学 位 論 文 概 要

題 目　Designing Controllers for Robotic Swarms with Deep Reinforcement Learning
(深層強化学習によるロボティックスワームのコントローラーの設計)

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This thesis presents the designing controllers for robotic swarms with deep reinforcement learning. Swarm robotics studies how systems composed of a large number of homogeneous robots can be used to accomplish tasks. The robots only have limited local sensory capabilities, yet in a swarm, they can accomplish tasks beyond a single robot's capability. One of the promising approaches in designing a controller for a robotic swarm is deep reinforcement learning. Recently, deep reinforcement learning has achieved considerable success in applications, such as games and controlling robots. In addition, deep reinforcement learning is known to work well in both single-agent and multi-agent applications. This thesis aims to contribute to the field of swarm robotics in these aspects.

First, this thesis discussed the generation of collective behaviors with raw camera images as the primary information input. The swarm robotic system exhibits considerable advantages when faced with individual-level failure or the lack of global information. Spatial information has always been a necessity in generating collective behavior. The rise of deep neural network technology makes it possible for a robot to perceive the environment from its visual input. This part shows the use of deep reinforcement learning in training the robotic swarm to generate collective behavior. The collective behavior is evaluated in a transportation task and a flying collective flocking task. Robots need to learn to process image information. We applied a deep Q- Learning algorithm and several improved versions to develop controllers for robotic swarms.

Second, this thesis presents a case study of a multi-objective task with sparse rewards. Training a robotic swarm to complete a multi-objective task under sparse rewards is challenging in reinforcement learning. The performance of reinforcement learning highly depends on how the reward functions are designed. Therefore, reinforcement learning struggles in problems with sparse rewards, often in complex tasks. One possible solution to overcome this difficulty is reward shaping, i.e., additional rewards are assigned to guide a robot to reach the final goal. However, applying this approach to a complex task makes the robot controller more likely to converge to a local optimum. Besides, in multi-objective tasks, the reward shaping approach requires elaborate reward functions that prevent the robot from learning efficient strategies. Based on the idea of task decomposition, we designed a hierarchical training method for reinforcement learning to train the controller. We expect that the combination of these cross-domain concepts enables the trained controller to perform efficient control policies to solve the problem. For comparison, a conventional reinforcement learning method is employed with two different reward settings; sparse rewards and reward shaping.