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Evolving a Team of Self-organizing UAVs to Address Spatial Coverage Problems

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Abstract: *We evolve controllers for a team of unmanned aerial vehicles (UAVs) with the task to observe or cover a partially obstructed area. The respective agents are limited in their sensory inputs to local observations of the environment without the ability to determine their absolute position or those of others. Each agent is equipped with a number of sensors that can detect the presence of other agents, an obstacle and the border of the area. The controller of an agent is implemented as an artificial neural network. The fitness for a given configuration is derived from the average spatial coverage over several simulation runs. The area coverage performance of the evolved controllers with different number of sensors is compared to reference movement models like random walk, random direction, and an algorithm based on the belief of the intention of agents met during the execution of the simulation. Our results show that evolved controllers can create a self-organizing cooperating team of agents that exploit the advantages provided by their sensors and outperform naïve coverage algorithms and also reach the performance of a recent algorithm that is using additional information as well.*

Keywords: UAV; self-organization; multi-agent systems; evolutionary algorithms; neural networks

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1. Introduction

The problem of covering a given area with one or more mobile agents has many applications such as vacuum cleaning, exploration and mobile surveillance. If multiple agents and uncertainty regarding the environment and sensors are involved, finding a solution becomes non-trivial. A self-organizing approach for the coordination of such mobile agents promises small, cost-efficient solutions fitting possible target systems like autonomous mobile vehicles equipped with a few sensors, such as ground robots or unmanned aerial vehicles (UAVs).

Many existing solutions require external control, explicit communication, localization, and/or map building to solve a coverage task. In contrast, to reduce implementation complexity we are aiming at simple distributed approaches supporting general hardware that are robust enough in the event of a failure of a few agents.

In this paper, we present simple control algorithms for unmanned aerial vehicles in order to cooperatively achieve maximum coverage of a partially obstructed area under certain constraints like limited time (minimum time-to-complete) and minimum energy (with minimum number of turns) (Choset, 2001). The area to be covered is modeled as a time-discrete and space-discrete lattice of obstacles and free space. The control algorithm is modeled as a neural network and programmed via an evolutionary algorithm. The evolutionary design approach has the advantage of automatically exploring a vast number of solutions including configurations which appear to be counterintuitive (Elmenreich, 2008).

2. Problem Statement

We introduce a time-discrete, value-discrete model of agents, obstacles and free space area. The discrete model is a strong abstraction from real applications, but allows for a precise comparison to previous work on discrete-space coverage algorithms (Yanmaz, 2010) and simplifies reproducing the results of our model. The area to be covered is modeled as a finite two-dimensional lattice where each cell can contain at most one agent or obstacle. In each time step, an agent is allowed to move to one of the four directly neighboring cells given that the target cell is within the lattice and is neither occupied by another agent nor an obstacle. Figure 1 depicts an example with 5 agents in an 8x8 area.

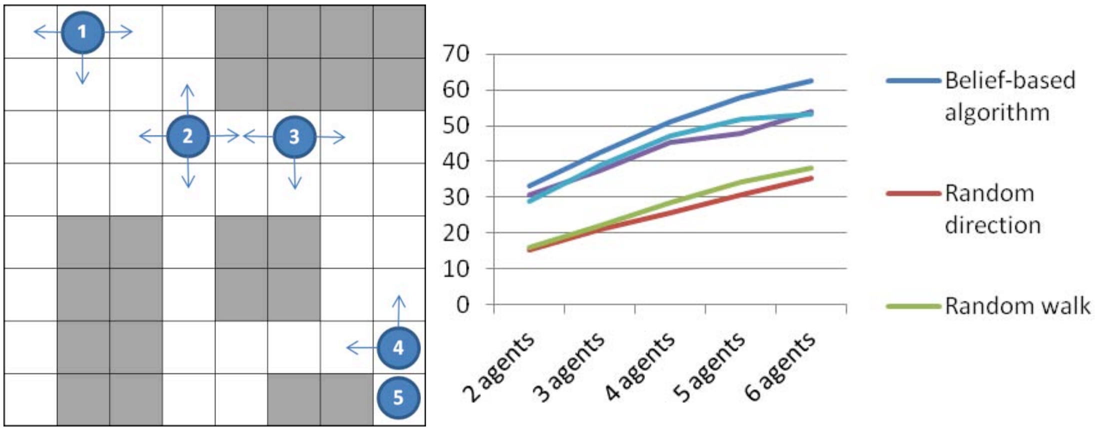

Figure 1: Example with occluded areas (shaded) and five agents and performance curves for different approaches

The goal of the agents is to have each non-occluded cell visited by at least one agent in minimum time. This problem is similar to the Traveling Salesman Problem (TSP) (Applegate, 2006), but the initial position of the agents, the position and shape of the obstacles, and the size of the lattice are initially unknown in our case. Therefore, a TSP solver or other *a priori* search approaches cannot be applied. Instead the agents need to learn to efficiently explore the area. Furthermore, we assume that the agents have limited computational capacities regarding map building and position estimation.

The completeness of the given goal is measured by two performance metrics, the *spatial coverage* (number of cells visited at least once divided by the total number of unobstructed cells) and the *completion time* (number of simulation steps needed). Therefore, the spatial coverage is defined as a value between 0 and 1, or 0% and 100%, respectively. In case the agents manage to fully cover the unobstructed area before the time expires, the completion time is used as an additional metric. These performance metrics are not normalized to the number of agents, thus a larger number of agents is expected to achieve better spatial coverage and shorter completion time. The performance will converge, when the number of agents is higher than a threshold.

3. Agent Controller Models

In order to exploit possible cooperation among the agents an adaptive controller is needed. In this work, we use artificial neural networks (ANNs) to control each aerial robot throughout the simulation of each map. ANNs are very versatile and can encapsulate a generalized solution for the given problem domain. During a simulation, each agent has its own instance of a time-discrete ANN with the same structure and properties. In general, ANNs possess very limited memory regarding previous states; therefore we apply fully-connected, recurrent networks with only one hidden layer with 4 neurons.

Training of the networks is done using an evolutionary algorithm, since we deal with belated rewards we get after a simulation of many executions of the revised ANN. We use the open-source FREVO framework to model our simulation environment and evolve the agent controllers with the built-in *nnga*[1] module. The algorithm is explained in more detail in (Fehervari, 2010).

The performance of the evolved controllers is compared to the following reference models: random walk (agent decides randomly in each step), random direction (agent changes direction randomly when occlusion would occur) and a recent belief based algorithm (Yanmaz, 2010).

4. Results and Discussion

For the evaluation, we use three test scenarios of 40x40 cells, one without obstacles, one with 10 % of the area covered with obstacles and one with 20 % covered area. The maximum time was set to 400 ticks. We never reach full coverage in any simulation run, thus the completion time did not play a role as performance metric for this setup. The numbers in Figure 1 are thus obtained by the average spatial coverage in % over 100 evaluations for each respective combination of number of agents, algorithm, and scenario. The results show that in general more agents achieve higher coverage, as expected. Moreover, the evolved cooperative agents achieve higher coverage than non-cooperative ones (non-cooperative agents cannot distinguish a neighboring obstacle from a neighboring agent). This means that the cooperative agents learned to actually cooperate in a way to improve the coverage task. In comparison to the reference algorithms, the evolved algorithms achieve always better performance than the random walk approach. However the belief-based algorithm shows better performance, due to the implied information exchange among the UAVs.

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[1] http://frevotool.tk

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