Cooperative Surveillance in GPS-denied Environments with deployed Sensor Network

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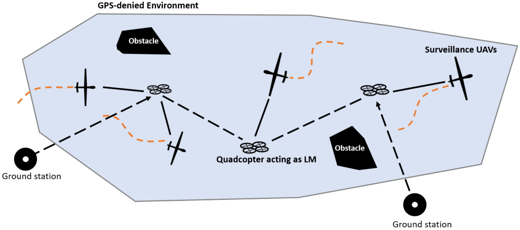
Introduction

- Multiple UAVs are being preferred for several civilian and military applications, because of their robustness and efficiency.
- Vehicle localization is the key challenge is autonomous applications like surveillance.
- Sensors help in localizing the robot by providing measurements from known landmark/features from the environment.
    - GPS based navigation
    - Vision, sonar, radar, LiDAR etc.

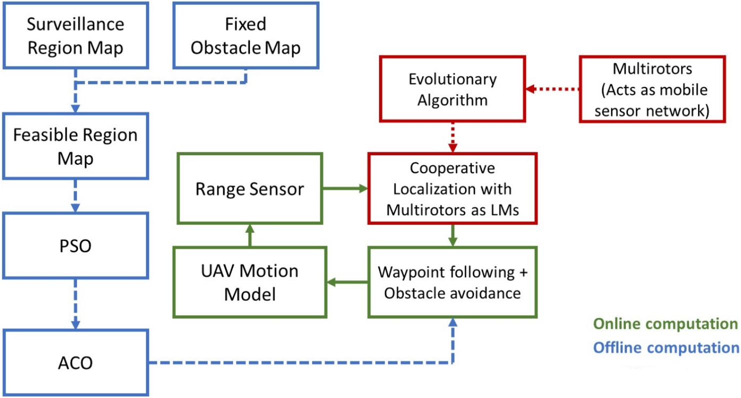
Objectives

In this project, we solve surveillance of an unknown environment, using multiple agents in a GPS-denied hostile environment described below :

- Maximize Search Area: Use Particle Swarm Optimization to determine the optimal location of waypoints in the environment.
- Vehicle Routing: Allocate these waypoints randomly to all the vehicles, and find optimal route for each vehicle by solve the Travelling Salesman Problem (TSP).
- Sensor Network Control: Use Genetic Algorithm to determine optimal paths for the vehicles in the sensor network to maintain graph connectivity,



System Architecture



Methodology: Search Area Optimization

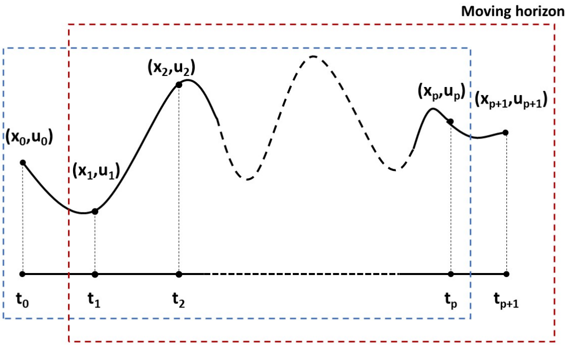
- To increase the coverage, multiple waypoints has to be optimally placed in surveillance area
- A modified PSO with constriction coefficients has been used to place all waypoints.
- Cost function of PSO has three parts.
  - Cost Function for Feasibility, ensures waypoints are inside search area $CF_f = \frac{n_{wp_{if}}}{n_{WP}} + n_{oc}$
  - Cost Function for Coverage,ensures maximum coverage of the search space, $CF_c = 1 - \frac{A_C}{A_T}$
  - Cost Function for Overlap, minimizes the overlap between the waypoints, $CF_o = \frac{A_O}{n_{WP} A_{ij}}$

Methodology: Vehicle Routing

- The waypoints obtained from PSO are distributed randomly among vehicles such that all waypoints are covered.
- Optimal route for each vehicle is determined based on allocated waypoints i.e., TSP is solved for each vehicle.
    - Each vehicle begins and ends its route at the same waypoint.
    - Each waypoint is visited exactly once.
    - The distance travelled for the whole route is minimized.
- Ant Colony Optimization technique is used for solving the routing problem.

Methodology: Sensor Network Control

- As vehicles move through the environment, network topology changes.
- Vehicles in the sensor network can plan their routes such that the connectivity is maintained.
- Genetic Algorithm coupled with Model Predictive Control is used for path-planning of the vehicles in the sensor network.



Methodology: Sensor Network Control

- The solution genome consists of turn-rate for the next T time-steps for each vehicle.
- Solutions are evolved using single point crossover and two point crossover, coupled with mutation.
- Best solution selection: 45% by elitist selection, 45% by tournament selection, 10% are chosen randomly.
- Second lowest eigenvalue of Graph Laplacian is used as cost for selection.

$$L = D - A \tag{1}$$

Results: Search Area Optimization

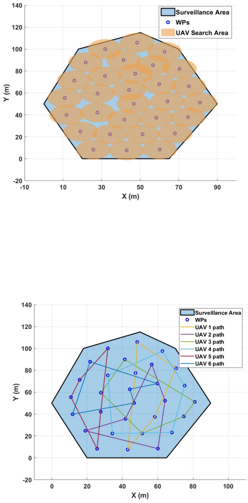
Lagrangian multipliers $\lambda_{\text{env}}, \lambda_{\text{coverage}}$ and λ_{overlap} can be varied to prioritize the cost

Cases	λ_{env}	$\lambda_{coverage}$	$\lambda_{overlap}$
1	100	80	0
2	50	100	100
3	20	200	200

