Yan Meng and Yaochu Jin (Eds.)

Bio-Inspired Self-Organizing Robotic Systems

Studies in Computational Intelligence, Volume 355

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Preface

Robotic systems are increasingly required to work under various dynamic, unpredictable, and unknown environments to accomplish various complex tasks. To address these challenges, self-organizing swarming robots and self-reconfigurable modular robots have been proposed. For example, emerging collective behaviors of large-scale swarm robotic systems can provide high flexibility and adaptation to deal with environmental changes. Self-reconfigurable modular robots can automatically change the morphology of the systems to adapt to complex terrains. To deal with more complex and demanding environments as well as task requirements, autonomous development of cognitive abilities together with the body plan of robots also becomes extremely important nowadays. Compared to traditional, preprogrammed techniques, self-organizing robotic systems are more promising in dynamic, unknown environments, particularly in terms of robustness, self-repair, and self-adaptation. To exhibit the above-mentioned properties, self-organizing systems must be controlled in a distributed manner, ideally through local interactions among individual simple robots without an external global control. Unfortunately, design of distributed self-organizing robotic systems remains one of the most challenging problems in robotics.

Biological systems, from macroscopic swarm systems of social insects to microscopic cellular systems, can generate robust and complex emerging global behaviors through relatively simple local interactions in the presence of various kinds of uncertainty. Borrowing ideas from biological systems for developing self-organizing robotic systems has become increasingly popular and enjoyed considerable success in recent years. For example, swarm intelligence, a novel paradigm for solving complex problems with massively parallel systems, has been inspired by behaviors observed in social insect colonies and flocks of birds. Another self-organizing process in biology is morphogenesis of multi-cellular organisms. Morphogenetic approaches based on computational models of embryogeny to self-organizing robotic systems, which are now known as morphogenetic robotics, have shown to be very promising.

This edited book presents a collection of the most representative research work on biological inspired self-organizing robotic systems. This book is composed of four parts. Part I discusses bio-inspired self-organizing approaches to swarm robotic systems, such as morphogenetic approaches inspired by biological morphogenesis in multi-cellular organisms, swarm intelligence based approaches simulating the behaviors of social insects (e.g., birds, honeybees), hormone-based approaches to robotic organisms, and genetic stigmergy based communication mechanism for swarm robots. In Chapter 1, a new emerging research field in developmental robotics, morphogenetic robotics, is introduced by Jin and Meng. The main philosophy of morphogenetic robotics is to apply development principles to design the morphology and controller of self-organizing robotic systems. The main topics belong to morphogenetic robotics are summarized and the relationship between morphogenetic robotics to evolutionary robotics and epigenetic robotics are discussed. Evolutionary developmental robotics, which is a natural marriage of evolutionary and developmental robotics, is envisaged. Chapter 2, contributed by Schmickl, first presents different swarm robotic systems using controllers inspired from collective behaviors of honeybees and slime model aggregation. Then, a hormone-based control paradigm for multi-modular robotic organisms is discussed. All these systems are self-organized in a distributed manner. In Chapter 3, La and Sheng propose two flocking control algorithms, namely, Multi-CoM-Shrink and Multi-CoM-Cohesion, for multi-robot target tracking in cluttered and noisy environments inspired from flocking behaviors of birds, bees, and fish observed in nature. The stability and scalability of the algorithms have also been investigated theoretically. Inspired by the pheromone-based stigmergy in ant systems, in Chapter 4, Brandoff and Sayama describe an artificial genetic stigmergy for indirect communications among robots in a swarm system, where swarm robots conduct an unknown environment mapping task. In the last chapter of Part I, Garnier,a biologist, shares his points of view on how swarm roboticsinspired from biological self-organization in animal societies can benefit from and contribute back to the study of collective animal behaviors.

Part II introduces several bio-inspired approaches to self-reconfigurable modular robots. Kernbach et al., in Chapter 6, propose constrained-based self-optimization of self-assembly of heterogeneous modular robots, which is mainly inspired from gene regulatory networks observed in molecular organisms. Mechanical and integration constrains of robot modules are taken into account. Inspired by the embryonic development of multi-cellular organisms, hierarchical morphogenetic approaches are presented for self-reconfiguration of two modular robots (i.e., Cross-Cube and Cross-Ball) by Meng and Jin in Chapter 7. This hierarchical framework consists of three layers, where the virtual-cell based layer 1 controller is responsible for automatically generating appropriate target configurations for robots based on environmental constraints, the gene regulatory network based layer 2 controller provides self-reconfiguration plans for modules, and the skeleton-based layer 3 controller guides the modules to move to the target configuration with the mechanical and connectivity constraints of modules. By using this hierarchical morphogenetic framework, the target patterns of the robots can be automatically generated to adapt to changing environments. In Chapter 8, Miyashita et al. first discuss three basic research issues in self-assembling robots for manufacturing 3D micro products, namely, assembly, dynamic, and interaction issues. Then, a case study with passive modules (actuated by permanent magnet) and active modules (actuated by vibration motors) has shown the segregation behaviors of modules in a distributed manner. Entropy analysis is also provided to govern macroscopic self-assembly systems.

Whereas Part I and Part II concentrate on the self-organizing of swarm and modular robots, autonomous mental development of robotic systems is the main focus of Part III. In Chapter 9, Weng presents a developmental network (DN) based general purpose model of the brain for robotic systems. A cell-centered in-place learning scheme is proposed to handle all levels of brain development and operation based on biological genomic equivalence principles, which is automatically built up from five basic brain puzzles: development, architecture, area, space and time. The focus of this chapter is the analysis on how this model deals with temporal contexts.

Two specific applications of self-organizing robotic systems are presented in Part IV. Inspired by the slime mouldPhysarumpolycephalum in biological organisms, Jones et al. propose physarum robots in Chapter 10, where physarum can be considered as a smart computing material. A particle-based computational model is proposed for physarum robots, which spontaneously generate complex oscillatory patterns from simple local interactions in a distributed manner. The authors expect that physarum robots may be used as physical instances of smart materials for the future robotic devices. In the final chapter of the book, Chapter 11, a layered architecture is presented by Hoffmann et al. to build up self-organizing robotic cells for industrial robots. In the proposed system, an organic computing based model is employed to combine the system emergence and self-organization properties.

We believe that this book will provide readers an up-to-date and comprehensive view of bio-inspired self-organizing robotic systems. We hope this book will bridge multi-disciplinary research areas such as robotics, artificial life, cognitive sciences, systems biology, developmental biology and evolutionary computation, thereby inspiring researchers and engineers to generate more creative ideas to further promote this emerging and exciting research field.

We would like to thank all contributors who prepared excellent chapters for this book. We would also like to thank Prof. JanuszKacprzyk, Editor-in-Chief of this book series and Dr. Thomas Ditzinger from Springer for offering us the opportunity to edit the book.

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