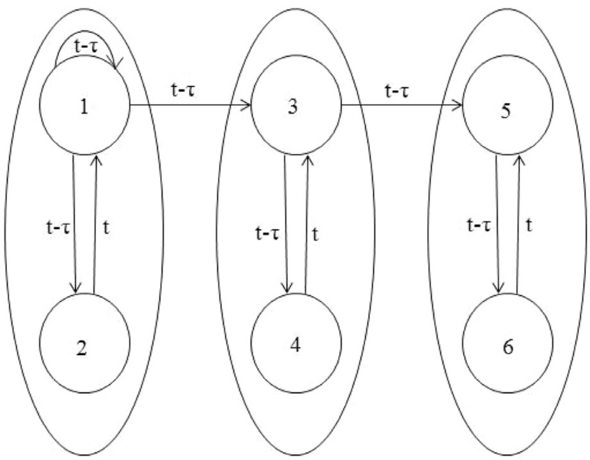

Fig. 1. Feed-forward three-neuron network model.

network model (see Fig. 1):

$$\begin{cases} \dot{x}_1 = -x_1(t) + af(x_2(t)) + bf(x_1(t-\tau)), \\ \dot{x}_2 = -\alpha x_2(t) + x_1(t-\tau), \\ \dot{x}_3 = -x_3(t) + af(x_4(t)) + bf(x_1(t-\tau)), \\ \dot{x}_4 = -\alpha x_4(t) + x_3(t-\tau), \\ \dot{x}_5 = -x_5(t) + af(x_6(t)) + bf(x_3(t-\tau)), \\ \dot{x}_6 = -\alpha x_6(t) + x_5(t-\tau). \end{cases} \tag{1.3}$$

a, α and b are positive coupling coefficients, $\tau \geq 0$ is a delay. The output function f is assumed as: $f(x) = tanh(x)$. Variables $x_i(i = 1, 2 \cdots, 6)$ are the state of neurons respectively.

There are many interesting properties in the feed-forward chain model which have great potential application prospect. For example, signal propagation in the feed-forward neural network has been discussed by some researchers, see [14–18]. In Ref. [14], the authors presented the results of an experimental investigation of a network of nonlinear coupled oscillators which are coupled in feed-forward mode. By exploiting the nonlinear response of each oscillator near its intrinsic Hopf bifurcation point, they found remarkable amplification of small signals over a narrow bandwidth with a large dynamic range. The effect is exploited to extract a small amplitude periodic signal from an input time series which is dominated by noise.

In the classical Hopf bifurcation theorem for ordinary differential equations, as a pair of complex-conjugate simple eigenvalues crosses the imaginary axis, there is born a unique branch of periodic orbits near an equilibrium point. If the purely imaginary eigenvalues at criticality are assumed to be double and non-semisimple, then 1: 1 resonant will happen. In this paper, we show that 1: 1 resonant Hopf bifurcation will occur in feed-forward neural network model (1.3).

Neural networks have been widely used in the field of image processing, and have achieved a lot of good effect. In Ref. [19], the authors constructs a memristive pulse coupled neural network (M-PCNN) for medical image processing. Tan et al. [20] proposed a new method of image brightness and contrast enhancement based on high frequency enhancement and neural network. A low contrast image adaptive enhancement algorithm based on RBF neural network was proposed by Zhao et al. [21]. Kamil Dimililera [22] and others proposed about effect of image enhancement on MRI brain images with neural networks. Recently, nonlinear dynamic system image process methods have been reported in some researches, where they have been shown that some nonlinear oscillators network have devoted to image processing [21–25]. For example, in Ref. [25], a contrast enhancement and image inverting tool using a lattice of uncoupled nonlinear oscillators was been proposed. In Ref. [26], the authors proposed a dynamically coupled neural oscillator network for image segmentation. In this paper, based on amplification of small signals over a narrow bandwidth with a large dynamic range, which is caused by 1: 1 resonant Hopf bifurcation, we presents a method of image enhancement using feed forward neural network model. To the best of our knowledge, this research has not been reported.

The remote sensing image is a special image recording the geomorphological features and information. It is widely used in many fields, such as agriculture, forestry, geology, marine, meteorology, hydrology, environmental protection, and so on. In the acquisition, transmission, and reception of remote sensing images, image quality is affected by atmospheric radiation, external interference, and poor performance of the sensor. These factors lead to poor image quality and weaken the ability to recognize features therein. Therefore, the use of image enhancement technology is required, see Ref. [27,28]. The idea here is to use feed-forward neural network model (1.3) to selectively amplify an input gray of an remote sensing image image as initial value of the feed-forward neural networks model with delay, in which the 1:1 Hopf bifurcation occurs of the system.

In this paper, we first give the dynamic properties of three-neuron feed-forward neural network model (1.3). In Section 2, the results on pitchfork and Hopf bifurcations are given by employing the functional differential equations theories. In particular we shall consider two stages of the concerning the Hopf bifurcation and the 1:1 resonant Hopf Bifurcation. The former of these deals with the bifurcation from stationary to periodic dynamics in the second neuron, the latter deals with the third neuron concerns the 1:1 resonant Hopf bifurcation. Some numerical simulation support our conclusions. Furthermore, from the experimental investigation, we found remarkable result: the amplitude of the periodic solutions can be expected to grow bigger in the x_5 and x_6 then in the x_3 and x_4 which is simply to the conclusion of Golubitsky [14]. In Section 3, by exploiting the nonlinear response of each neuron near it's intrinsic Hopf bifurcation point, we found the amplification of small signals. This is achieved using stochastic resonance for small signals transmission motivated by the reported. As an application, an image contrast enhancement tool using the feed-forward neural networks is proposed. In section 4, based on the analyses a remote sensing image enhancement method is proposed in this article. We show theoretically and numerically that the gray scale picture contrast of remote sensing image is strongly enhanced even if this one is initially very small. We show that Eq. (1.3) allows a contrast enhancement in real time.

2. Dynamic properties of feed-forward neural networks

2.1. Codimension one simple or double zeros bifurcation

The existence of zero eigenvalue make the system have zero singularities (steady-state bifurcation, Bogdanov–Takens bifurcation, etc.). Nilpotent bifurcations have been extensively studied by many researchers. If the Jacobian of a system evaluated at a critical point involves one or two zero eigenvalues, the so-called simple zero or double zero bifurcation may occur. In this paper we attempt to study the bifurcations from such singularities arise in feed-forward neural network model (1.3). It is clear that (0, 0, 0, 0, 0, 0) is an equilibrium point of Eq. (1.3). The linearization of Eq. (1.3) at the origin leads to