A Planner for Autonomous Risk-Sensitive Coverage (PARCov) by a Team of Unmanned Aerial Vehicles

Alex Wallar [1]   Erion Plaku [2]   Donald Sofge [3]

[1]School of Computer Science
University of St Andrews

[2]Departement of Electrical Engineering and Computer Science
The Catholic University of America

[3]Naval Center for Applied Research in Artificial Intelligence
Naval Research Laboratory

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Goals

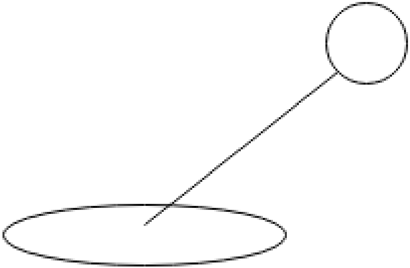
- To allow groups of robots cooperatively provide persistent surveillance of a given area
- To reduce the risk of damage incurred on the robots
- To maximize the quality of sensory information

Motivation

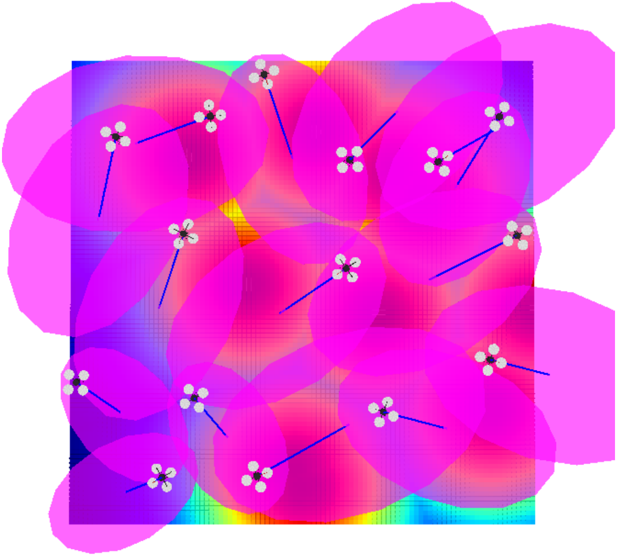
- There are many cases where high quality sensory information is needed from areas where risk of vehicle damage is high
- *Examples*
  - Disaster relief
  - Covert surveillance
  - Safety critical missions

Maximizing Aerial Coverage

- The experiments conducted consider spotlight sensors
- The sensed area corresponds to an ellipse which is a function of the sensor angle ϕ and the conic aperture α.



Maximizing Aerial Coverage



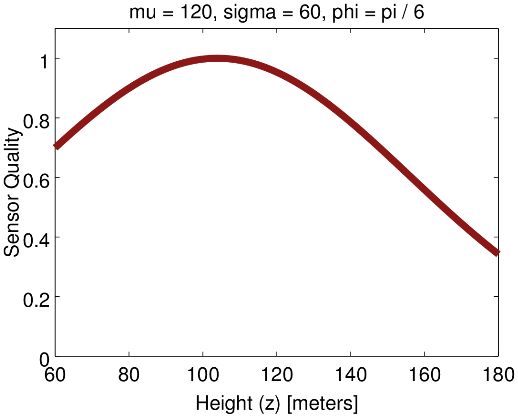
Maintaining High Sensor Data Quality

- One algorithmic objective is to maintain high sensor data quality
- It is assume that there is an optimal altitude, μ_{sq}, in order to achieve the highest sensor quality
- μ_{sq} varies based on the situation
- The sensor quality is assumed to decrease exponentially as the deviation from μ_{sq} increases

Maintaining High Sensor Data Quality

Sensor Quality

$$SQ(z) = \exp\left(-\left(\frac{z}{\cos\phi} - \mu_{sq}\right)^2 / (2\sigma_{sq}^2)\right)$$



Reducing Risk

- While surveying an area, the quadrotors seek the reduce the risk of being detected
- Risk is modelled based on ground level risk, R_0 which indicates the likelihood of a quadrotor being detected at (x, y)