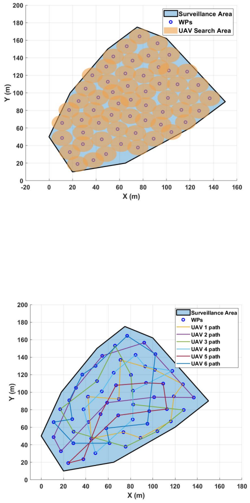
Cases	Map1		Map2		Map3	
	Cov.%	Ov.%	Cov.%	Ov.%	Cov.%	Ov.%
1	92.54	10.80	88.88	12.91	83.76	19.45
2	92.54	10.80	89.17	12.53	85.00	17.71
3	92.37	10.80	89.04	12.70	83.76	19.45

Case 2 where Coverage and Overlap weights are twice as Environment are found optimal

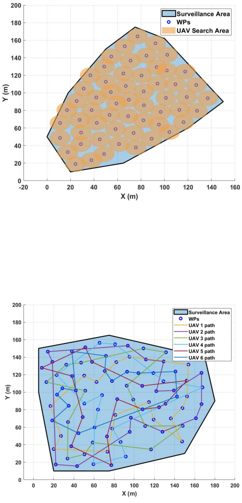
Results: Search Area Optimization Vehicle Routing



(a) Map 1



(b) Map 2

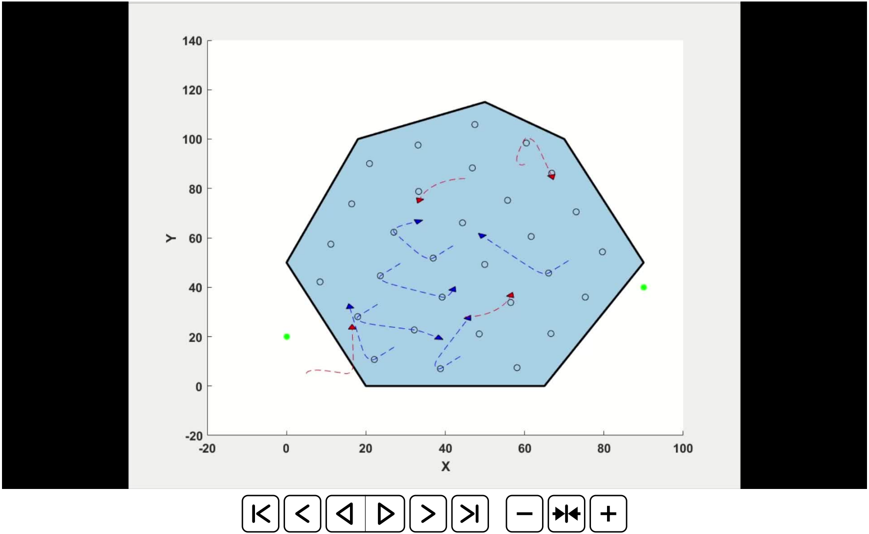


(c) Map 3

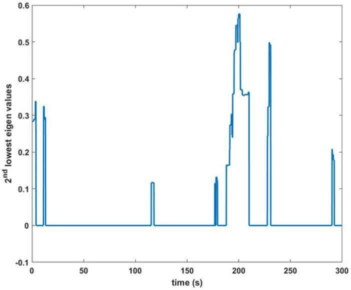
Results: Sensor Network Control

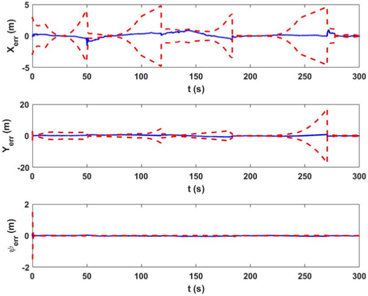
- We notice that both Genetic Algorithm and traditional optimization technique fail in optimization.
- The eigen values of Graph Laplacian are invariant in the neighborhood of the initial point/solution and hence cannot be exploited for choosing better solution.
- Observability based cost functions that vary with changes in position can be derived and used.
- We present some intuitive trajectories for the vehicles in thesensor network and observe the variation of uncertainty withthe second lowest eigenvalue of graph laplacian.

Results: Simulation Video



Results: Localization Accuracy





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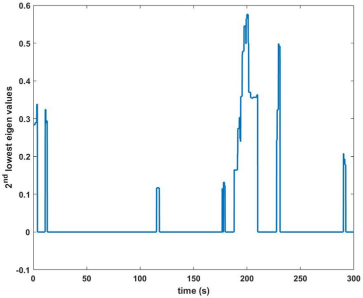

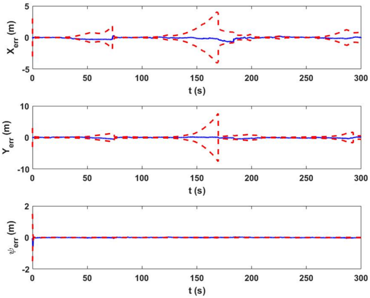

Conclusion

- PSO performs well in small surveillance region but takes more time as surveillance area increases. Parallel computing can be exploited to decrease the run time.
- ACO is simple and also found to be scalable in vehicle routing when number of waypoints increase.
- Although the second least eigenvalue of graph laplacian is a good measure of connectivity of a graph, it is not ideal for developing optimal control strategies to maintain graph connectivity.
- Observability gramian based cost metrics can be useful in solving such optimization problems as they are sensitive to change in relative positions between vehicles.

Thank You !