Abstract

Performing search and surveillance missions in hostile, inaccessible and unknown regions is a difficult task For these operations the scope of using unmanned aerial vehicles/robots (referred to as agents) has increased considerably over the years These agents can perform the task autonomously and efficiently without any loss of life Use of multiple agents for such tasks is an appealing notion as these can perform search faster while covering larger regions Moreover, they are robust to single point failures Thus, decision-making algorithms need to be designed to perform the search operation autonomously and cooperatively With increase in number of agents, the decision-making and coordination complexity will also increase Also, these agents are subject to practical constraints like limited communication range, restricted fuel capability, low sensor range, and limited payload Hence, there is a necessity to develop search algorithms for multiple agents that can address these issues and can scale up to large number of agents In this thesis, we develop and evaluate search strategies for multiple agents performing a search operation that address some of the above mentioned issues The search strategies we develop are based on concepts from graph theory, game theory, negotiation, and self-assessment

The basic model for the search space considered is a discretization of the search space and search time, where the search region is represented as a collection of hexagonal cells through which the agents pass The a priori knowledge about the search space is represented as an uncertainty map The objective of the agents is to determine their own search routes so as to maximize uncertainty reduction

First, a graph theoretical model of the uncertainty map is developed, where the center of the cells are considered as nodes and the arcs connecting the nodes as edges. The uncertainty values of the edges are assumed to be static for the sortie The k-shortest path algorithm is used to find a search route that maximizes the effectiveness of the search in terms of searching through the maximum uncertainty region, given a constraint on the endurance time of the agent and on the location of the base station from which the agent operates These constraints set apart this class of problems from the usual search and surveillance problems in the search literature The performance of this algorithm is compared with a random search and a greedy strategy search scheme The search operation may be subject to delays in updating the uncertainty map, hence the cases of delayed and partial information are also considered An online implementation of the strategy based on dynamic route planning is also discussed Simulation results that demonstrate the efficacy of the technique with different information structures are presented

The graph theoretical model assumes that the uncertainty map is static during a sortie, which is not true for a real time search Because of this reason, the k-shortest path based search algorithm cannot be used for multiple searchers emanating from the same base station To take into account the dynamics of the uncertainty map, real time search strategies based on game theoretical notions were developed next The search effectiveness functions are computed using the q step look ahead policy A generalized N-person game model is formulated for N agents The performance of the game theoretical search strategies, namely, noncooperative Nash, coalitional Nash, cooperative, and security strategy was compared with that of the greedy strategy A 2-person game model was also presented as a special case Although game theoretical strategies provide optimal solutions in their restricted framework, they require large computational overheads Hence, some heuristic rules were devised to reduce the computational burden on the agents The effect of these heuristics and the comparison of different game theoretical search strategies is studied using simulations on a large search space A route planning algorithm for multiple agents performing the search with limited endurance

time constraints is also developed

Although the heuristics for game theoretical search strategies reduces the computational burden but still the strategy is difficult to implement where large number of agents are present Hence, a model, based on a negotiation based scheme used in economics, is developed that can be used for large scale search missions However, unlike the game theoretical strategies, the negotiation based schemes require some limited information exchange and communication between agents In negotiation schemes, all the practical limitations are considered, such as limited communication within a neighborhood, and limited sensor range In this scheme, the agents broadcast their proposals to their neighbours and receive "accept" and "reject" decision from them Based on these received decisions an agent performs its next action The negotiation model developed is shown to accommodate different negotiation schemes and different information structures like complete information and partial information (one step information sharing, route information sharing, etc) Simulations are carried out for various negotiation schemes with different information sharing schemes on large search spaces with large number of agents to demonstrate the scalability of negotiation scheme to multiple agent real time search However, fast decision-making is realized with somewhat sub-optimal decisions A software agent architecture is proposed for implementing the negotiation schemes

The implementation of the negotiation scheme involves some amount of communication between agents To reduce the communication requirement further, a self assessment scheme was proposed In this scheme, each agent broadcasts its intention to its neighbours, and, based on this information, an agent independently takes a decision The basic self assessment scheme also accommodates different versions of self assessment schemes, with different information structures as in the negotiation scheme Simulation results are presented to demonstrate that the scheme performs well even with reduced communication overheads Finally, a software agent architecture is developed for implementing the self assessment schemes

The search strategies developed in this thesis contribute to the growing research in

the field of multiple agent cooperative search problems The thesis concludes with a discussion on some future directions of research in the area of multiple agent cooperative search problems