Risk

$$R(x,y,z) = R_0(x,y) \cdot \exp\left(-\frac{z^2}{K \cdot R_0(x,y)^2}\right)$$

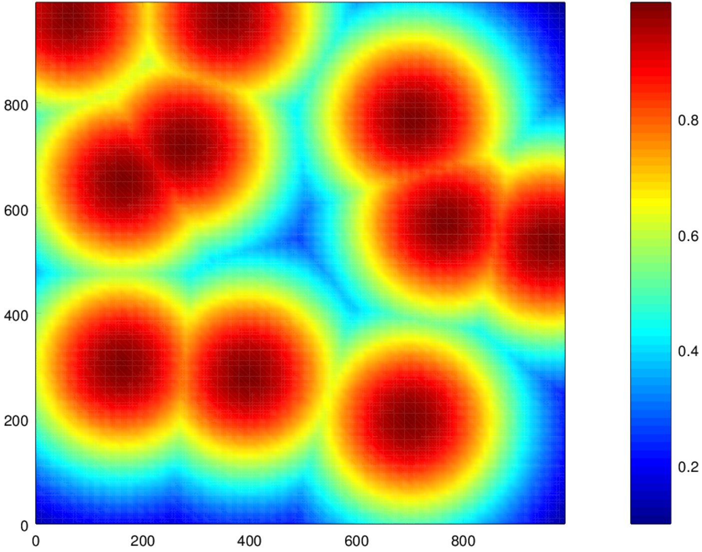
Ground-level Risk

- Ground level risk, R_0, is modelled by centering normal distributions around a set of points given a priori
- The risk decreases exponentially as the distance from a risk point increases

Ground-level Risk

$$R_0(x, y) = \max_{p \in \textit{RiskPoints}} \exp\left(-\frac{||p - (x, y)||_2}{L}\right)$$

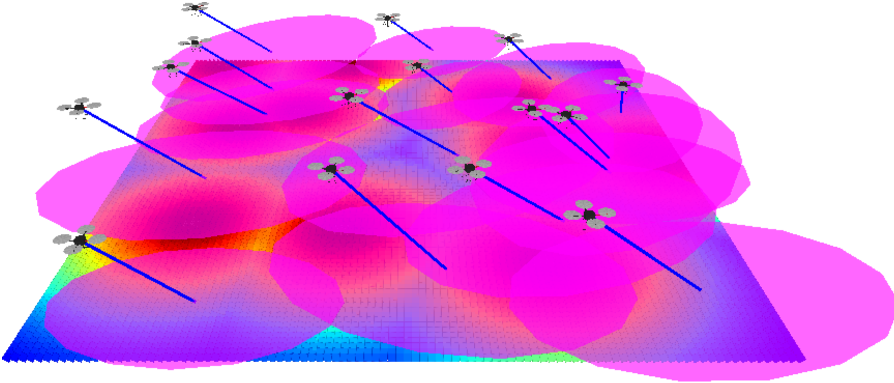
Ground-level Risk



Problem Statement

- Given:
  - An area to be surveyed
  - A sensor quality model
  - A risk model
  - Initial placements of the quadrotors
- Goals:
  - Maximize area coverage
  - Maintain high sensor data quality
  - Ensure persistent coverage
  - Reduce the risk incurred by the quadrotors

Method: PARCov

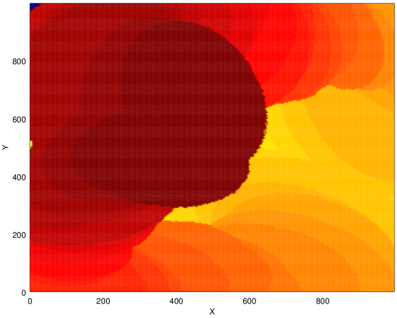


Planning to Promote Area Coverage and Persistency

- PARCov seeks to move the quadrotors to areas that have not been covered in a long time
- This simple rule ensures that no part of the search area goes to long a time without being surveyed
- This goal promotes persistent coverage

Planning to Promote Area Coverage and Persistency

- Impose grid, $\mathcal{G}$, over the xy bounding box of the area being surveyed
- Use $\mathcal{G}$ to keep track of which parts were surveyed and when they were last surveyed



Planning to Promote Area Coverage and Persistency

1. Sample potential orientations
2. For each orientation, sample segments along sensor footprint
3. Determine the sample with the maximum average uncertainty for each orientation
4. Move in the direction of the sample with the maximum uncertainty
5. Change the orientation to the sampled orientation

Planning to Promote Area Coverage and Persistency

- There is a function *WaitTime*$(\mathcal{G}, x, y)$ that given the grid $\mathcal{G}$, determines the amount of time that has passed since (x, y), has been sensed.
- There is also a function *AvgWaitTime*$(\mathcal{G}, s)$ that returns the average wait time for a set of points, where $s = \{(x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n)\}$ is a segment of points along the sensor footprint.

