Title	局所的相互作用に基づいた群ロボットの未知作業環境への適応的移動
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Citation	
Issue Date	2007-03
Type	Thesis or Dissertation
Text version	author
URL	http://hdl.handle.net/10119/3621
Rights	
Description	Supervisor:丁　洛榮，情報科学研究科，修士

Adaptive Flocking for a Swarm of Robots in an Unknown Environment Based on Local Interactions

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February 8, 2007

Keywords: swarm robotics, flocking, adaptating to unknown environment, local interaction, school of tuna.

In recent years, the study of swarm robotics that can independently move with a group on a two-dimensional plane in order to accomplish some task in cooperation has gained much attention. The main reason for this interest is that a swarm of simple robots offers many advantages over a fully integrated, single robot system in its efficiency, fault-tolerance, costs per robot, and generality. Therefore, swarm robotics is expected to be deployed as a team in a wide variety of applications including odor localization, firefighting, medical service in human body, surveillance-and-security, and search-and-rescue.

In order to enable the swarm to perform these tasks above, it is basically required to possess the following function: team navigation, namely, flocking - multiple robots move from one place to another while maintaining their relation constantly. In particular, the focus on a flocking over an unknown environmental constraint has grown in order to accomplish an assigned task successfully. From a cooperative point of view, the meaning of team level is very important in that swarm robotics is the coordination for large-scale numbers of relatively simple robots rather than a powerful individual.

In the field of flocking, the one major question that arises is: how is it possible to flock a swarm of robots in unknown environment, so that they can achieve together what they asked do under environmental constraints? From the motivated question, my approach begins with the following weak assumptions: no identification number (anonymous), no pre-determined leader, no common coordinate system, no memory for the past actions (oblivious), no any communication, and unknown task environments. Under these assumptions, I address a flocking problem: a swarm of robots is required to navigate in the presence of unknown environmental constraints while locally interacting with other robots in closed proximity instead of no global information and communication. For the purpose, I pay attention to the adaptive swimming behavior of a school of tuna and imitate three motional models such as maintenance, partition, and unification from the schooling. In detail, swimming behavior of a school of fishes is regarded as an archetype of flocking behavior adapting to various environmental conditions under the sea. When a school of fishes is faced with an obstacle such as a large rock or a predator on the way of navigation, they can avoid while being partitioned into mainly two groups and then re-unified into one after escaping from these problems. Marvelous interest in their swimming is that the school behavior is based on local interaction each other in the closed proximity. For example, a local geometric model for swimming behavior of tunas is described as a diamond pattern. As using this geometric model, tuna display three noticeable schooling behaviors as follows: school maintenance with the geometric pattern while swimming; school partition when encountering a predictor or an obstacle, school unification from the divided organization. Therefore, my flocking approach adapting to an environment for a swarm of robots intends to imitate the schooling behaviors of a school of tuna.

In this study, I propose a Adaptive Flocking algorithm that enables the robots to autonomously navigate in an environment populated with obstacles. The Adaptive Flocking algorithm is decomposed into solving three different sub-problems such as Team Maintenance Problem, Team Partition Problem, and Team Unification Problem, each of which is solved by a different algorithm. The input of each algorithm for each time instant is observation of other robots and environmental information with respect to the local coordinate system by taking a snapshot. As the output, each robot obtains the target point computed by the algorithm. When executing the algorithm every time instant, each robot firstly checks the environmental constraint in its local sensing boundary. If there is the constraint, the robot executes the Team Partition algorithm and then computes a target adapting to an environment. Unless there is an environmental constraint, each robot located on the outside of the group determines the execution of Team Unification according to observation of robots separated from its group. Otherwise, the robot unobserving the cases executes the Team Maintenance algorithm and then navigates toward a goal while locally interacting with neighboring robots. Through the series of these procedures, a swarm of robots can achieve a task while adapting to an environment.

A valid solution for the Adaptive Flocking problem is to control how the robots autonomously navigate in an environment populated with obstacles. Therefore, I presented results of two kinds of simulations that show the effectiveness of the proposed solution. Firstly, the initial trial demonstrated how a swarm of robots adaptively flocks in an unknown environment while maintaining. As locally interacting toward an assigned goal, the swarm navigates toward a stationary goal. On the way to the goal, the swarm encounters an obstacle forcing robots to be split into two multiple teams that adapt to the environment efficiently as if reducing the overall size of the swarm. In spite of a limited sensing boundary, robots unobserving the environment can adapt to the constraint while following a behavioral direction of proceeding robots. Secondly, the next simulation results demonstrated the adaptive flocking toward moving a goal. The simulation setting is equal to the first simulation, but the test aims to check whether the swarm follows a moving goal regardless of environmental constraints. In the second simulation, robots do not know where the goal to move. As moving the goal, the swarm starts to follow. On the way of encountering an obstacle, robots are split into multiple teams and/or re-unified into one while maintaining the geometric configuration. Consequently, a swarm of robots can flock toward a moving goal while adapting.

I verified the proposed strategy using an in-house simulation system for a swarm of robots. The proposed Adaptive Flocking algorithm featuring decentralized, self-organized, self-stabilizing, and deterministic design is evaluated by simulations. Analyzed results show that the Adaptive Flocking is a simple and efficient approach to uniform movement in a changing environment. Finally, Adaptive Flocking is a first step toward real-world implementations of a swarm of robots. For example, this approach is expected to be deployed in odor localization as an example of a moving goal or search-and-rescue in disaster area.