A Neural Network Approach to Classifying Banana Ripeness

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Introduction

- Motivated by study by Saad et al. [2009].

Data Collection

- Generated the data set by taking pictures of bananas and objects that are not bananas.
- Lighting, camera (Canon S90) and background were controlled.
- Used 12 unique bananas at various stages to represent the three stages ripeness:
  1. pre-ripe,
  2. ripe, and
  3. rotten.
- Used green pepper, apple, tomato, lemon and lime as non-banana objects.
- Pictures were resized and cropped.
- To minimize the number of pictures taken,

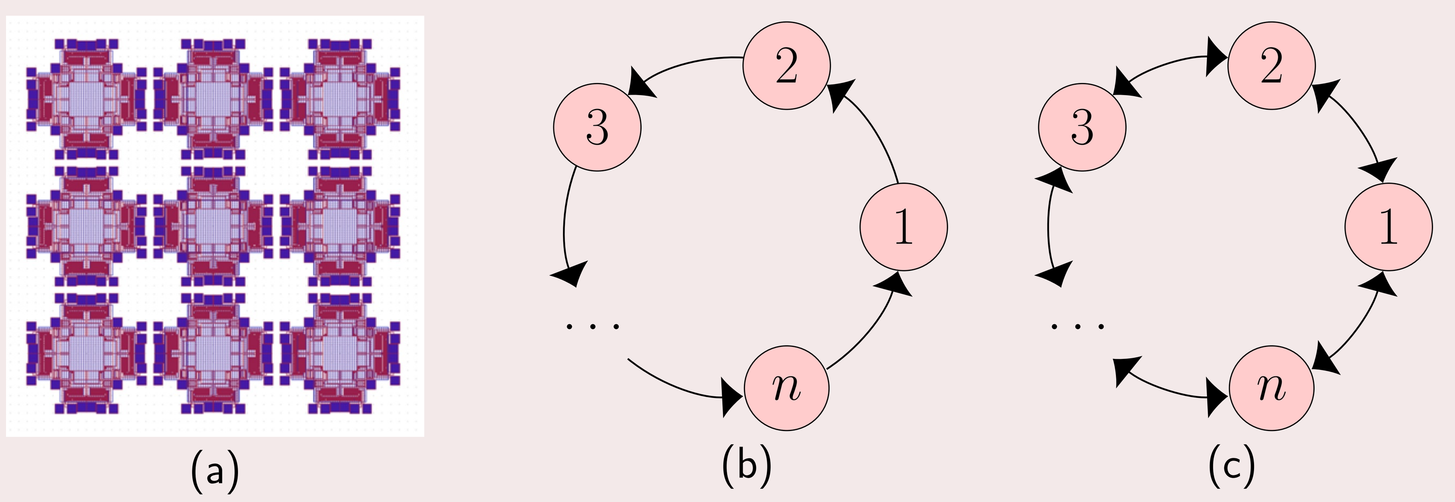

Figure 1: (a) Nine MEMS gyroscopes on a chip. (b) Unidirectionally coupled ring. (c) Bidirectionally coupled ring

This result implies that, when coupling Hamiltonian subsystems with identical coupling functions, the coupling topology alone could determined whether the coupled system remains Hamiltonian. Arising naturally from the aforementioned result, we have the following question:

Question on Topology and Coupled Hamiltonian Systems

Hamiltonian Coupled Cell System

For the purpose of this work, a Hamiltonian coupled cell system is a Hamiltonian differential system that satisfies the definition of a coupled cell system as defined by Krizhevsky et al. [2012]. As such, each cell is a system of differential equations with phase variable $x_i \in \mathbb{R}^{k_i}$, for $i \in \{1, \dots, n\}$. Suppose that cell i receives input from cells $j_1, \dots, j_{m_i} \in \{1, \dots, n\}$, then the dynamics of the i^{th} component is

