Adaptive Near-Field Imaging with Robotic Arrays

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Imaging and Robotics

Why imaging?
- Surveillance
- Search and rescue
- Archaeology

Why robots?
- Emerging in many fields
- Can go to hazardous places
- Flexible positioning

Jackal UGV, clearpathrobotics.com

Robotics in Imaging

- **How to benefit from robots in near-field imaging?**

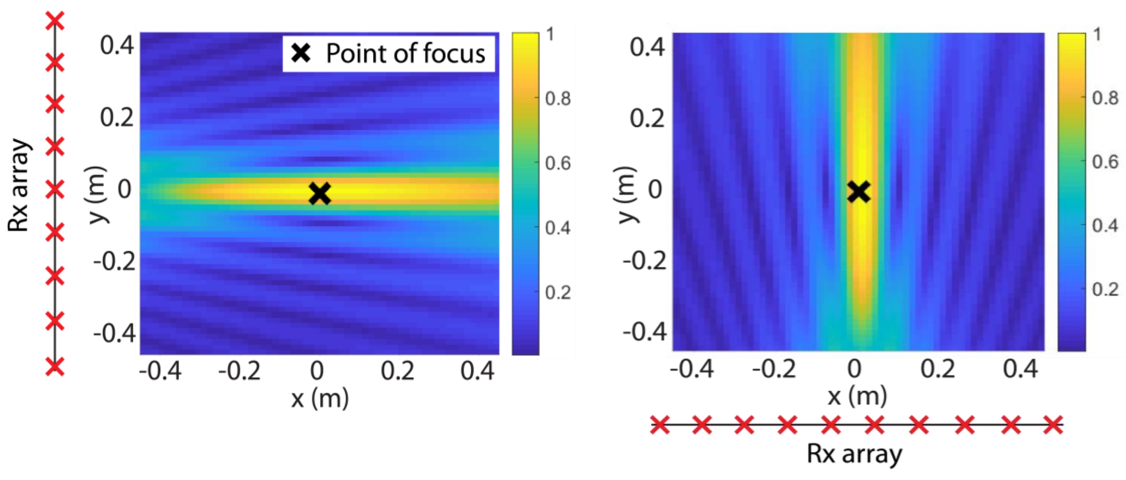
- Near-field beamforming

$$I(x) = \left| \sum_{r=1}^{N} R(q_r) e^{j\frac{2\pi}{\lambda}\left(\|x-p_t\|_2 + \|x-q_r\|_2\right)} \right|$$

