Editorial

Special Issue on Stochasticity in Robotics and Bio-Systems

Stochasticity has been addressed in robotics for two distinct motivations: one for practical engineering objectives and the other to study natural phenomena underlying collective behaviors and adaptation in biological systems. The former, engineering motivation is evident in many recent works. As complexity increases, deterministic approaches to analyze and synthesize a robotic system often become intolerably difficult or inefficient. It is inevitable that, as robotics deals with complex problems, stochastic approaches have been explored for quantifying uncertainty, better decision making, designing and synthesizing systems, and better analyzing interactive and collective behaviors in a scalable manner. Understanding the stochastic nature of robotic systems and its strategic use are integral parts of developing effective systems. The latter, scientific motivation is rather subtle. Biological systems, a metaphor for robotics, are known to be noisy systems. It is amazing that, despite a high level of stochasticity in their construction and behavior, biological systems function quite accurately and reliably. At all levels, ranging from molecule, cell, tissue, and organ to individual animals/plants and their population, biological systems are highly regulated and adaptive. In particular, their collective behaviors are well organized, exhibiting unique functionality that cannot be explained based on single-unit behaviors. Inspired by biological stochasticity, robotics would learn ways of exploiting stochasticity, leading to a new system design concept beyond engineering convenience.

This special issue aims to achieve two objectives. One is to display the state-of-the-art of stochastic approaches to robot system architecture, planning, control, and behavior analysis. The other aims to bring together biology and robotics for exploring a new direction and methodology based on stochastic approaches. Of the 31 papers submitted 17 have been accepted and are published in two parts. The papers span various topic areas of stochasticity as described below.

Bio-inspired systems

Pavlic and Passino address decision-making algorithms inspired by animal foraging for task-processing agents facing a stochastic environment. Parker and Zhang’s paper is concerned with collective group decisions based on observations of ants and bees, and addresses how it can be adapted for use by robotic swarms. MacNair and Ueda’s paper discusses stochastically controlled cellular actuator arrays, which exhibit ‘natural’ movements observed in humans and animals. Mitrovic, Klanke, and Vijayakumar consider variable impedance actuation to achieve the agility and robustness seen in biological systems and propose an algorithm to learn an optimal impedance and command profile for reach and hold tasks.

Multi-robot systems

The paper by Prorok, Correll, and Martinoli proposes a probabilistic model of swarm robot systems in which an agent’s spatial distribution is modeled by the Fokker–Planck equation. Mather and Hsieh analyzed the dynamics of multi-robot deployment system having task execution time delays, and designed agent-level stochastic control policies based on the Pade approximation of time delay dynamics. The paper by Lidoris, Rohrmüller, Wollherr, and Buss proposes an information-theoretic approach to system interdependence analysis in order to improve robustness of complex autonomous robots by evaluating and predicting the effects of component failures that influence others through an interdependent network. Correll and Martinoli propose a probabilistic model for predicting self-organized aggregation dynamics of robot swarms, and use the model to analyze the bifurcation of aggregation dynamics in relation to robot mobility and communication range. Miyashita, Göldi, and Pfeifer demonstrate the effect of stochasticity on the yield of self-assembly using self-propelling, centimeter-scale robots capable of aggregation on the water surface.

Collective behaviors of cells and bacteria

Sakar, Steager, Kim, Julius, Kim, Kumar, and Pappas developed a bacteria-propelled micro-robot, analyzed the collective stochastic behavior of a population of bacteria, and validated the stochastic model and control method through experiments. The paper by Wood, Kamm, and Asada addresses stochastic behaviors of endothelial cells collectively constructing a vascular network pattern.

Stochastic optimization, task planning and programming

Hauser and Ng-Thow-Hing propose a random multi-modal motion planning method for robot manipulation tasks
by using a sampling technique for effectively solving high-dimensionality problems. Lim, Balakrishnan, Gifford, Madden, and Rus develop a stochastic motion planning algorithm that optimizes a cost function for traffic navigation with probabilistic models of traffic delays. Napp and Klavins propose a formal compositional framework for programming multi-robot systems and show how complex stochastic behaviors can be used to create robot programs that are robust to the failure of individual modules.

**Estimation and mapping**

Stochasticity arises naturally in the setting of noisy sensors, uncertainty in the environment, and process noise. Park, Midgett, Madden, and Chrikjian model the noise and the errors in the alignment of micrographs in single-particle electron microscopy. Ranganathan and Dellaert consider the set of all possible graph topologies for the Simultaneous Localization and Mapping (SLAM) problem and propose an algorithm that constructs the best posterior on the space of all possible topologies. Nerurkar and Roumeliotis propose a new estimator for simultaneous localization and mapping and a Power-SLAM algorithm that is computationally superior to the more traditional extended Kalman filter (EKF)-based SLAM algorithms.

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*Guest Editors:*

H. Harry Asada  
MIT, USA  

Vijay Kumar  
University of Pennsylvania, USA