07/8101 EVOLVING A COLLECTIVE CONSCIOUSNESS FOR A SWARM OF PICO-SATELLITES

Type of activity: Medium Study (4 months, 25 KEUR)

Background and Motivation

Many researchers have recently pointed out that swarms will play a role in the future of space exploration [1,2]. This forecast is largely based on the principle that a large number of simple components can take advantage of their collective behaviour to meet ambitious mission goals. As with all concepts that are far in the future, a lot of basic research has still to be carried out in order to understand the potential of this concept in each of the various applications proposed (planetary exploration, on orbit assembly, sensor webs and formation flying only to quote a few). This study proposes to take inspiration from methodologies well known in evolutionary robotics to construct a generic approach to the design of the decentralized control strategy of orbiting swarms. By orbital swarm we intend here a large number of satellites orbiting around a massive body.

The space environment typically puts stringent constraints on the capabilities of one single agent. Hence the intelligent coordination of a large number of agents is a particularly attractive feature that seems unavoidable in a number of future scenarios. This observation, in a more general context, forms the basis of a whole new scientific discipline commonly named 'swarm intelligence' [3]. One of the main challenges faced by scientists working in this field is to design the control system of each individual agent as to allow the swarm to achieve a pre defined collective behaviour. Preliminary results in this area have been obtained [4] using a methodology borrowed from evolutionary robotics and extended to swarms. The idea behind evolutionary robotics is to represent the control system of an agent as an artificial chromosome and then to evolve it using a fitness function based on the achievements of the single agent. Thinking about swarms, one could link the fitness function to the collective achievements while still evolving the single control system of one agent. This is a small step from the implementation point of view, yet it makes a big difference in terms of applications allowed. Besides, the procedure is particularly attractive as it could, in principle, be used as a general methodology to synthesise collective behaviours, thus contributing to advance substantially swarm intelligence methods. A control strategy for a swarm of satellites able to acquire and reconfigure a number of formations has been recently published [5-6]. This result, though, is based on a specific methodology that limits its value to the particular behaviour chosen. The introduction of swarms able to evolve a "collective consciousness" could, on the other hand, allow for a more general procedure.

Certain group behaviours such as collision avoidance, the maintenance of a bounded formation with little fuel consumption are example of possible collective behaviours that could be considered. More ambitious goals could reward the construction of a given structure, or the acquisition of some given relative formation in space.

Research and Study Objectives

The main objective is to study under what constraints and how control systems of single agents can be designed to allow an orbital swarm to achieve a pre-assigned collective behaviour.

- The control system of each single agent shall be defined first. It will map the sensed environment into actuation commands and it will typically depend upon a number of parameters.
- These shall then be optimised globally in order to minimise some objective function rewarding the achievement of the considered collective behaviour. One possibility is to think about the combination of neural controllers and evolutionary strategies, but this study is opened also to different suggestions.
- Various optimisation techniques shall be considered as well as different control system parameterisations.
- Various behaviours shall be chosen during the research and will include 'remain grouped with little fuel consumption', 'establish a formation', 'maintain a formation'
- Swarm elements and the optimised controls will be defined and simulated on a number of case studies defined during the research. The satellites will be modelled as three or six degrees of freedom bodies and the sensed quantities will be the relative positions and velocities or the absolute ones.

References

[1] D'Arrigo, P. and Santandrea, S., The APIES Mission, Advances in Space Research, Vol. 38, N. 9, pp. 2060-2067, 2006

[2] Clark P.E., Curtis S.A. , and Rilee M.L., ANTS: Applying a New Paradigm for Lunar and Planetary Exploration, Proceedings of the Solar System Remote Sensing Symposium, pp.15+, 2002

[3] Bonabeau E., Dorigo M. and Theraulaz G, Swarm Intelligence From Natural to Artificial Systems, Oxford University Press, 1999

[4] Dorigo, M., Trianni, V., Sahin, E., Labella, T.H., Gross, R., Baldassarre, G., Nolfi, S., Mondada, F., Deneubourg, J.-L., Floreano, D. and Gambardella, L.M., Evolving Self-Organizing Behaviors for a Swarm-bot. Autonomous Robots, Vol. 17, N. 2-3, pp. 223-245, 2004

[5] Izzo, D., Pettazzi, L., Autonomous and Distributed motion planning for satellite swarm, to appear in Journal of Guidance Control and Dynamics, 2007 [available at www.esa.int/act]

[6] Izzo, D., Pettazzi, L., Girimonte, D. (2007) Swarm Intelligence For Orbital Control Applications, Workshop on Artificial Intelligence for Space Applications at 20th International Joint Conference on Artificial Intelligence (IJCAI), Hyderabad, India, 2007