Next-Best-View-based Task and Motion Planning for Autonomous Photography & Inspection

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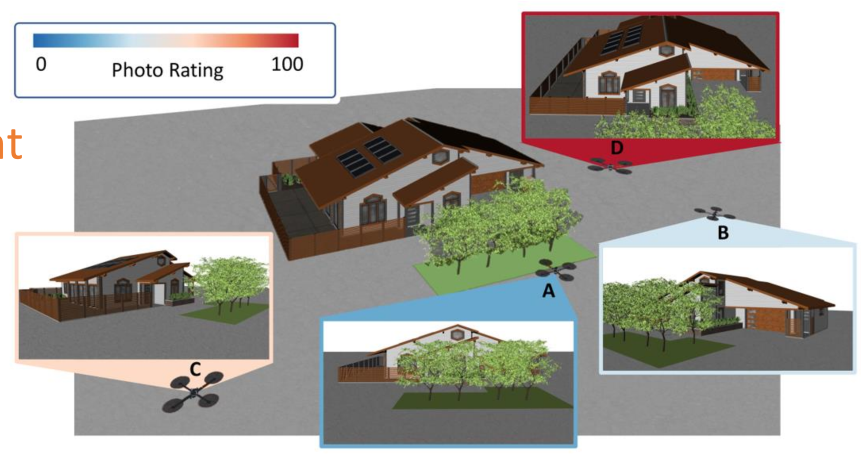
Motivation

- Acquiring autonomously the best inspection viewpoints is challenging for mobile robots due to the unknown presence of objects that occlude a desired target
- Most of current inspection frameworks are not fully autonomous or data efficient
- The quality of an inspection viewpoint has not been mathematically formalized for real-time operations

