Summary of Dissertation

Automatic Generation of Collective Behaviors for Robotic Swarms

(ロボティックスワームにおける群れ行動の自動的設計)

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Swarm robotics studies how systems composed of a large number of homogeneous robots can be used to accomplish collective tasks. It has been well recognized that evolutionary robotics is a promising approach to the automatic generation of collective behaviors for robotic swarms. However, the artificial evolution often suffers from the bootstrapping problem and deception when the underlying task is complex. Moreover, while one of the long-term goals of automatic design is to develop controllers directly using high-dimensional raw inputs, most existing swarm robotics studies require hand-crafted feature extraction on which the system performance heavily relies. In this thesis, we aim to address these issues, and contribute to the swarm robotics community in three aspects.

Firstly, we investigate the use of an evolutionary robotics approach in developing effective strategies for robots to manage the congestion problem in a path formation task. The results show that a strategy that the robots specialize their roles emerged during the artificial evolution, which is able to manage the congestion. Additionally, we report a case study in which the covariance matrix adaptation evolution strategy is adopted to develop controllers to accomplish a difficult foraging task, where the robots not only have to distinguish between foods and poisons collectively but also have to cooperatively transport foods to the nest. The results show that a collective cognition behavior is successfully developed, that the robotic swarm is able to effectively transport only foods.

Secondly, to overcome the bootstrap problem and deception in evolutionary robotics approaches, we propose a two-step scheme that takes advantages of both task partitioning and task allocation behaviors. In the first step, the original task is partitioned into simpler subtasks, and in the second step, an evolutionary approach is used to synthesize a composite artificial neural network based controller to generate autonomous task allocation behaviors for the robotic swarm. We demonstrate the proposed method in a complex variation of a typical collective foraging problem. The results show that the proposed method is able to develop controllers with better performance, scalability, and flexibility, compared to the conventional evolutionary robotics approach.

Thirdly, we explore the use of the deep Q-learning algorithm in developing end-to-end controllers for robotic swarms. Compared to evolutionary robotics approaches, the deep reinforcement learning techniques enable researchers to develop controllers in an end-to-end fashion while requiring fewer computation resources. The proposed approach is evaluated in a round trip task, and the results show that controllers using only high-dimensional raw camera pixel inputs for robotic swarms can be obtained with proper reward design.