- Difficult problem of considerable interest

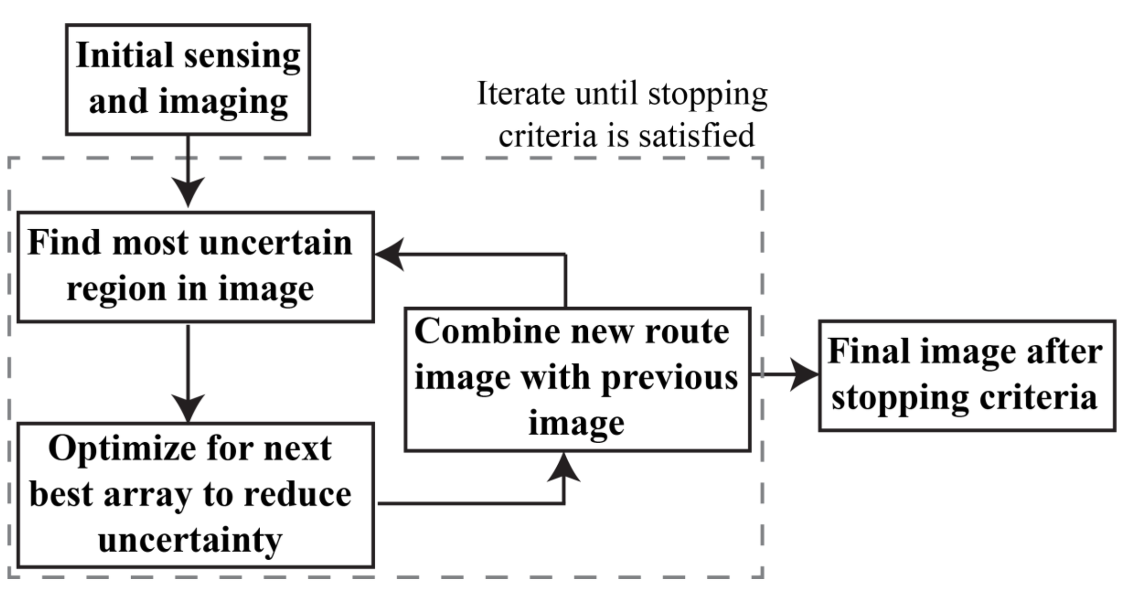
Narrowband Phased Array Imaging

- Point Spread function has a high spread



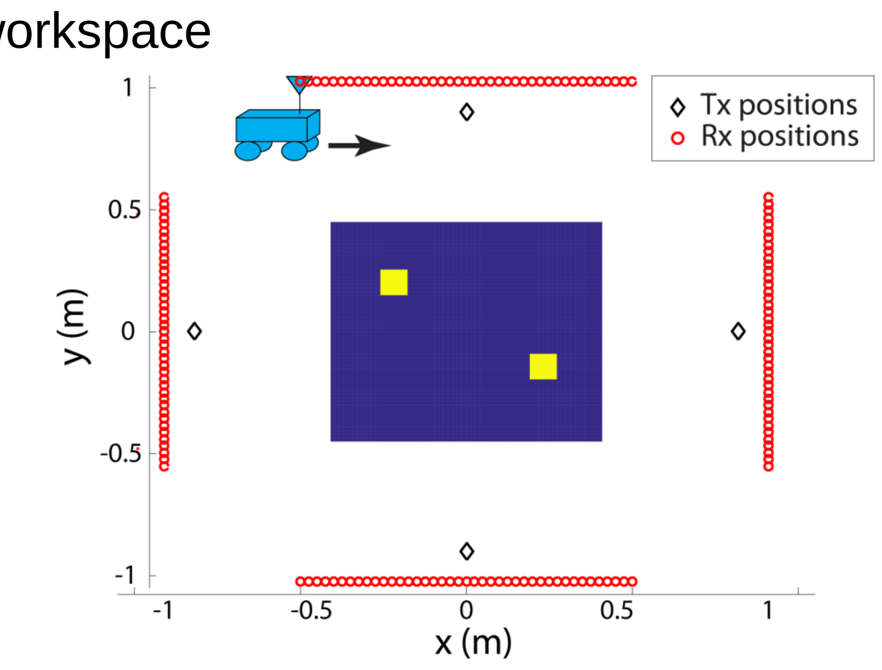
- Multiview imaging improves imaging quality
  - Multiplicative and additive fusion
  - Relies on fixed array locations
- Robots can adaptively synthesize arrays to further improve imaging quality

Proposed Adaptive Imaging Algorithm



Initial Sensing and Imaging

- No prior information: additive fusion of images from arrays with any configuration
- Example: four arrays at four different sides of workspace

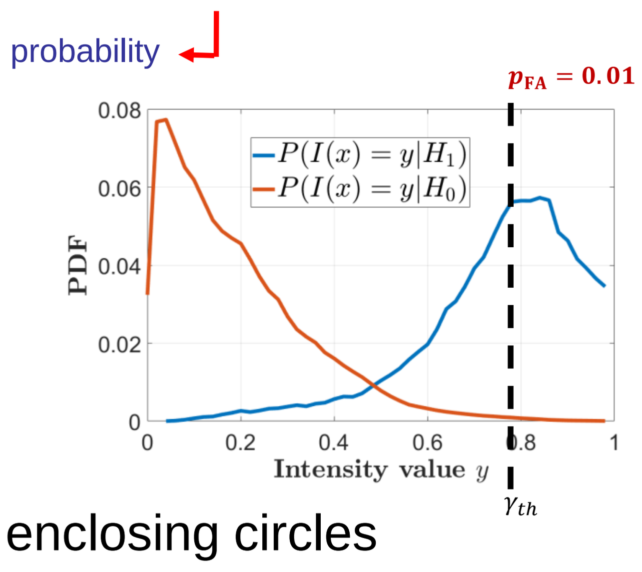


Finding Object Regions

- Threshold the image using γ_{th}, which can be determined using Neyman-Pearson criterion