Planning to Promote Area Coverage and Persistency

- The quadrotor will move toward the line segment, s, with the maximum average wait time
  - $s = \underset{s' \in \mathit{SampledSegments}}{\arg\max} \mathit{AvgWaitTime}(\mathcal{G}, s')$
- Formally, the position becomes

Position Update

$$-(q.x, q.y) + \sum_{(x,y) \in \mathit{points}(s)} \frac{\mathit{WaitTime}(\mathcal{G}, x, y)}{\sum_{(x',y') \in \mathit{points}(s)} \mathit{WaitTime}(\mathcal{G}, x', y')} (x, y)$$

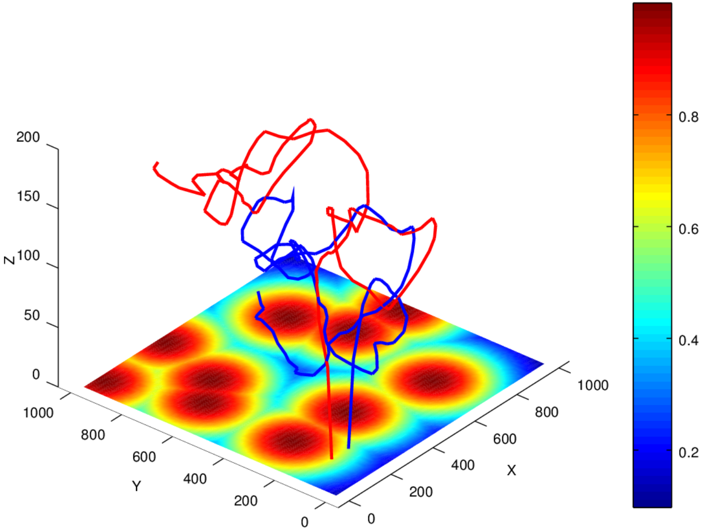
Planning to Reduce Risk and Maximize Sensor Quality

- PARCov optimizes an objective function that maximizes the sensor data quality and minimizes the risk
- Nonlinear optimization solvers can be used numerically compute the optimal altitude

Objective Function

$$\arg\max_{z \in [z_m in, z_m ax]} \quad SQ(z) - R(x, y, z)$$

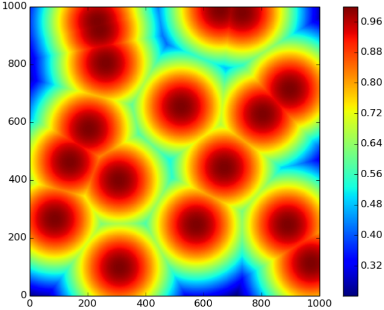
Trajectories

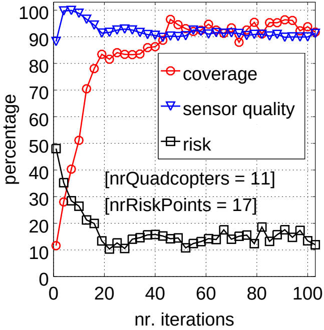


Experimental Setup

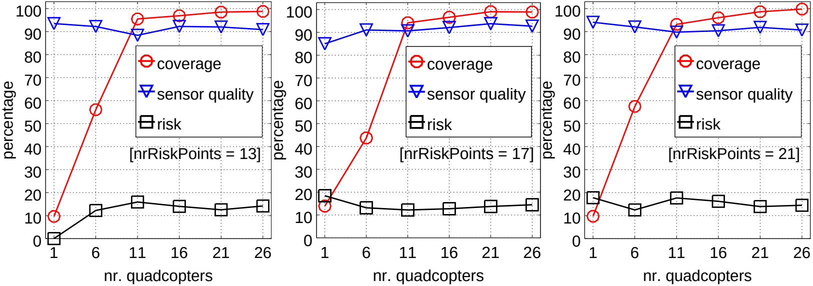
- Three scene dimensions were used for experimentation
- For each scene size, 11 different amounts of randomly placed risk points were used
- The number of quadrotors varied from 1 to 26 with a step of 5
- The metrics that we collected included
    - Average risk
    - Average sensor data quality
    - Average wait time

Real-time Results

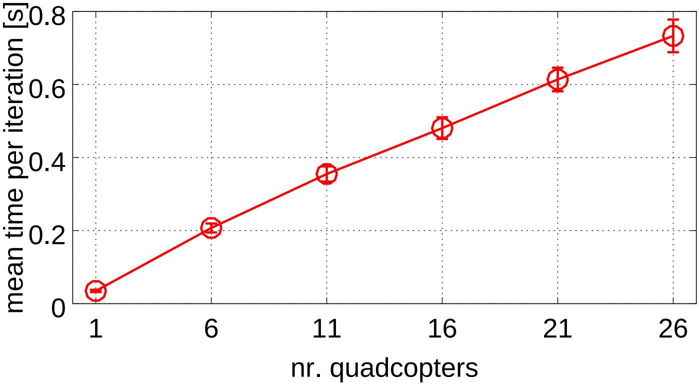




Algorithmic Performance



Runtime Performance



Conclusions

- Maximizes sensor coverage
- Maximizes the quality of sensory data
- Minimizes the risk incurred by the quadrotor
- The algorithm is scalable, configurable, and succeeds in all of the areas in which it was designed

Future Work

- Apply the algorithm on real quadrotors in a practical setting
- Take battery life into account when planning and allow the quadrotors to recharge automatically

Questions?