Map Merging Using Hough Peak Matching

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Outline

- Introduction
- Background of Research and Problem Statement
- Map Merging with Hough Transforms
- Experimental Results
- Conclusion

Introduction

- Simultaneous localization and mapping (SLAM)
  - Multiple robot SLAM
  - Relative transformation of maps are required

- This paper:
  - Uses Hough transform to:
    - 1) identify overlaps between maps
    - 2) find the relative transformation from overlaps

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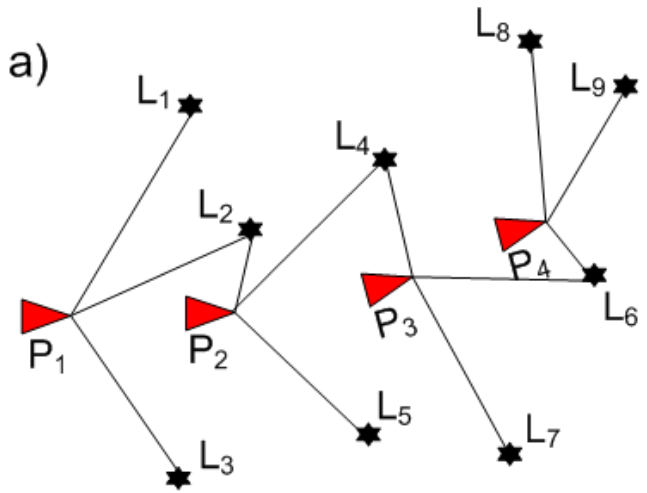
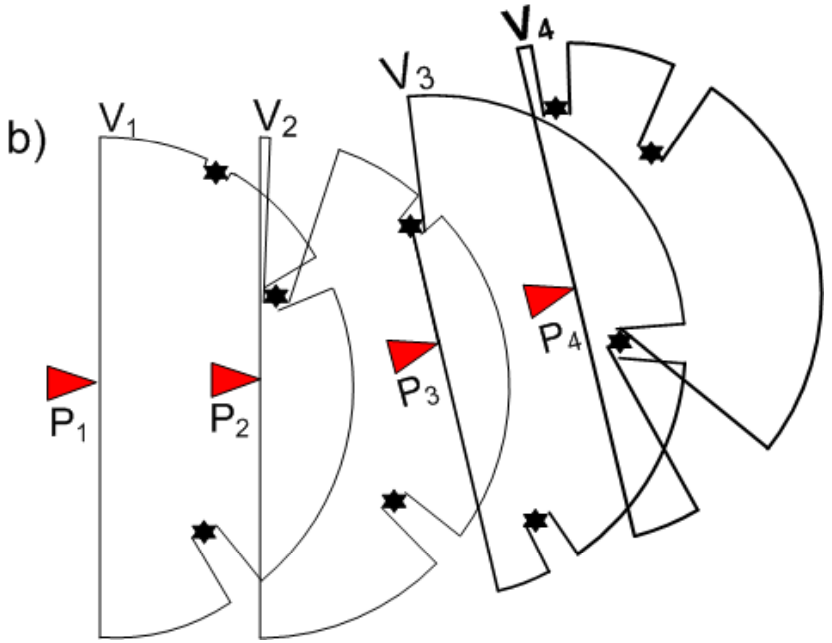
Background of Research

