Cooperative Tracking of Multiple Targets by a Team of Autonomous UAVs

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ABSTRACT
This research is concerned with dynamically determining appropriate flight patterns for a set of autonomous UAVs in an urban environment, for persistent and accurate tracking of moving ground targets. The authors assume that there are limited communication capabilities between the UAVs, and that there exist possible line of sight constraints between the UAVs and the targets. Each UAV (i) operates its own dynamic feedback loop, in a receding horizon framework, incorporating local information on the targets (from UAV i perspective) as well as remote information on the targets (from the perspective of the ‘neighbor’ UAVs) to determine the optimal flight path of UAV i over the planning horizon. This results in a decentralized and more realistic model of the real-world situation. As the flight-plan optimization formulation is NP-hard, a new heuristic for continuous global optimization is applied to solve for the flight plan. Results show that efficient flight patterns for the UAVs can be achieved.

Keywords: Continuous GRASP, Cooperative Tracking, Decentralized Autonomous Control, Ground Target Tracking, Optimal Path Planning

INTRODUCTION
Military forces face ever increasing challenges to provide timely and accurate information on targets of interest, especially those targets that are mobile and elusive in nature. These tasks expand significantly in complexity when the targets are operating in an urban environment. The use of multiple unmanned vehicles to provide this target information allows our military personnel to stay out of the line of fire. However, many remotely controlled UAVs (i.e., swarms) require as many skilled pilots as there are swarm members, and these pilots must be able to deconflict airspace demands, mission requirements, and situational changes in near real time (Bamburger et al., 2006). On the other hand, autonomous unmanned vehicles allow military personnel to focus on more important issues like interpreting the gathered information, as opposed to determining how to acquire the information (Hirsch et al., 2007). Hence, there

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is a need to build intelligent unmanned vehicles that can plan and adapt autonomously to the environment they perceive. The clear benefit is shortened mission-critical decision chains.

There has recently been much research done in the area of autonomous vehicle control for surveillance-type missions. Almost all of the research has dealt with centralized cooperative control, with little research concerned with the more realistic decentralized problem (Shima & Rasmussen, 2009). Steinberg (2006) provided an overview on research and limitations of autonomous technologies for the control of heterogeneous unmanned naval vehicles. Experiments in this paper examined aspects such as multi-vehicle task allocation, dynamic replanning of vehicle tasks, as well as human-in-the-loop management. Constraints considered in the experiments included pop-up threats, adverse weather conditions, and communication issues between the autonomous vehicles, among others. Liang et al. (2010) present a decision support framework to accurately reconstruct the current picture of the battlespace, by correctly identifying target tracks (i.e., target location, movement, identity) as seen by multiple wide area search munitions. Ahmadzadeh et al. (2006) described their Time Critical Coverage planner as a component of the Office of Naval Research Autonomy program, ICARUS. Each autonomous vehicle was modeled as a Dubin’s vehicle (Dubins, 1957), where-by the vehicles were assumed to be point masses with constant speed and a prescribed minimum turning radius. The vehicles also had prescribed starting and ending spatial-temporal locations, as well as polygonal obstacles to be avoided throughout flight. The objective was to determine the flight path of the UAVs to maximize the total sensor footprint over the region of interest.

The algorithm utilized to solve this problem was based on sampling a discretized search graph (LaValle, 2006).

Ma and Miller (2005) implemented a receding-horizon approach to solve a mixed-integer linear program modeling a trajectory planning problem. They limited their focus to a single vehicle navigating through three-dimensional obstacles and terrain. They considered threat avoidance and made use of the commercial software CPLEX (2008) to solve their problem. Shetty, Sudit, and Nagi (2008) considered the strategic routing of multiple unmanned combat vehicles to service multiple potential targets in space. They formulated this as a mixed-integer linear program, and through a decomposition scheme looked at solving the target assignment problem (vehicles to targets) and then determining the tour that each vehicle should take to service their assigned targets (a classical vehicle routing problem). They implemented a tabu-search heuristic to find solutions to their problem. However, they assumed the vehicles were holonomic, which enabled the mixed-integer linear program formulation. Kenefic (2008) utilized techniques from particle swarm optimization (Kennedy & Eberhart, 1995) to efficiently define tours for a Dubin’s vehicle, visiting multiple ground targets in two-dimensional space. Schumacher and Shima (2009) considered the problem of wide area search munitions, which are capable of searching for, identifying, and attacking targets. Whenever a new target is found, or a new task needs to be assigned, a capacitated transshipment assignment problem is solved, to determine the optimal assignment of munitions to tasks. Note that from one solution to the next solution, the assignment can change significantly.

Sylvester, Wiens, and Fitz-Coy (2004) presented a path-planning algorithm for two non-holonomic vehicles engaged in a docking maneuver. A bijection search method was used to determine the trajectory of the vehicles, such that the minimum turning radius constraint of each vehicle was satisfied. Santilli et al. (1995) and Bicchi, Casalino, and Santilli (1995) considered planning a path for a non-holonomic autonomous vehicle in the presence of fixed obstacles. Jiang, Seneviratne, and Earles (1999) also presented a path planning algorithm for a non-holonomic vehicle subject to obstacles. This algorithm employed a global and local strategy to find the shortest path in two-dimensions that was free of collisions with the obstacles. Schouwenaars et al. (2001) considered fuel-optimal paths for multiple vehicles. They for-
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