$$\frac{dx_i}{dt} = g_i(x_i) + h_i(x_{j_1}, \dots, x_{j_{m_i}}),$$

where g_i and h_i represent the internal and coupling dynamics, respectively. Then, at the linear level, the matrices for the internal and coupling dynamics can be written as

$$\left.\frac{\partial g_i}{\partial x_i}\right|_{x=0} = Q_i \text{ and } \left.\frac{\partial h_i}{\partial x_j}\right|_{x=0} = R_{ij},$$

where $x = (x_1, \dots, x_n)^T$, $Q_i \in \mathbb{R}^{k_i \times k_i}$, and $R_{ij} \in \mathbb{R}^{k_i \times k_j}$. Let 0_l and I_l denote the $l \times l$ zero and identity matrices, respectively. Then the general skew symmetric matrix J can be written as

$$J = \operatorname{diag}(J_1, \dots, J_n), \text{ where } \ell_i = k_i/2 \text{ and } J_i = \begin{bmatrix} 0_{\ell_i} & I_{\ell_i} \\ -I_{\ell_i} & 0_{\ell_i} \end{bmatrix}.$$

Based on these definitions, we can state the linear criteria for coupling Hamiltonian subsystems.

General Linear Criteria

Suppose we have a connected coupled cell system. Let the functions for the internal dynamics be Hamiltonian. Then, the linearized system at the origin is Hamiltonian if and only if

$$R_{ji}^T J_{l_j} + J_{l_i} R_{ij} = 0, \qquad \text{for } 1 \le i, j \le n.$$

Regular Hamiltonian Coupled Cell Systems

A system is called *homogenous* if all the nodes are of the same type and a homogenous system with identical couplings is a *regular* system. We may represent the topology of these systems graphically using digraphs. The *adjacency matrix* $A(G)$ associated with a directed graph G is the integer matrix with rows and columns indexed by vertices of G, such that the $A(G)[i, j]$ is equal to the number of arcs from cell i to cell j.

Criteria for Regular Hamiltonian Systems

For a regular coupled cell system, the linearized system at the origin is Hamiltonian if and only if the adjacency matrix of the digraph associated with the coupled cell system is symmetric.

Nonlinear Systems

Thus far, we have discussed the linear criteria for coupling general Hamiltonian subsystems together. To investigate general Hamiltonian coupled cell systems, we must investigate nonlinear topological criteria.

General Nonlinear Criteria

Suppose that a coupled cell system is Hamiltonian and the associated digraph is connected, then the digraph must be bidirectionally coupled. i.e., if there is an arc from cell i to j, then there must be a reciprocal connection from cell j to i.

Based on all aforementioned criteria, the digraph in Figure 2 is a nontrivial example that would admit a general nonlinear Hamiltonian coupled cell system.

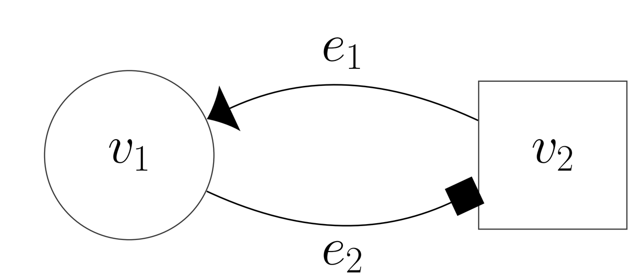

Figure 2: Example of a digraph representing a Hamiltonian coupled cell system.

Conclusion and Future Work

As shown by the example from the gyroscopic system, we found that, when coupling Hamiltonian subsystems together, not all topological configurations will allow the overall system to remain Hamiltonian. Motivated by this counterintuitive example, we showed that there are linear and nonlinear criteria to consider in coupling Hamiltonian systems. Hence, we are now ready to construct general Hamiltonian systems and investigate their dynamics. Currently, we are investigating the generic codimension-one bifurcations that could arise from Hamiltonian coupled cell systems.

Acknowledgement

References

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