Occlusion-aware Multi-UAV Surveillance

(Extended Abstract)

Eduard Semsch, Michal Jakob, Dušan Pavlíček and Michal Pěchouček
Agent Technology Center, Dept. of Cybernetics,
Technická 2, 16627 Prague 6,
{semsch, jakob, pavlicek, pechouce

ABSTRACT

We present an agent-based coordination and planning method for autonomous aerial surveillance of multiple urban areas using a group of fixed-wing unmanned aerial vehicles (UAVs). The goal of the surveillance is to observe a set of ground points of interest within the target areas as often as possible. The method differs from the existing work by explicit consideration of sensor occlusions that can occur due to high buildings and/or other obstacles in the target area. The solution employs a decomposition of the problem in two subproblems: the problem of single-area surveillance and the problem of allocating UAVs to multiple areas. The overall method is evaluated empirically on a realistic simulation of aerial surveillance built using the AgentFly framework.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Coherence and coordination, multiagent systems*

General Terms

Algorithms

Keywords

UAV-based surveillance, coordination, simulation, occlusions

1. INTRODUCTION

With the increasing deployment of unmanned aerial vehicles (UAVs) for information collection, there is a growing need to enable the UAVs to perform information collection missions autonomously without the need for direct human control, which is costly. Intelligent multi-agent techniques have been employed to address this problem (e.g. [1]).

In this paper, we address a particularly challenging variant of the problem – controlling a team of autonomous UAVs performing persistent surveillance of *geometrically complex environments* such as those present in dense urban areas. In such environments, the field of view of UAV's on-board sensors can get occluded in the presence of tall buildings and/or narrow streets (see Fig. 1), especially if the UAV is flying low. This can result in areas left uncovered, which might be exploited by an adversary. Although the problem of occlusions has been studied in other contexts (e.g. [3]), *occlusion-aware* surveillance has not yet been considered in the field of autonomous UAV control. In this paper, we address the problem and provide a multi-agent coordination mechanism that realistically models and explicitly eliminates the effect of occlusions and, in addition, can handle simultaneous surveillance of multiple disjoint areas[1].

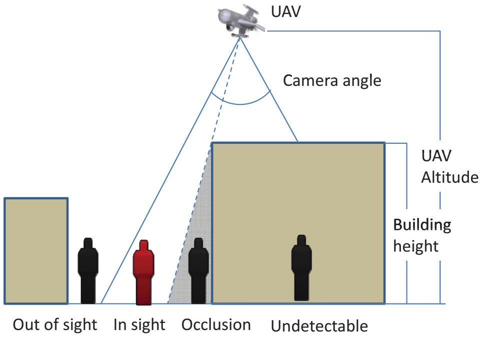

Figure 1: Occlusions in urban environment.

2. MULTI-UAV INFORMATION AGE MINIMIZATION PROBLEM

We formally define multi-UAV area surveillance as a problem of finding a set of trajectories for a group of UAVs which, when followed, minimize the average age of the information collected about a set of points of interest located within multiple disjoint areas.

The environment is a set $\mathcal{A} = \{A_1, A_2, \ldots, A_k\}$ of k rectangular areas A_i. In each area A_i, there are a set of buildings modeled as quadrilateral prisms, and a set of *points of interest* $P_i = \{p_1, p_2, \ldots, p_m\}$. We control a fleet of fixed-wing UAVs modeled as point masses moving with a constant speed v and capable of turning with a minimum turning radius R (such a model is generally referred to as *Dubins vehicle*). Each UAV carries a sensor of a conical field of view pointing down to the ground with the field-of-view angle φ; the sensor "sees" points of interest only if *not occluded* by buildings or other obstacles (see Fig. 1). We define the function $\tau(p, t)$ as the last moment in time prior to time t when a point of interest p was seen by any of surveilling UAVs. If the point has not yet been seen, we set the value to 0.

Cite as: Occlusion-aware Multi-UAV Surveillance (Extended Abstract), Eduard Semsch, Michal Jakob, Dušan Pavlíček and Michal Pěchouček, *Proc. of 9th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2010)*, van der Hoek, Kaminka, Lespérance, Luck and Sen (eds.), May, 10–14, 2010, Toronto, Canada, pp. 1407-1408

---

[1] More details can be found on the project's website: `http://agents.felk.cvut.cz/projects/tactical_agentfly/`

For a time instance t and a point of interest p, we call the value $t - \tau(p, t)$ the *information age* of p at time t. The objective of area surveillance is then to minimize the average information age of all points of interest over a period of time, i.e., to minimize the expression

$$\frac{1}{t_1 - t_0}\frac{1}{|P|}\sum_{t=t_0}^{t_1}\sum_{i=1}^{k}\sum_{p\in P_i}\left(t - \tau(p,t)\right), \tag{1}$$

where a discrete time model is assumed, t_0 is the time at the beginning of the evaluation period (typically zero), t_1 at the end of the period, and $|P|$ is the number of points of interest. We term this objective function *average information age* and the resulting optimization problem the *information age minimization problem.* A solution of the problem is a set of flight trajectories for all surveilling UAVs; the trajectories must respect the minimum turn radius of the UAVs.