$$\text{argmax} \quad p_D \quad \text{(Detection probability)}$$
$$\text{subject to} \quad p_{FA} = \beta \quad \text{(input)}$$

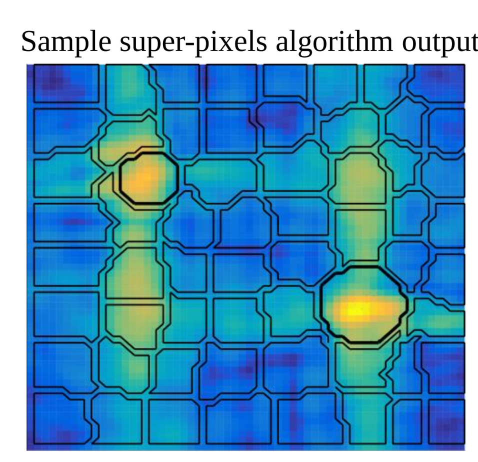
False alarm probability



- Create enclosing circles
- Binary object mask $\mathbf{O}(x)$

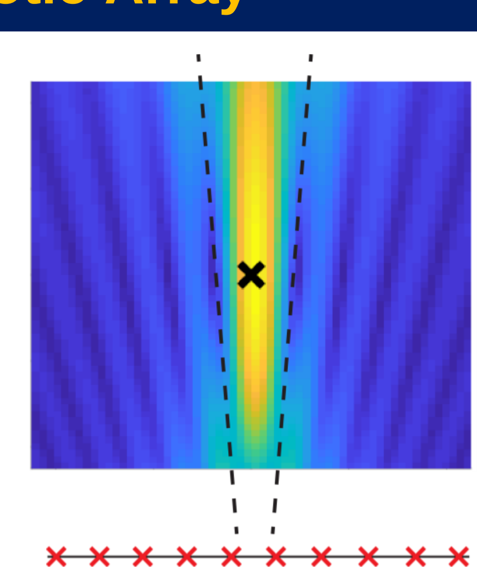
Finding Most Uncertain Region

- Generate super-pixels for the remaining part of image
- Choose super-pixel whose mean intensity is closest to $E(I(x)|I(x) < \gamma_{th}, H_1)$
- Binary uncertainty mask $\mathbf{U}(x)$



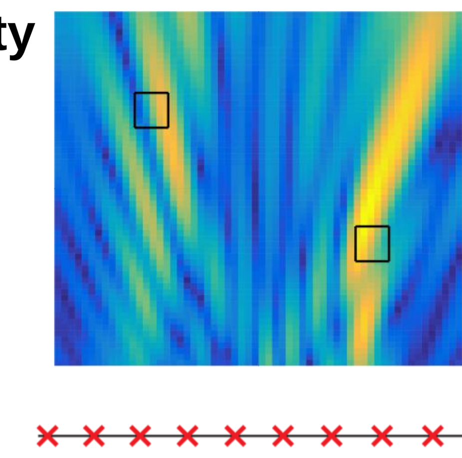
Optimal Robotic Array

- **Requirement 1: PSF Focus**
  - PSF is concentrated inside a cone
  - $\mathbf{U}(x)$ be inside the cone
  - $\mathbf{O}(x)$ be outside the cone