- Feature-based SLAM and view-based SLAM



feature-based SLAM

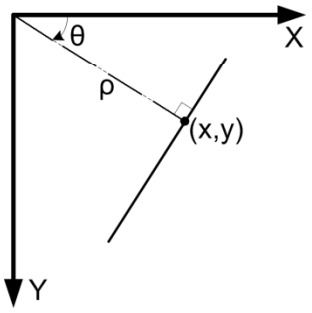


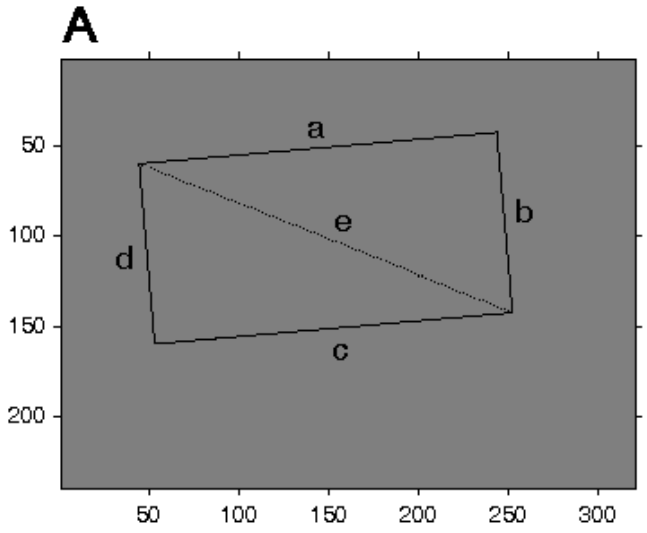
View-based SLAM

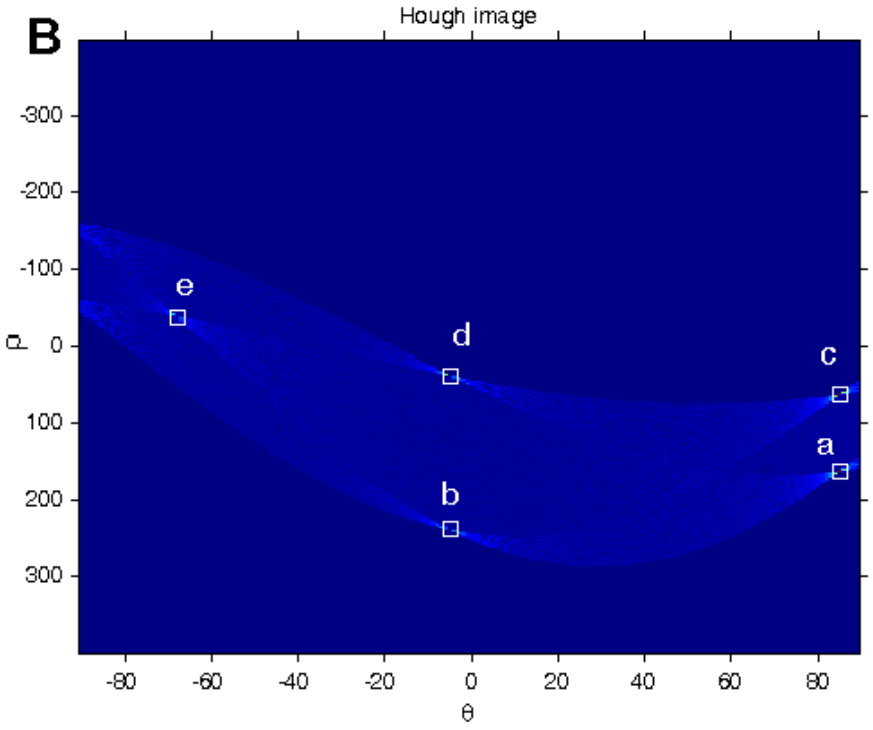
Background of Research

- The Hough Transform

$$\rho = x\cos\theta + y\sin\theta$$