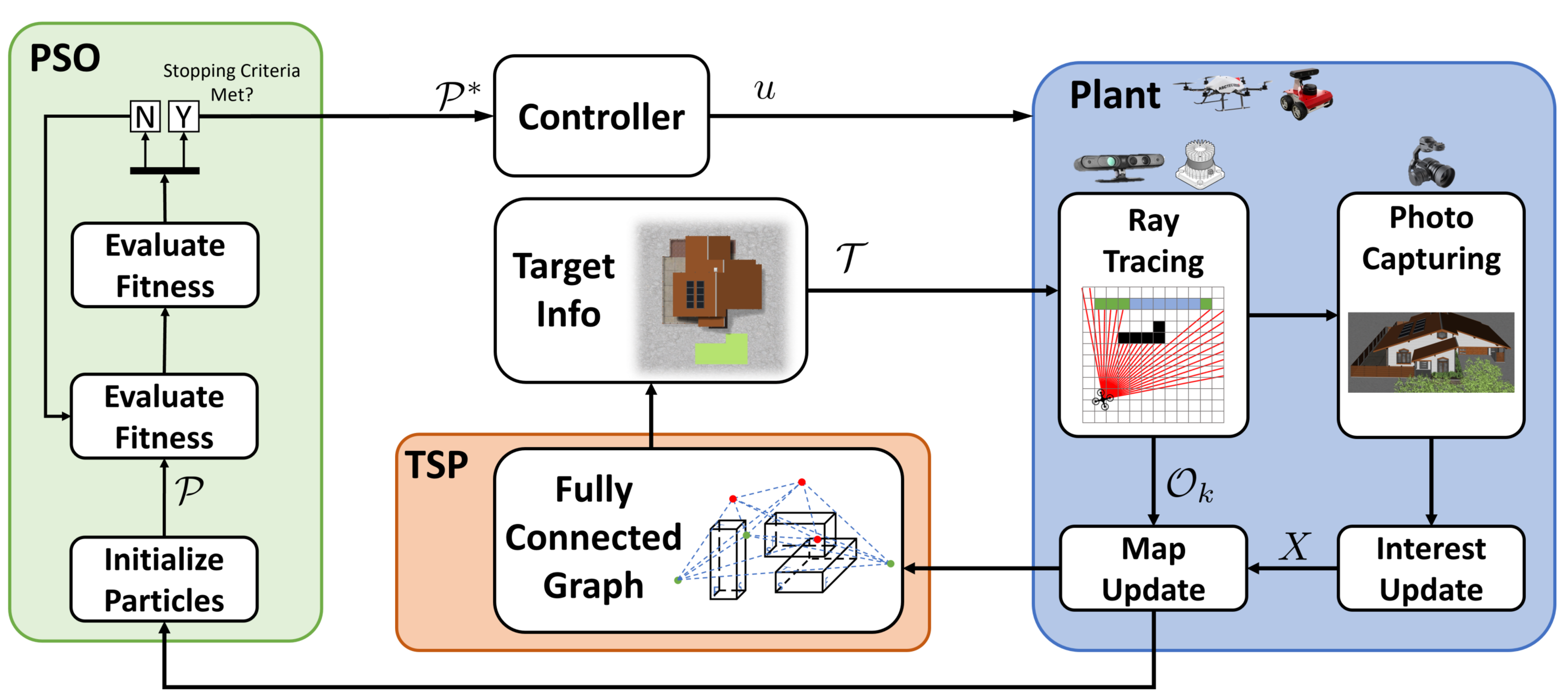


Objective

- An end-to-end Task and Motion Planning (TAMP) framework for autonomous photography & inspection with minimum number of viewpoints in uncertain environment.

Approach

- Traveling Salesman solution used for high-level task planning.
- Next-Best-View-based motion planning method to obtain the fewest best viewpoints to capture the most information.
  - I. A formally defined evaluation metric to estimate information gained over an inspection operation.
  - II. A computationally efficient Gaussian process (GP) interpolation and Particle Swarm Optimization (PSO) for evaluating viewpoints at runtime.



Traveling Salesman Task Planning

- A fully connected graph is constructed considering the target's location, dimensions, and camera properties.
- A Traveling Salesman solution is computed considering energy consumption and completion time.

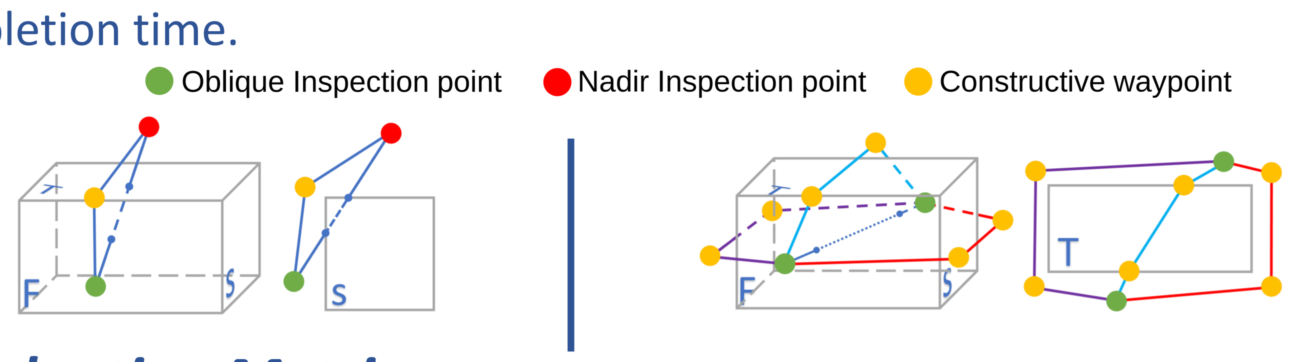


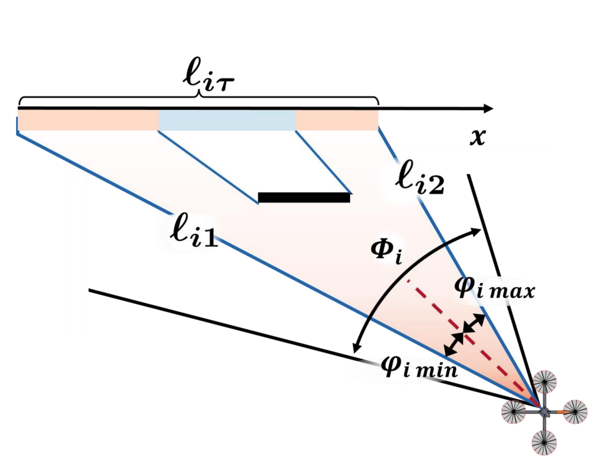
Photo Evaluation Metric

- A formal method for constructing an evaluation metric based on user preference is introduced.
- An example metric for keeping the target in the center of the frame with minimal occlusion and distortion is provided.