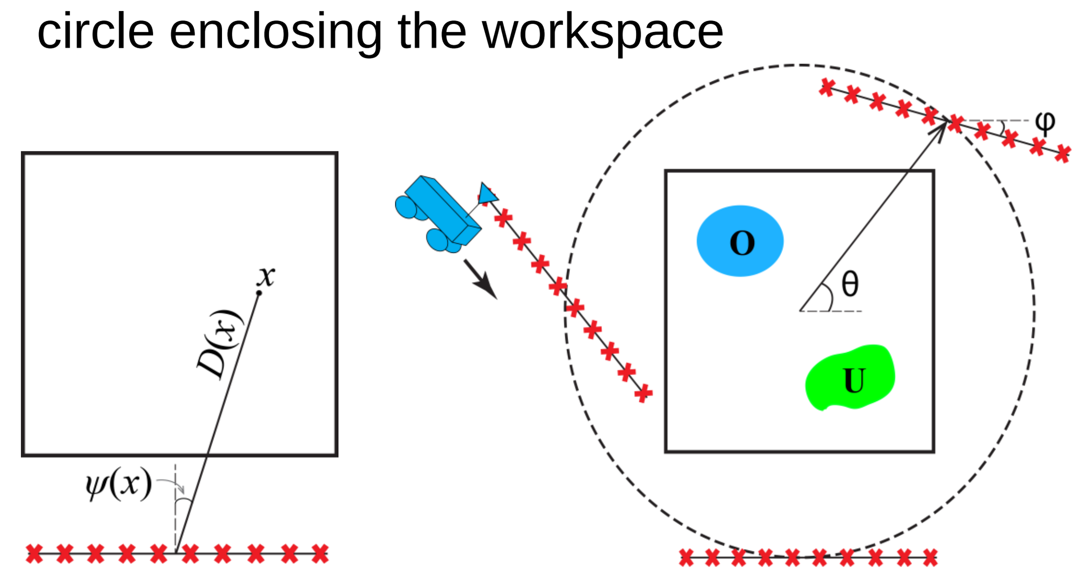
Optimal Robotic Array (cont'd)

- **Requirement 2: proximity to uncertain region**
  - Objects farther from array outpowered by closer objects
  - $\mathbf{U}(x)$ preferred closer to array than $\mathbf{O}(x)$



Finding Optimal Robotic Array

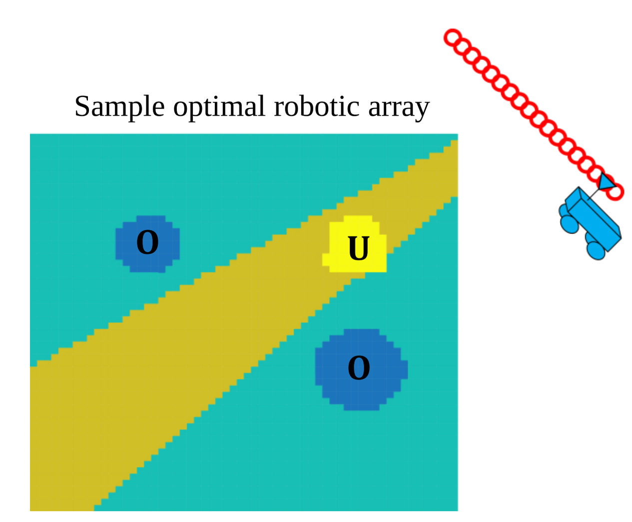
- Modeling the requirements: introduce a mask $\mathbf{P}(x) = \frac{1}{\psi(x)D(x)}$
- Objective: maximize $\mathbf{P}(x)\mathbf{U}(x)$, minimize $\mathbf{P}(x)\mathbf{O}(x)$
- Consider arrays with any orientation on a circle enclosing the workspace



Finding Optimal Robotic Array (cont'd)

- Optimization problem:

$$\{\theta^*, \phi^*\} = \underset{\theta,\phi}{\text{argmax}} \sum_{x} \mathbf{P}_{\theta,\phi}(x)(\mathbf{U}(x) - \alpha\mathbf{O}(x))$$
$$\text{subject to} \quad 0 \leq \theta < 2\pi, \quad 0 \leq \phi < \pi$$



- Combine image obtained from optimized array with the previous image

Conclusions

- New framework for adaptive imaging using robotic arrays
- Proposed a method for detecting object areas and areas of high uncertainty
- Optimized the best array to image the uncertain region
- Simulations show efficacy of algorithm to remove uncertainty

