

Dynamical Systems Approach for Predator–Prey Robot Behavior Control via Symbolic Dynamics Based Communication

R

Sumona Mukhopadhyay

University of Calgary, Canada

Henry Leung

University of Calgary, Canada

1. INTRODUCTION

The study of complex systems (Badii & Politi, 1997; Macau & Grebogi, 1999) has created a lot of research interests especially due to its diverse applications in science, engineering, management and biological systems. These exhibit emergent behavior that is neither completely ordered and predictable, nor completely random and unpredictable. It produces patterns and hierarchy of structures which emerge due to its attractor dynamics (Grassberger, 1991; Poon & Grebogi, 1995). Artificial intelligence, adaptive networks, collective intelligence, and chaos fall under this category. Out of these, chaotic system is the area under investigation in this work. Chaotic systems can be controlled through the technique of chaos synchronization (Pecora & Carroll, 1990). It involves the coupling of two chaotic systems so that both achieve identical dynamics asymptotically with time. Such non-linear systems have been effectively used in a plethora of engineering and scientific applications (Maoyin, 2008; Fallahi & Leung, 2010; Mukhopadhyay et al., 2010; Fan et al., 2010; Banerjee et al., 2012).

An emergent area of robotics is based upon the paradigm of behavior-based robotics and it deals with an entirely different information flow structure than that of the classical artificial intelligent systems. This work presents an application of a nonlinear biological system in the area of chaos navigation with mobile robots and accomplishment of its control. The objective is to extend the phase synchronization of identical unidirectional coupled chaotic food webs (Blasius & Stone, 2000; Stone & He, 2007) in a robot foraging task. Chaotic synchronization promotes cooperative task

achievement. Collaborative mobile robot exploration is achieved through noise aided synchronization of a two-wheeled mobile robot that follows the predator – prey dynamics. Thus, a bio-inspired mobile robotic design is proposed for the task of coverage of a workspace that is completed when a specified portion of the workspace is explored.

2. BACKGROUND

Robots are a complex dynamical system characterized through statistical measures and mathematical expressions describing the system dynamics. Cooperative robots accomplish the goal of workspace coverage faster than an atomic robot (Cao et al., 1997). Effective collision-free robot motion and coverage, planning (Shiller & Gwo, 1991; Klomkam & Sooraksa, 2004; Yang & Luo, 2004; Hazan, et. al, 2006; Willms & Yang, 2006; Fallahi & Leung, 2010; Volos & Kyprianidis, 2012), robustness of synchronous speeds against robot and communication failures (Zang et al., 2006) are important issues in robotics currently under research. In order to execute cooperative task assignment, control strategies must be formulated.

Over the past few years, research has been conducted to propose methods that ensure a chaotic navigation of the search space (Sekiguchi & Nakamura, 2001) based on the chaotic features of sensitive dependence on initial conditions and topological transitivity. Recently, a dynamical perspective has paved its way into cognitive science (Garson, 1996; Beer, 2000; Nehmzow, 2006; Khansari-Zadeh & Billard, 2012). Such an approach implies that the process of natural cognition is dynami-

DOI: 10.4018/978-1-4666-5888-2.ch651

cal in nature and mathematically can be modeled to describe its evolution. Special emphasis is laid over the emergent structure of the trajectories of the system and its component parts which influence its shape and allows in comprehending the underlying mechanisms that instantiate such complex dynamics. A minute perturbation to the inputs of the robots control would affect the relationship and interaction with its operating environment. Hence, it is imperative for a thorough understanding of the complex interaction and stability of the robot system. Dynamical systems can generate trajectories for movement that are robust against minute perturbations. It is in this light, that dynamical systems theory is adept at the analysis of all aspects of mobile robots behavior. It mathematically describes methods to visualize an agent's (robot) motion through space and to analyze its properties. This area of study can reach its potential by augmenting with situated agent whose objective is to take action appropriate to its circumstances and goals. The benefits of the dynamic behavior of chaotic nonlinear systems find its application as a controller to aid autonomous robots in foraging and exploration task. A promising new field in the study of robotics concerns the bio-inspired robotics (Hoffmann et al., 2009) wherein attempt is made to transfer the behaviors observed in the biological world to robots. It is necessary to observe the solutions that occur naturally for the problems that most autonomous robots must face, which includes obstacle avoidance and goal-oriented search.