3. TWO-STAGE MULTI-AREA SURVEILLANCE ALGORITHM

The information age minimization problem is an instance of constraint optimization problems, which are known to be generally intractable. It is also known that the traveling repairman problem for Dubins vehicle, a special case of the single-area information age minimization, is NP-hard [4].

We therefore propose an approximate solution consisting of two stages: (1) Allocate UAVs to the target areas. As a result, each UAV will have exactly one area assigned. Multiple UAVs can be assigned to one area. (2) For each area separately, solve the single-area information age problem employing the allocated UAVs.

Improving on the algorithms developed earlier [5], we have developed a novel *occlusion-aware zig-zag* algorithm for single-area information age minimization problem. The algorithm produces zig-zag trajectories with the number of rows minimized while ensuring that all ground points of interest will be visible to the UAV's sensors.

In case of multiple target areas, a multi-area allocation algorithm is first used to assign the available UAVs to the areas of interest, where they are subsequently controlled by a single-area zig-zag algorithm. The optimum assignment of UAVs $\kappa : \mathcal{A} \to \mathbb{N}^0$ is sought by a greedy algorithm based on an estimate of the average information age that would result from a particular assignment. For a given assignment κ, the estimated average information age is calculated as

$$\hat{I}(\kappa) = \sum_{i=1}^{n}\frac{1}{v\kappa(A_i)}\left(\frac{S(A_i)}{2\rho} - \frac{\rho}{\pi}\right) \tag{2}$$

where v is the UAV's velocity, $S(A_i)$ is the spatial area of A_i and $\rho = 2 \cdot h \cdot \sin(\frac{\varphi}{2})$ is the ground sensor radius of an UAV flying at altitude h and having the sensor with field-of-view angle φ. It can be shown that the greedy algorithm finds the optimum assignment with $O(n^2)$ time complexity, where n is the number of allocated UAVs.

4. EVALUATION

All evaluation was performed using the AGENTFLY framework [2] for UAV flight and air traffic simulation. The specific scenario used for the evaluation is modeled after a real-world settlement with surroundings located in a flat 1500m-by-1500m square area with total of 300 buildings 6 to 22 m tall and with streets 3 to 10 meters wide. The testbed and the scenario used is depicted in Fig. 2.

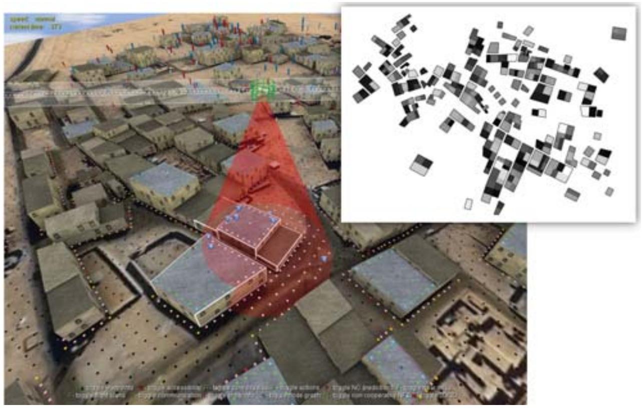

Figure 2: AgentFly UAV simulation testbed with an occlusion-aware sensor model. A height map of the area is depicted in the overlay.

We have performed three groups of experiments: (1) single UAV and single area, (2) multiple UAVs and single area, and (3) multiple UAVs and multiple areas. In all cases, we evaluated the performance based on a number of factors, including the UAV flight altitude and turn radius, and the number and shape of target areas. On the single-UAV single-area problem, the zig-zag algorithm outperformed the previously reported *spiral* [5] and *alternating* algorithms [4], in particular at low flight altitudes where it was on average 50% better. Due to the lack of suitable benchmarks for the multi-UAV problems, the performance was compared to a theoretical estimate; the measured performance of the method followed the same trend as the estimate and was on average 30% worse. In all cases, the algorithms achieved 100% coverage of the points of interest.

Acknowledgments

Funded by the U.S. Army (grant no. W911NF-08-1-0521-_1312AM01) and by the Czech Ministry of Education, Youth and Sports under grant ”Decision Making and Control for Manufacturing III” (grant no. MSM 6840770038).

5. REFERENCES

[1] N. Nigam and I. Kroo. Persistent Surveillance Using Multiple Unmanned Air Vehicles. In *2008 IEEE Aerospace Conference*, pages 1–14, 2008.

[2] M. Pechoucek and D. Sislak. Agent-based approach to free-flight planning, control, and simulation. *IEEE Intelligent Systems*, 24(1):14–17, Jan./Feb. 2009.

[3] A. Sarmiento, R. Murrieta-Cid, and S. Hutchinson. A multi-robot strategy for rapidly searching a polygonal environment. *Lecture notes in computer science*, 3315:484–493, 2004.

[4] K. Savla. *Multi UAV Systems with Motion and Communication Constraints.* PhD thesis, University of California, 2007.

[5] E. Semsch, M. Jakob, D. Pavlicek, and M. Pechoucek. Autonomous UAV surveillance in complex urban environments. In *Proceedings of 2009 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (IAT 2009)*, 2009.