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# Local and global Hopf bifurcation analysis on simplified bidirectional associative memory neural networks with multiple delays \*

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**Abstract** In this paper, a class of simplified bidirectional associative memory (BAM) neural networks with multiple delays are considered. By analyzing the associated characteristic transcendental equation, their linear stability is investigated and Hopf bifurcation is demonstrated. By applying Nyquist criterion, the length of delay which preserves the stability of the zero equilibrium is estimated. Some explicit results are derived for stability and direction of the bifurcating periodic orbit by using the normal form theory and center manifold arguments. Global existence of periodic orbits is also established by using a global Hopf bifurcation theorem for functional differential equations (FDE) and a Bendixson' criterion for high-dimensional ordinary differential equations (ODE) due to Li and Muldowney. Finally, numerical simulations supporting the theoretical analysis are carried out.

**Keywords:** Neural networks; Stability; Hopf bifurcation; Delay; Periodic solution

## 1. Introduction

In recent years, the dynamical behaviors of neural networks with delays have become a subject of intense research in mathematical fields because of the successful application to many areas such as intelligent control, optimization solvers, associative memories (or pattern recognition) and so on. Many excellent and interesting results have been obtained (see [1-14]). It is well known that the dynamics such as periodic phenomenon, bifurcation and chaos are of great interest and periodic phenomenon has become an important aspect of neural information processing. There are a large number of results about the existence of periodic solutions of neural networks (see [3,14-19]) which help us grasp the system's dynamics. Also these results are important complements to experimental and numerical investigations using analog circuits and digital computers. The delayed bidirectional associative memory neural networks are described by the following system:

$$\begin{cases} \dot{x}_i(t) = -\mu_i x_i(t) + \sum_{j=1}^m c_{ji} f_i(y_j(t - \tau_{ji})) + I_i, i = 1, 2, \dots, n, \\ \dot{y}_j(t) = -\nu_j y_j(t) + \sum_{i=1}^n d_{ij} g_j(x_i(t - \nu_{ij})) + J_j, j = 1, 2, \dots, m, \end{cases} \quad (1.1)$$

where  $c_{ji}, d_{ij} (i = 1, 2, \dots, n; j = 1, 2, \dots, m)$  are the connection weights through neurons in two layers: the  $I$ -layer and  $J$ -layer;  $\mu_i$  and  $\nu_j$  describe the stability of internal neuron processes on the  $I$ -layer and  $J$ -layer, respectively. On the  $I$ -layer, the neurons whose states are denoted by  $x_i(t)$  receive the inputs  $I_i$  and the inputs outputted by those neurons in the  $J$ -layer via activation functions  $f_i$ , while on the

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