$$G(\mathbf{T},\mathcal{M},\mathbf{P}) = \gamma_d\cdot\gamma_s\cdot\int_{\mathbf{T}} g(\tau)d\tau,\ \ \tau\in\mathbf{T}$$

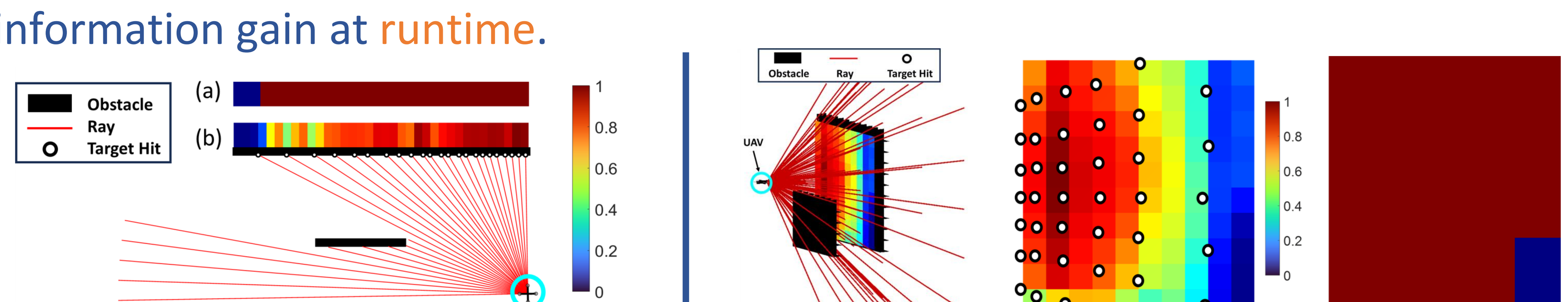
$$\gamma_d = \prod_{i=1}^{n_d-1} U_d\left(\frac{|\ell_{i2}-\ell_{i1}|}{\ell_{i\mathbf{T}}}\right)$$

$$\gamma_s = \prod_{i=1}^{n_d-1} U_s\left(\frac{(\phi_{i\max}-\phi_{i\min})}{\Phi_i},\beta\right)$$



Information Gain Estimation

- Sparse ray-tracing combined with Gaussian process is utilized for estimating the information gain at runtime.



(a) 2D example (b) 3D example

Candidate View Particle Swarm Optimization (PSO)

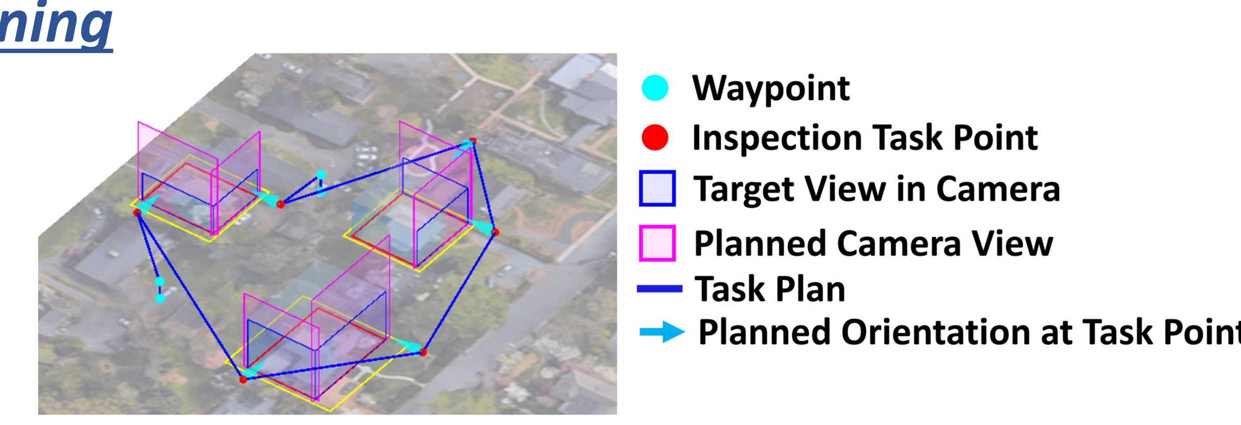
- PSO has the advantage of solving highly non-linear problems and the ease of adaption to runtime considerations.
- The viewpoint evaluation is used in conjunction with PSO to find the best inspection point.