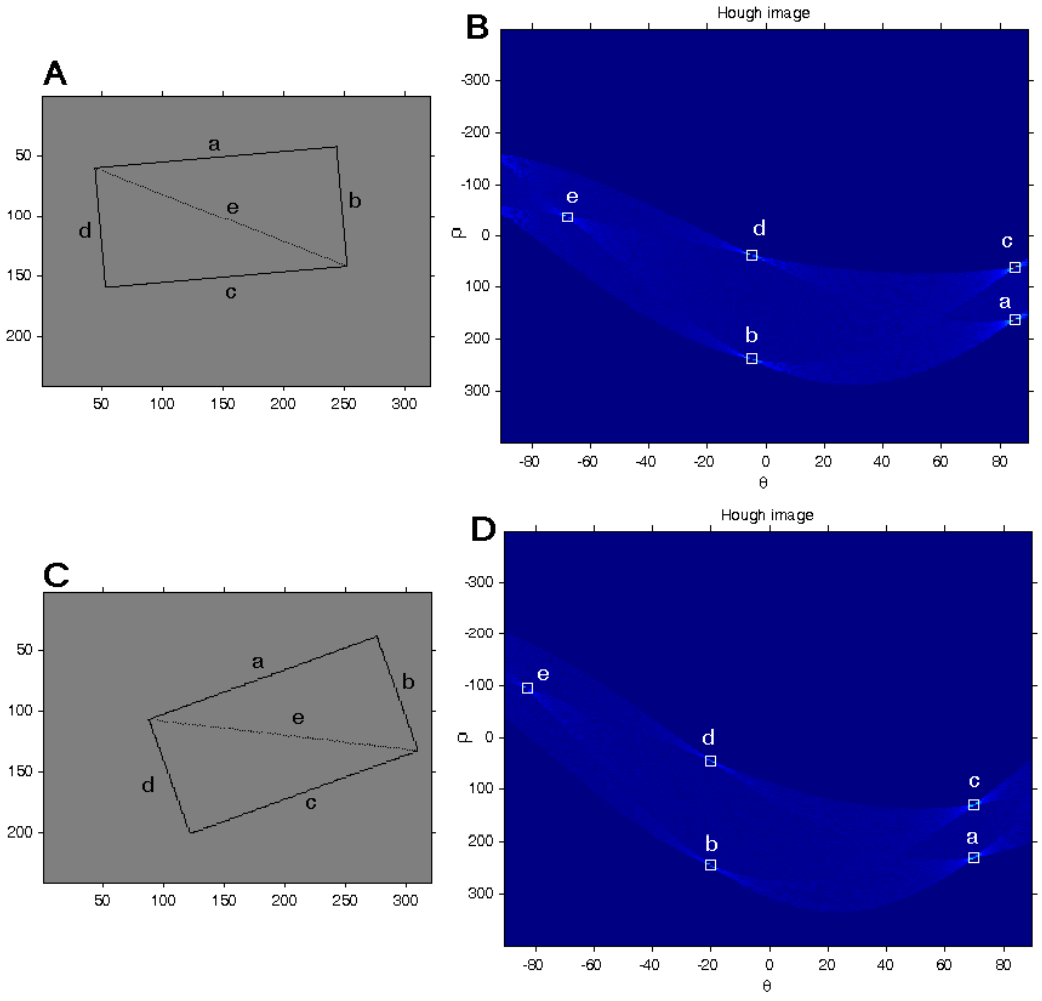






Background of Research

- Transformation in the Hough space



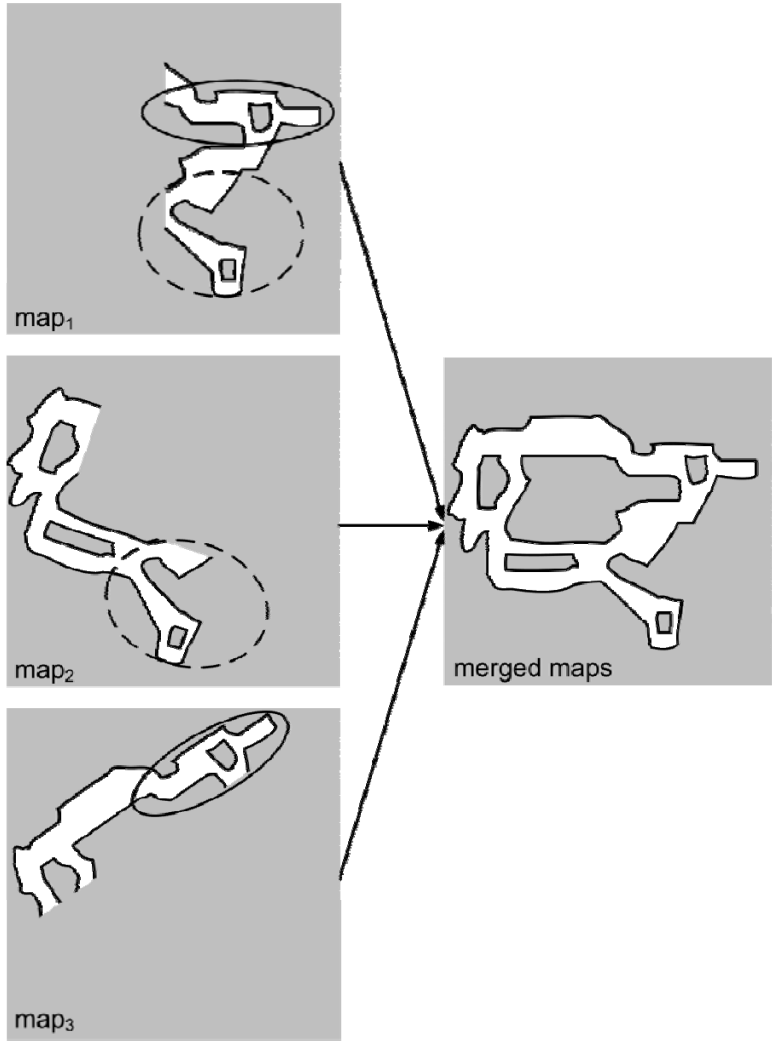
Background of Research

- Map Merging
  - Transformation

$$R_\psi = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix}, T = \begin{bmatrix} \delta_x \\ \delta_y \end{bmatrix}$$