The rest of the article is organized as: Section 3 discusses the problem statement and objective. Section 4 elaborately describes the synchronized chaotic dynamics of the system model followed by a detailed analysis of its synchronization through symbolic dynamics in Section 5. Section 6 presents the simulation result. Section 7 highlights few of the future research directions followed by a conclusion in Section 8.

3. PROBLEM STATEMENT AND OBJECTIVE

The mechanism for coordination to perform a collaborative task is non-trivial for which effective solutions are being explored. The complex dynamics of an ecological system is used to drive a two-wheeled mobile robot around a set of arbitrarily distributed

fixed obstacles. The mobile robot is chaotically synchronized in the presence of noise that behaves as a controller with another mobile robot operating under the same dynamics. We examine the efficiency of the synchronization of such a complex high dimensional system modelled as an extended system of a three species predator-prey system using symbolic dynamics (Kennel & Buhl, 2003; Hirata et al., 2004; Caneco et al., 2008; Mukhopadhyay & Leung, 2013).

4. THE CHAOTIC PREDATOR PREY SYSTEM

The general form of a three species vertical food-web ecological model (Stone & He, 2007):

$$\begin{aligned}\dot{x}_1 &= x_1 - x_1^* - \alpha_1 x_1 x_2 \\ \dot{x}_2 &= -\beta \left(x_2 - x_2^* \right) + \alpha_1 x_1 x_2 - \alpha_2 x_2 x_3 \\ \dot{x}_3 &= -\gamma \left(x_3 - x_3^* \right) + \alpha_2 x_2 x_3\end{aligned}\quad (1)$$

where the state variable x_1 , x_2 and x_3 denote the vegetation, herbivores and predator population respectively in a competitive environment. System (1) exhibits a chaotic regime with the parameters $\alpha_1=0.1$, $\alpha_2=0.6$, $\beta=1$, $\gamma=10$ representing the respective net growth rates of each species in the food web with $x_1^*, x_2^*, x_3^* = (1.5, 0, 0.01)$ as the steady states. We assume a two-wheeled mobile robot for mathematical modeling with v [m/s] and ω [rad/s] as the linear and the angular velocity respectively. The state equation of the mobile robot is:

$$\begin{aligned}\dot{a} &= v \cos \theta \\ \dot{b} &= v \sin \theta \\ \dot{\theta} &= \omega\end{aligned}\quad (2)$$

where the trajectory of the robot is described by the position $[a, b]$. The integrated system (3) describes the robot architecture of two chaotically driven robots driven by the first state variable of (1). Formulated as under:

10 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage:
www.igi-global.com/chapter/dynamical-systems-approach-for-predator-prey-robot-behavior-control-via-symbolic-dynamics-based-communication/113123

Related Content

Technology Design and Routes for Tool Appropriation in Medical Practices

Manuel Santos-Trigo, Ernesto Suasteand Paola Figuerola (2018). *Encyclopedia of Information Science and Technology, Fourth Edition* (pp. 3794-3804).

www.irma-international.org/chapter/technology-design-and-routes-for-tool-appropriation-in-medical-practices/184088

The Systems Approach View from Professor Andrew P. Sage: An Interview

Miroljub Kljajicand Manuel Mora (2008). *International Journal of Information Technologies and Systems Approach* (pp. 86-90).

www.irma-international.org/article/systems-approach-view-professor-andrew/2540

The Single Patent for Portuguese or Spanish Language Countries

Sofia Vairinho, Tara Branstad, Joao Guerreiro, Francisco J. Leon Sanzand Sonia R. Sanchez (2015). *Encyclopedia of Information Science and Technology, Third Edition* (pp. 3265-3277).

www.irma-international.org/chapter/the-single-patent-for-portuguese-or-spanish-language-countries/112757

Pareto Artificial Life Algorithm for Multi-Objective Optimization

Jin-Dae Songand Bo-Suk Yang (2013). *Interdisciplinary Advances in Information Technology Research* (pp. 100-115).

www.irma-international.org/chapter/pareto-artificial-life-algorithm-multi/74535

Building Organizations Image: How to Control a Public Relations Crisis and Communication

Badreya Al-Jenaibi (2019). *Handbook of Research on the Evolution of IT and the Rise of E-Society* (pp. 89-107).

www.irma-international.org/chapter/building-organizations-image/211612