Intelligent autonomous controllers based on genetically evolved neural networks for flying robots: experiments in two and three dimensions

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1. Description of the work

The work described herein focuses on the application of Evolutionary Robotics [1] design methodologies to a domain yet not thoroughly investigated in the literature: the domain of flying robots.

Since the late 1980s, a number of studies have been carried out concentrating on the application of Evolutionary Robotics on both wheeled (land-based) and underwater robotic vehicles [2][3]. With the only notable exceptions being those systems developed by Buskey [4], De Nardi et al. [5], and Hauert et al. [6], it seems that the current approach to the development of autonomous controllers for aircraft mainly rely on techniques other than neural networks. At last three reasons can be easily identified to explain this trend: (1) the lack of a readily accessible flying robotic platform comparable to the Khepera [7] or the e-puck [8]; (2) the difficulty involved in carrying out experiments (mainly due to the fragility of the robots, and to the space requirements); (3) the high complexity of the software simulator required.

In our work we focus on robotic aircraft with a small size (consider a typical wingspan in the 35-70cm range), generally referred to as Micro-unmanned Aerial Vehicles (MAVs). The main goal of this research is to demonstrate how the Evolutionary Robotics design methodology can be used to make MAVs with the ability to autonomously navigate through an unknown urban-like environment (avoiding static or dynamic obstacles), reach a specific target area (without relying on any map of the reference environment), and cooperate with other aircraft without the need for any external supervision.

The Evolutionary Robotics approach relies on the combined use of neural networks and evolutionary algorithms [9] for designing autonomous controllers for robots. A robotic platform to be made "intelligent" through this approach must be engineered in a specific way. In particular, it must be able to sense the environment in which it operates via a suitable set of sensors. The readings made by these sensors are translated into numerical values that directly operate the robot's motor effectors, thus generating in turn a specific behaviour in response to the stimulus coming from the environment at any given time. The robot's behaviour is therefore governed by the values of the connection weights and biases of the neural network controller. Various methodologies can be used to identify a proper set of connection weights and biases. This research, as most of the work done in Evolutionary Robotics, relies on a genetic algorithm. An initial population of controllers is created with random values assigned. Each of these controllers is tested for a certain number of trials and its performance is evaluated according to a specific fitness function. The best controllers are then selected for reproduction; they generate a certain amount of offspring, inheriting the connection weights and biases from the parents, but with the addition of some random mutations. The new population of controllers constitutes a new generation. The whole process is re-iterated for a certain amount of generations. In order to accelerate the evolution of proper network configurations, the evolutionary process is typically performed on software simulators rather than directly on real robots. The work presented here is no exception, since it uses computer simulators written specifically for this purpose.

The research has been carried out in two distinct phases. During the first stage [10][11], a 2D simulator was used. The reference environment is a simplified representation of Canary Wharf, London, with the principal buildings present in that area considered as no-fly zones for the MAVs. Teams consisting of four aircraft, each of them starting from one of the environment corners, have to navigate through the environment - avoiding any collisions - and reach a target deployed in a random position at the beginning of each test. Once there, in order to accomplish their mission, one of the MAVs has to clear the area activating a specific Boolean output neuron of its network controller. MAV teams relying on controllers evolved for 2,500 generations have demonstrated the ability to successfully perform the task 87.18% of times. Further investigations - relying on a longer evolutionary process and different fitness functions - have been carried out using both a movable target (76.4% success rate, calculated as an average of 5 separate trials, each with a different target speed) and a "more robust" one, requiring two MAVs to reach the target at the same time in order to accomplish the mission (72.3% success rate when the target is stationary, 49.6% when the target is moving). The second part of the research [12], which is still ongoing, aims to replicate the results obtained during the first stage, using a more realistic 3D simulator. The latest MAV controllers have been evolved to navigate and reach a target area within an obstacle-free three-dimensional environment (64.91% average success rate for the members of the last generations; 99.52% for the best individual), also when the target can move (98.75% best success rate when the target's speed is 1/5th of the MAVs' speed, 99.55% when a/4th, 97.07% when 1/3rd, 90.5% when half).

The results obtained so far show how the Evolutionary Robotics approach might be successfully used to design autonomous controllers for flying robots. Future work will be focused on strengthening the results obtained with the 3D model through a sophistication of the reference environment, as well as introducing new tasks where explicit communication between members of the same team is required.

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