  - Given each pair of maps

$$(R_\psi, T) = \underset{\psi,\delta_x,\delta_y}{\operatorname{argmax}} V(m_1, m_2')$$



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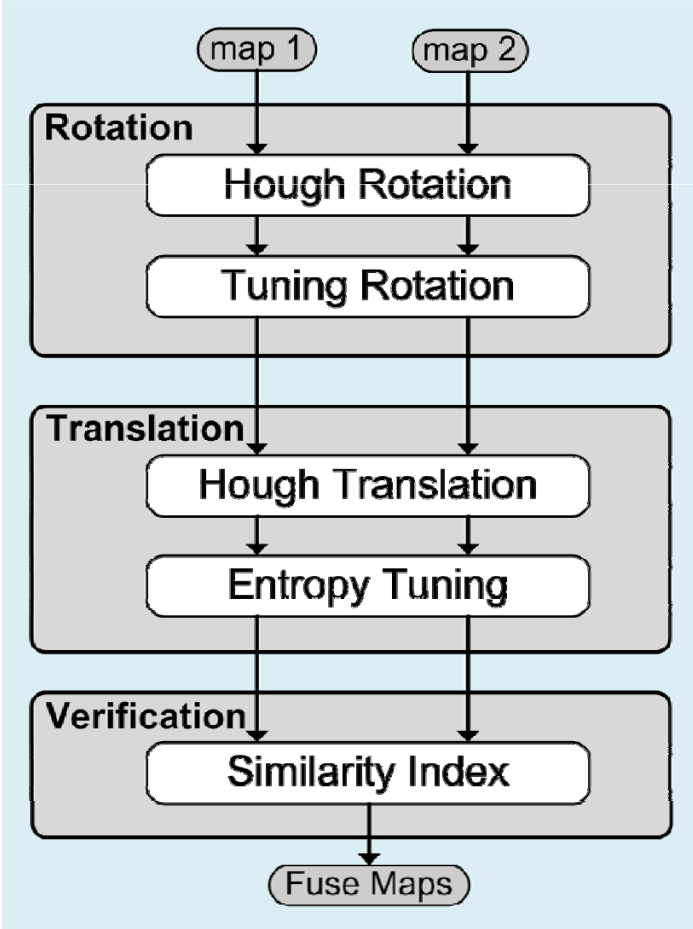
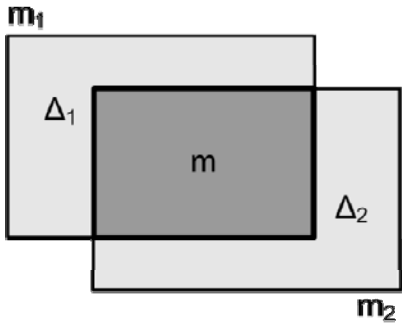
Map Merging with Hough Transforms