Next-Best-View-based motion Planning

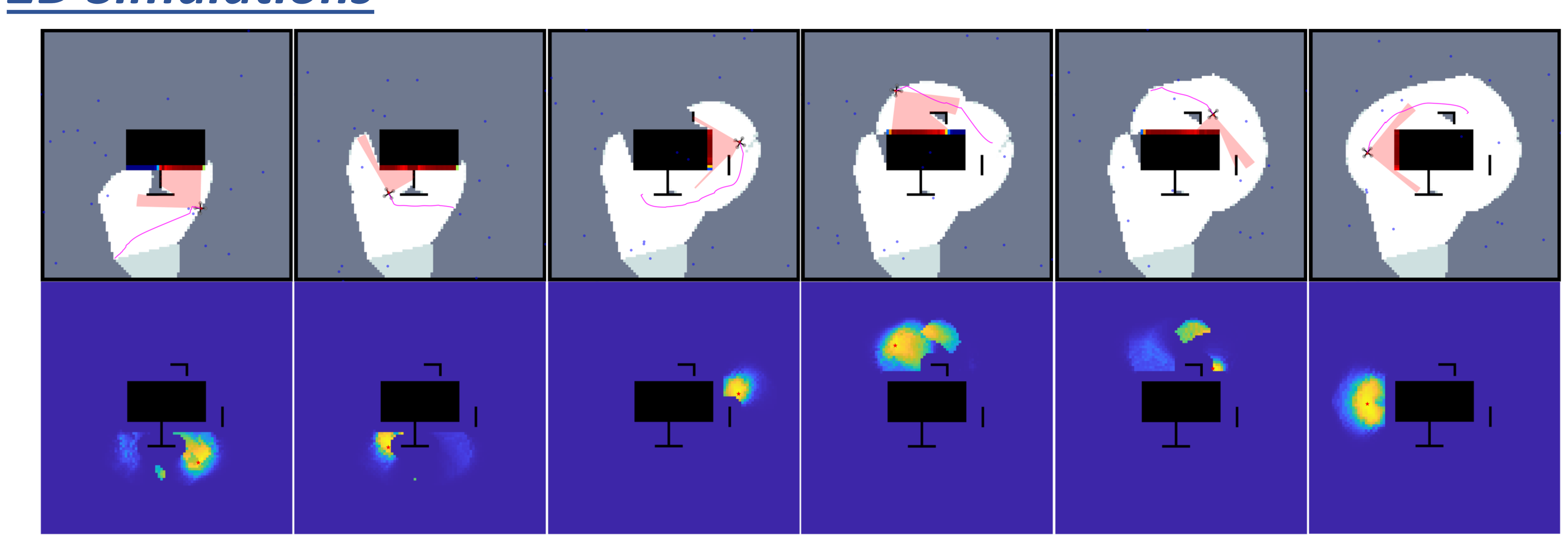
- Given the optimal viewpoint, local motion planning is achieved by leveraging common path planning methods (e.g., A*, RRT*, etc.)

