

# Adaptive Task Allocation for Search Area Coverage

Ryan J. Meuth\*, Emad W. Saad†, Donald C. Wunsch II\*, John Vian†

\* - Applied Computational Intelligence Laboratory, Department of Electrical and Computer Engineering, Missouri University of Science and Technology, Rolla, MO.

† - Boeing Research and Technology, The Boeing Company, Seattle, WA.

Corresponding Author:

Ryan J. Meuth

[rmeuth@gmail.com](mailto:rmeuth@gmail.com),

(636) 578-4171

631 Houston Rd.  
Rolla, MO, 65401

## Abstract:

Many operations require an area search area function, including search-and-rescue, surveillance, hazard detection, structures or sites inspection and agricultural spraying. Furthermore, these area search applications often involve varying vehicle and environmental conditions. This paper explores the problem of optimizing the behavior of a swarm of heterogeneous robotic vehicles executing a search area coverage task. Each vehicle is equipped with a sensing apparatus and the swarm must collectively explore an occluded environment to achieve a required probability of detection for each location in the search area. The problem is further complicated with the introduction of dynamic vehicle and environmental properties making adaptability a necessary requirement in order to achieve a high level of mission assurance using unmanned vehicles. Novel methods for search space decomposition and task allocation are presented, with simulated and real-world results utilizing the Boeing Vehicle Swarm Technology Laboratory.

The search coverage problem for multiple heterogeneous vehicles is unique in that the task is defined in a general way, and must be divided into sub-tasks which are then allocated to each vehicle. The space of these possible assignments is continuous, and increases exponentially with the size and complexity of the region, as well as with the quantity and amount of variation among vehicles, making the problem extremely difficult to solve optimally. As a highly complex problem, multi-vehicle search coverage has been greatly explored in literature [1-3]. Additionally, many of the problem sub-components have been analyzed, including area decomposition, task allocation, and path optimization. The more general problem of collective robotics has also been greatly researched, but continuous environmental effects have rarely been considered [4-6]. In real-world applications such as automated surveillance and search-and-rescue, vehicle and environmental characteristics may be dynamic due to vehicle failures and changing weather conditions, so the optimization methods must be adaptable in real-time in order to maintain the required probability of detection.

The problem of optimal search coverage using multiple heterogeneous vehicles can be decomposed into two coupled problems - that of high-level task allocation for each vehicle, and low-level route optimization for the allocated task. At the highest level, vehicles must be coordinated to ensure that the total search space is covered in minimal time.

This paper addresses the task decomposition and allocation problems by first using a method for search area decomposition based on probabilistic occlusion maps and utilizing Voronoi diagrams to construct a set of points that provide complete coverage of the search space for a given vehicle sensing characteristic. This method is used in concert with one of two new task allocation algorithms to assign regions of the search space to vehicles with matching sensing characteristics in an effort to minimize total search coverage time. The first algorithm, Equilibrium Task Allocation is a gradient descent-based method that attempts to balance and equalize the task-load between all vehicles in the swarm, minimizing the total task-cost by utilizing all available resources.. The second algorithm, Hybrid Particle Swarm Task Allocation (HPSTA), is a Particle Swarm Optimization based method, combining a binary vehicle-to-region assignment vector with a real-valued assignment region-size for each vehicle. The two PSO update rules are combined under a single fitness value to minimize the assignment cost. The quality of allocation and computational requirements of the methods are compared against a brute-force task allocation implementation, in a variety of both simulated and real-world scenarios.

These algorithms are uniquely designed to operate in real-time, enabling adaptation to changing vehicle and environmental characteristics, while balancing the task-load between available resources and enabling the seamless control and optimization of swarms of heterogeneous vehicles.

These algorithms have been tested in Boeing's indoor rapid prototyping test-bed that provides a low cost means for technology integration, maturation and demonstration. The test-bed includes over 20 fully autonomous air and ground vehicles and utilizes a motion capture system for indoor localization. The adaptive area coverage task allocation software has been integrated with the defined test-bed Ethernet interface through which it exchanges waypoint commands and vehicle condition and capability data with the vehicles.

The results show that the probabilistic decomposition method and both Equilibrium and HPSTA are efficient methods for search area coverage task allocation, with Equilibrium task allocation providing the highest value solutions with low computational requirements across a variety of scenarios.

## References

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