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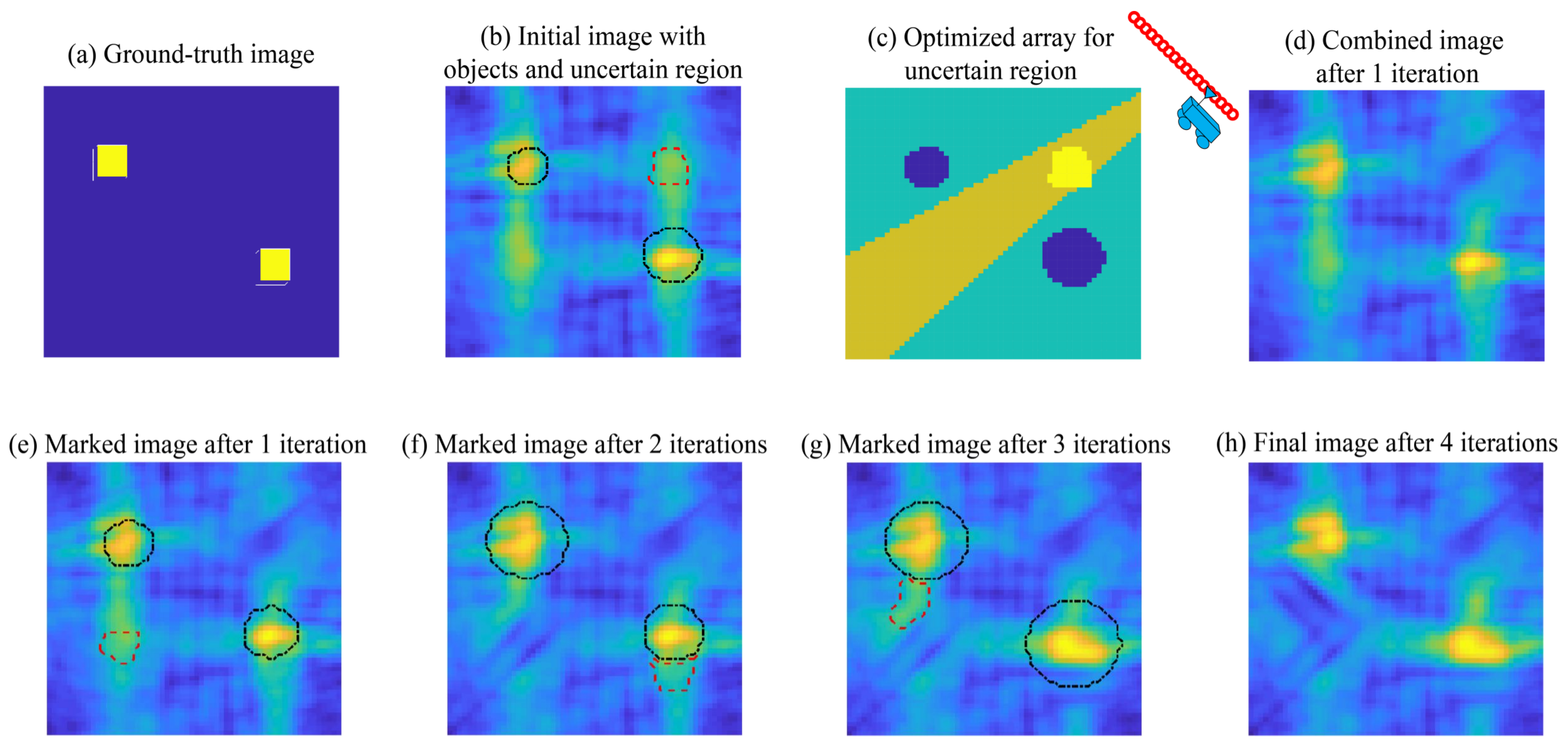
Results

- Example 1: uncertain regions are empty regions



- Example 2: uncertain regions contain objects