PhD Thesis Proposal

Distributed clustering and self-reconfiguration for modular robots based programmable matter

Supervisors: Pr. Abdallah Makhoul and Dr. Benoît Piranda
Contact: abdallah.makhoul@univ-fcomte.fr, benoit.piranda@univ-fcomte.fr
FEMTO-ST institute, computer science department DISC, OMNI Team
Montbéliard, France.

Summary

The vision for « programmable matter » is to create a material composed of micro-robots which can be programmed to change its shapes (self-reconfiguration) and to change its physical properties on demand. There are various ways to implement programmable matter. One is to build it as a huge modular self-reconfigurable robot composed of a large set of simple micro-robots. These micro-robots can have different shapes (spherical [8], cubical [9], etc.) and are capable of performing limited operations. They must be able to stick to each other and move around their neighbours to form one single robot capable of performing more complex tasks. Beyond sensing, processing and communication capabilities, a modular robot includes actuation and motion capabilities that allow it to reconfigure its shape by rearranging connections between modules [1, 2, 9]. A wide range of applications for modular robots reside unexplored, from surgical applications, to transportation applications or space exploration, to cite a few [3, 5].

A main challenge in modular robotics systems is to solve the self-reconfiguration problem i.e. how to reconfigure their shape autonomously in order to accommodate for variable conditions that need to be met in order to complete a given final goal [6]. This problem is very challenging because of the very high number of possible configurations and a fixed set of rules does not work for all possible situations. Existing solutions for the self-reconfiguration problem propose several algorithms using search-based and control-based techniques [4]. The main idea is to search for a goal configuration in the modular robots configuration space. These solutions are still very complex and not suitable for modular robots with low computation and energetic resources. The objective of this thesis is to study and propose solutions to minimize the cost of the self-reconfiguration by clustering/partitioning the modules in a modular robots system based on the goal configuration. The idea is to find the optimal number of clusters as well as the optimal number of members in each cluster corresponding to the goal configuration of the system. Once the best clustering has been found, the modules in each cluster remain together and try to move in order to find the new configuration. However, there are several research challenges that need to be addressed to find the best and optimal clustering for self-reconfiguration. The main tasks in this thesis will be as follows:

- First, modelling the clustering problem as a graph partition problem and study the complexity of such a partition, prove that is an NP-hard problem and propose some heuristic solutions with linear time complexity and logarithmic approximation.

- Second, finding the optimal self-reconfiguration algorithm for inter and intra clusters in order to achieve the desired and goal global configuration. In this part, we formulate the cost of energy consuming to communicate between cluster heads and the cost of physical movements. Furthermore, we will study and propose self-reconfiguration strategies according to the geometric properties and shapes of each robotic unit (square, disc, spherical, cubic, etc.) and possible movements (rotating, sliding, etc.) in 2D or 3D configurations.
- Third, implementing the proposed approaches using VisibleSim [7] (simulator developed in our team OMNI at FEMTO-ST), and by real implementation on a real modular robots system (blinky blocks) to evaluate the performance of these solutions.

Application

The candidate must send by e-mail to the PhD supervisors:

- her/his detailed curriculum vitae;
- her/his master's transcripts (and diploma if possible);
- letters of recommendation from her/his teachers and supervisors;
- motivation letter expressing her/his interests for the proposed subject.

References

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