Control and Design of Multiple UAVs for Persistent Surveillance
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Introduction
Persistent surveillance involves exploring a target space and revisiting all points in that space as frequently as possible. This study aims to develop high-level control laws for multiple UAVs performing persistent surveillance in a stochastic environment. We also investigate the design of such vehicles for optimum mission performance.

Motivation
Persistent surveillance has applications such as geographical surveys, weather monitoring, extra-terrestrial exploration, search & rescue, and tactical reconnaissance. The use of unmanned vehicles for such applications is motivated by missions which are long endurance, risky or can not involve manned vehicles.

Control Law for a Single UAV
First, we derive the optimal control policy for a very simple two-cell, single-UAV case (Fig. 2). We then extend this target-based policy to the multiple-cell case. We define the value for each cell to be a linear combination of its age and its distance from the UAV. The UAV moves toward the cell with maximum value.

Multiple UAV Coordination
We prefer control laws that are scalable, efficient, robust and conceptually simple. Consequently, we study two control laws: Multi-agent Reactive Policy (MRP) and Space Decomposition (SD) approach.

Simplified Problem Description
We use a simplified problem description for analyzing various control and design strategies. We assume a rectangular target space, discretized into cells, with cell size determined by the sensor footprint. The age of a cell is the elapsed time since it was last visited.

Comparison of MRP with SD, and a best-case bound on the optimum shows that the reactive policy exhibits emergent behavior in congested spaces (Figs 7-9).

Conclusions
• Control law for a single UAV near-optimal performance
• Multi-agent reactive policy improves performance in congested spaces
• Modified policy improves performance in the presence of vehicle-dynamic constraints
• System of systems architecture used to study effect of mission specifications on aircraft design, and potential advantages of using a heterogeneous fleet of UAVs

Acknowledgments
We would like to thank Stefan Bierwieser and John Yuan from Boeing Phantom Works for sponsoring this research and providing important input regarding problem formulation. We also thank Prof. Stephen Rock, Prof. Andrew Ng, Prof. Yoav Shoham, and Prof. Walter Murray for their feedback.

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Effect of Vehicle Dynamics
We use a 3-DOF UAV dynamics simulation to study the effect of minimum turn radius, governed by airframe C_{lmax}, on performance. Fig. 10 shows results for a small UAV flying at 5.3 m/s in a 135 x 135m target space. With this turn radius constraint, the functional form of our control policy allows a simple modification (use shortest path distances instead of Euclidean distances) which improves performance (Fig. 11).

System of Systems (SoS) Design
We now develop an architecture based on Collaborative Optimization (CO) to design a UAV for optimum mission performance (Fig. 12). This can be easily extended for designing a fleet of UAVs.

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