Results

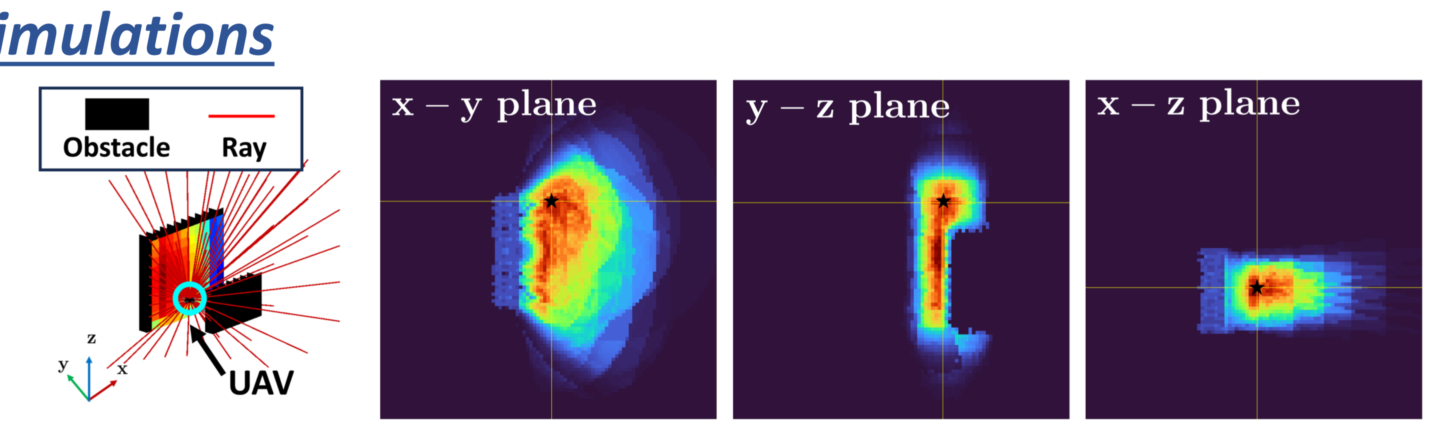
Task Planning



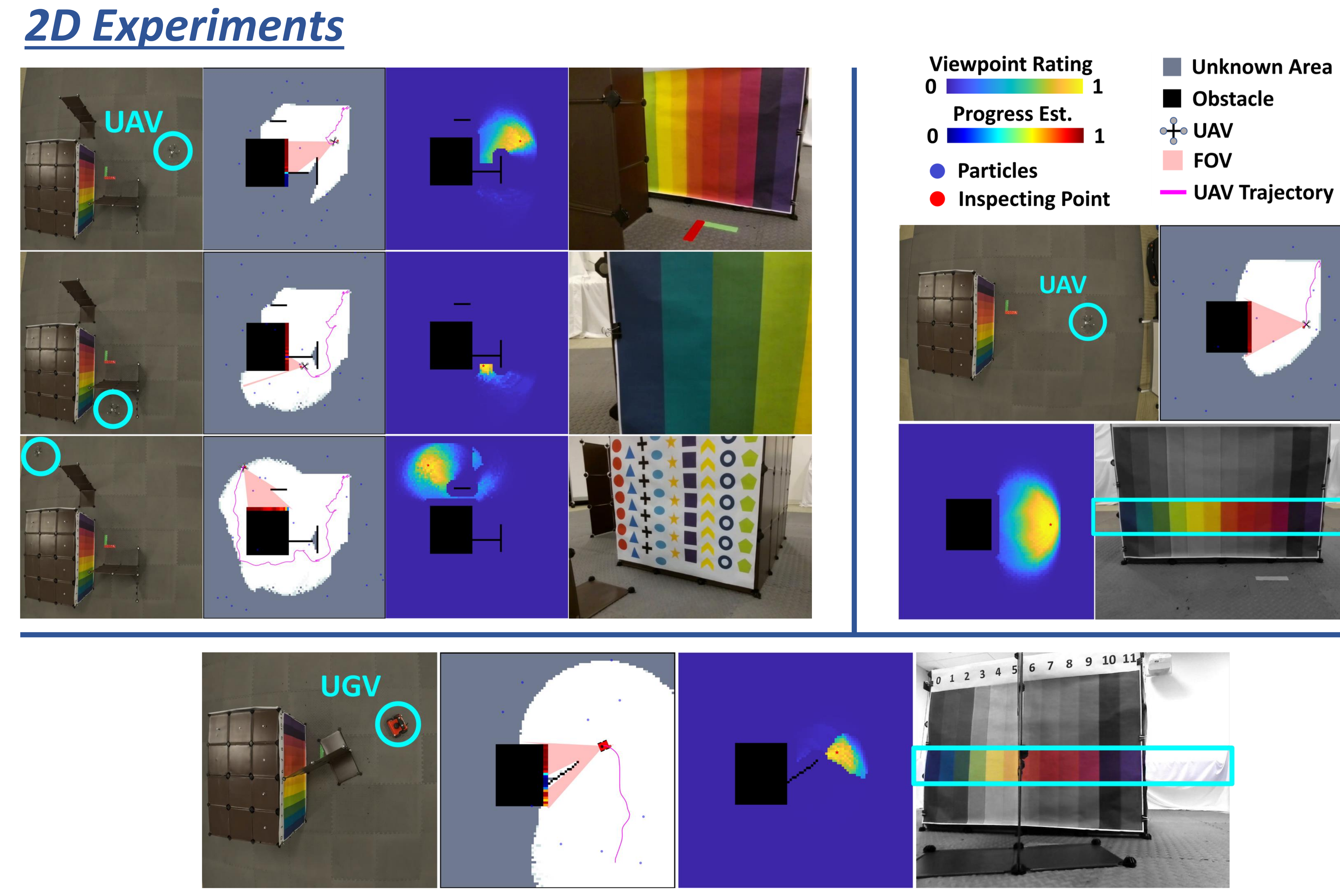
2D Simulations



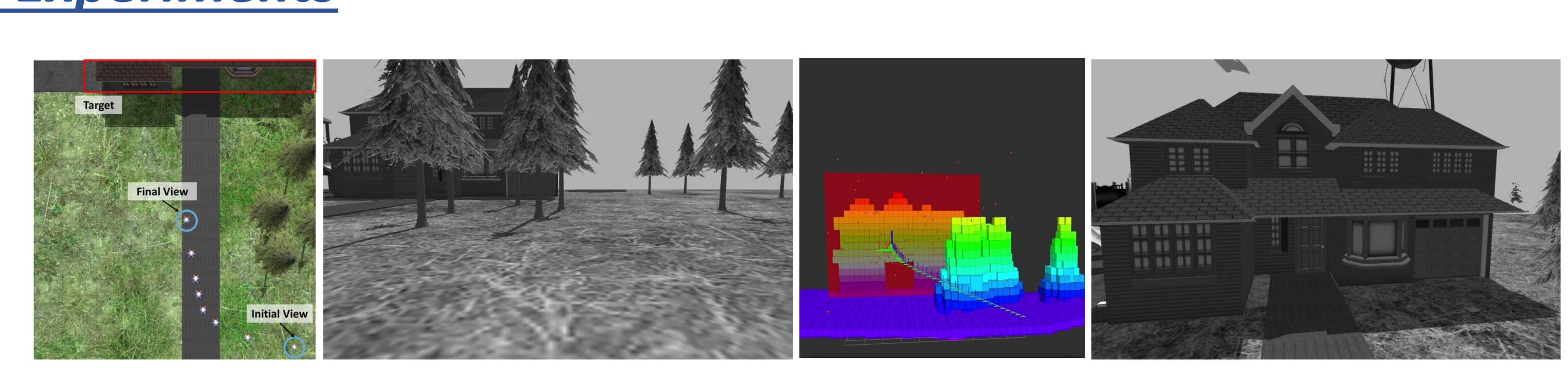
3D Simulations



2D Experiments



3D Experiments



Conclusion & Future Work

- Novel TAMP framework for autonomous photography & inspection in a partially-known environment.
- Future work: outdoor experiments with different sensor suites