Design of Swarms: Principles and Methods

Introduction

Swarm robotics is an emerging area of interest that aims to make use of unmanned systems, either ground-based or airborne, for many applications e.g. surveillance & reconnaissance, search & rescue, package delivery as well as entertainment related tasks. Further, while individual unmanned systems, also termed robots or drones, have proved to be useful, now there is a greater emphasis on using multiple systems, which collaborate / cooperate with each other to perform more complex tasks with greater effectiveness and efficiency. This has given rise to the discipline of swarm robotics. The present course aims to provide basic background to various swarming strategies and algorithms, applicable mathematical models, salient results and features.

Motivation

In recent times, we have come across many situations in which complex and hazardous tasks are required to be performed (e.g. surveillance / search and rescue operations in a disaster scenario), that greatly increase the risk to humans. Further, the tasks are such that they not only occupy a vast area (e.g. in case of floods) but are also many times required in difficult terrain e.g. hilly area with no or unprepared roads, urban areas with high density of buildings with varying heights, interior of damages buildings etc. In all such cases, it is found that unmanned systems such as robots or drones can be employed effectively to carry out the requisite task, while minimizing / avoiding risk to human life. In view of the fact that many times there is a time criticality involved in all such tasks, there has been an increased awareness about using a group of such unmanned agents in an autonomous mode, in order to carry out such tasks with speed and accuracy required in all such cases. The present course, which aims to discuss the various techniques for creating organized groups of agents (also called swarms), is an effort to provide basic information with regard to swarms, their features and methods to create these as per the requirements.

In this regard, the course touches upon both deterministic and heuristic models for swarming and their relative benefits and also presents some ideas about real system effects that are important to consider. Lastly, course also gives a perspective on system level design of such swarms from practical considerations.

Course Objectives

To introduce the concept of swarms of agents and their important features.
To describe the deterministic and heuristic strategies to create swarm like geometries.
To present a limited systems approach to swarm design and a design solution

Course Contents

Module-1: Introduction to Swarms - Basics of swarm robotics and various strategies, Overview of deterministic swarming strategies, Introduction to heuristic swarming methods. (**6 Hours**).

Module-2: Deterministic Swarming Methods – Graph theory based swarming solutions, concept of vector field for swarm design, basic concept of cyclic pursuit as a practical swarm design technique. (**6 Hours**).

Module-3: Heuristic Swarming / Path Planning Methods – Particle swarm optimization (PSO) and ant colony optimization (ACO) based swarming techniques. (**4 Hours**).

Module-4: Way-point Based Cyclic Pursuit Strategy – Concept of way-points for boundary following swarm design, swarming solutions for non-circular boundaries. (**6 Hours**).

Module-5: Systems Approach to Swarm Design - System level view of swarms for urban search and rescue, sub-system level views and configuration design of swarming solution, sample design exercise in a simulated context. (**6 Hours**).

Module-6: Real System Effects – Behaviour of swarms under failure of agents / communication, obstacle and collision avoidance strategies in specific scenarios. (**6 Hours**).

Text/ References

Heiko, 'Swarm Robotics: A Formal Approach', Springer, 2018.

Marcio, Cai, Feemster, 'Formation Control of Multi-agent System', Wiley & Sons, February 2019.

Kopfstedt, Mukai, Fujita & Ament, 'Control of Formation of UAVs for Surveillance and Reconnaissance Mission', IFAC, July 2008.

Zhang, Liu, Lei, Huang & Zhang, 'Multi Target Trapping with Swarm Robots Based on Pattern Formation', Elsevier, July 2018.

Dorigo and Blum, 'Ant Colony Optimization Theory: A survey', Theoretical Computer Science, 2005, 344, 243 – 278.

Walker, 'Particle Swarm Optimization', Nova Science Publishers, 2017.

Bernhard, 'Polygons of Pursuit', Scripta Mathematica, Vol. 24, 1959, pp. 23-50.

Klamkin and Newman, "Cyclic Pursuit or the Three Bugs Problem", The American Mathematical Monthly, Vol. 78, No. 6, 1971, pp. 631- 639.

Chang, Shadden, Marsden and Olfati-Saber, Collision Avoidance for Multiple Agent Systems,Proceedings of the 42nd IEEE Conference on Decision and Control, December 2003.

Mode of Conduct and Delivery

The course is planned to be conducted fully in the on-line format, with two hours per week engagement. Further, it will be run in a module-wise sequence.