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Recognition of noisy images by PLL networks

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ABSTRACT

We use networks composed of three phase-locked loops (PLLs), where one of them is the master, for recognizing noisy images. The values of the coupling weights among the PLLs control the noise level which does not affect the successful identification of the input image. Analytical results and numerical tests are presented concerning the scheme performance.

1. Introduction

Phase-locked loops (PLLs) are electronic devices employed in control and communication systems [1–4]. They can be also used for modeling neural networks [5–9]. These models can be useful for accomplishing signal processing tasks and for understanding the functioning of nervous systems. For instance, Hoppensteadt and Izhikevich [6] proposed to employ a network of n mutually coupled PLLs in order to determine if an input image is identical or not to any of the images stored in the memory of this network. Each PLL corresponds to one pixel of the image and the recognition occurs by the synchronization of the PLLs. Fig. 1 represents their network composed of five PLLs. Notice that the PLL outputs are weighted by the constants s_{ij} and used to form the input of each one of them. Parameter s_{ij} is defined as the coupling (synaptic) weight connecting the output of the j-th to the input of the i-th PLL.

Training the network means to find values of the weights s_{ij} so that, after an input pattern being introduced, the PLLs would converge to a steady state corresponding to one of the stored patterns. Hoppensteadt and Izhikevich argue that appropriate values of s_{ij} are given by [6]

$$s_{ij} = \frac{1}{n}\sum_{m=1}^{p} \xi_i^m \xi_j^m \tag{1}$$

where $\vec{\xi}^m = (\xi_1^m, \xi_2^m, \ldots, \xi_n^m)$ is the vector with n components representing the m-th pattern to be stored. For a binary (black-and-white) pattern, then $\xi_i^m \in \{-1, +1\}$, where -1 corresponds to white pixel and $+1$ to black pixel. Number p represents the total of memorized patterns. This choice of s_{ij} is inspired by the law of synaptic modification proposed by Hebb [10].

The input pattern is codified as the initial condition of the dynamical system describing this network; that is, the input is translated as the initial phase of each PLL. It can be assumed that a white pixel (-1) corresponds to phase equal to 0, and a black pixel ($+1$) corresponds to phase

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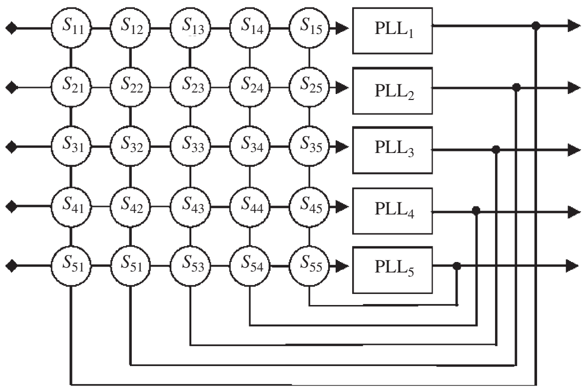

Fig. 1. Associative memory network with five mutually coupled PLLs, where s_{ij} is the coupling weight between the output of the j-th and the input of the i-th PLL.

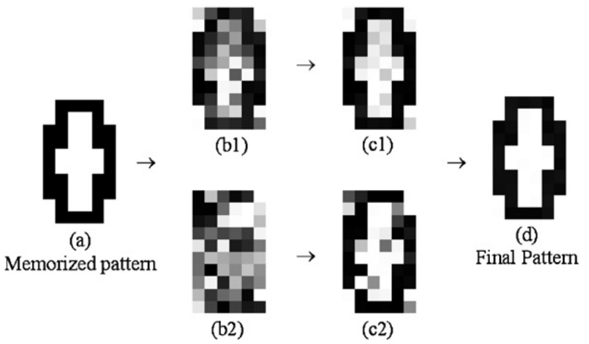

Fig. 2. Recognition of the stored pattern by Hoppensteadt and Izhikevich's network with 6×10 PLLs: (b1) and (b2) represent two distinct initial conditions (two input images), (c1) and (c2) are transient configurations, and (d) is the permanent regime reached by the network.

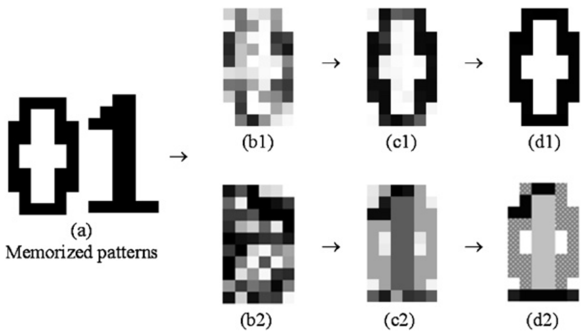

Fig. 3. Convergence to correct and spurious patterns in Hoppensteadt and Izhikevich's network with 6×10 PLLs: (b1) and (b2) represent two distinct initial conditions (two input images), (c1) and (c2) are transient configurations, and (d1) and (d2) are the permanent regimes reached by the network.

equal to π. Intermediate values between 0 and π are associated with gray levels.

Fig. 2 illustrates the recognition of the stored pattern (a) from two distinct initial conditions (b1) and (b2). The configurations (c1) and (c2) are transitory states of the network and (d) is the state reached in the permanent regime.

However, if more than one pattern is stored by employing Hebb's law to determine the weights s_{ij}, the network also stores undesirable patterns, usually called spurious patterns. Fig. 3 shows that when two patterns are memorized by using Hebb's law, the PLL network can converge to a spurious pattern. In fact, from the initial condition (b1) one of the deliberately stored patterns represented by state (d1) is reached in the permanent regime, but from the initial condition (b2) a spurious pattern (d2) is attained. A modified version of this network [11] only partially fixed this problem.

Here we propose a PLL network with four stages (A–D) for recognizing a unique pattern. Hoppensteadt and Izhikevich's network recognizes a unique pattern; however, any input converges to it (Fig. 2 illustrates this case). In our network, we can choose the noise level superposed to the stored pattern that does not affect its recognition. Thus, we can control the imperfection degree in the input image that does not have effect upon its identification. We did not find this feature in other neural oscillator networks. Possible applications include detection of pieces with irregularities in an assembly line (allowing automatic rejection), selection of fingerprints similar to what was found at a crime scene (where the similarity level is controlled by the values of s_{ij}), biometric authentication of a particular individual, etc. Our scheme can be the starting point for building a dedicated hardware device for accomplishing these tasks.

Recognition in our network is also given by synchronization among PLLs; however, instead of each pixel being associated with one PLL, in our network each pair of pixels is associated with three PLLs, where one of them is the master (the reference for the other two PLLs). This master is common to all pairs of PLLs as explained below.

The key for successful recognition is the choice of the values of s_{ij}. These numbers determine the existence and the stability of the synchronous solutions, as shown in the next section. In the third section, the four stages of our identification scheme are described and the results are presented.