- Overview of the algorithm



Map Merging with Hough Transforms



$$\begin{aligned} m_1 &\triangleq \{m\} \cup \{\Delta_1\} \\ m_2 &\triangleq \{m\} \cup \{\Delta_2\} \end{aligned} \quad \rightarrow \quad \mathcal{H}_{m_1}(\theta,\rho) = \mathcal{H}_m(\theta,\rho) + \mathcal{H}_{\Delta_1}(\theta,\rho)$$

Assuming that R_ψ and $T = \begin{bmatrix}\delta_x & \delta_y\end{bmatrix}^T$ are transformation elements

Based on the properties of the Hough transform, we have:

$$\mathcal{H}'_{m_2}(\theta,\rho) = \mathcal{H}_m(\theta+\psi, \rho + \begin{bmatrix}\cos(\theta+\psi) & \sin(\theta+\psi)\end{bmatrix} T) + H_{\Delta_2}(\theta+\psi, \rho + \begin{bmatrix}\cos(\theta+\psi) & \sin(\theta+\psi)\end{bmatrix} T)$$

It is desired to have:

$$\mathcal{H}_{m_1}(\theta,\rho) \approx \mathcal{H}'_{m_2}(\theta,\rho)$$

In this research we choose to apply max operator to each column of the Hough image to achieve this goal. A circular convolution is applied to the output of the max operator from two images to extract the **orientation.**

Relative Orientation of Maps

Algorithm 1 Multiple hypothesis handling.

Input: P_1, P_2, v_{gate}

Output: $\hat{\psi}$

1: $C \leftarrow \emptyset$
2: **for** $i^\star = 1 \rightarrow |P_1|$ **do**
3: $\quad j^\star \leftarrow \underset{j}{\operatorname{argmin}} |v_1^{i^\star} - v_2^j|$
4: $\quad \delta_v \leftarrow |v_1^{i^\star} - v_2^{j^\star}|$
5: $\quad$ **if** $\delta_v < v_{gate}$ **then**
6: $\quad\quad C \leftarrow C + (i^\star, j^\star)$
7: $\quad$ **end if**
8: **end for**
9: $\hat{\psi} = \frac{1}{|C|} \sum_{n=1}^{|C|} -(\frac{1}{\tan \theta_1^{i_n}} - \frac{1}{\tan \theta_2^{j_n}})$

Relative Translation of Maps

Algorithm 2 Translation by matching peaks of Hough images

Input: P_1, P_2', d_{gate}, v_{gate}
Output: T_o

$C \leftarrow \emptyset$
for $\alpha = -90° \rightarrow \alpha = 90°$ **do**
  $(i^\star, j^\star) = \underset{\mathcal{U}}{\operatorname{argmin}}(|v_1^i - v_2^j|, |\rho_1^i - \rho_2^j|) \;\Big|\; \theta_1^i = \alpha,\ \theta_2^j = \delta_\alpha$
  $\delta_v \leftarrow |v_1^{i^\star} - v_2^{j^\star}|$
  $\delta_\rho \leftarrow |\rho_1^{i^\star} - \rho_2^{j^\star}|$
  if $\delta_v < v_{gate}$ and $\delta_\rho < d_{gate}$ **then**
    $C \leftarrow C + (i^\star, j^\star)$
  end if
end for
Calculate A and B from C based on (22).
$T_o = (A^T A)^{-1} A^T B$

$$\begin{bmatrix} \rho_1' - \rho_1 \\ \vdots \\ \rho_N' - \rho_N \end{bmatrix} = \begin{bmatrix} \cos\theta_1 & \sin\theta_1 \\ \vdots & \vdots \\ \cos\theta_N & \sin\theta_N \end{bmatrix} T_o \quad \Rightarrow \quad B = AT_o$$

Verification of Results

- Verification Index

$$agr(map_1, map_2) = |\{p = (x, y) | map_1(p) = map_2(p)\}|,$$
$$dis(map_1, map_2) = |\{p = (x, y) | map_1(p) \neq map_2(p)\}|,$$

$$V(m_1, m_2') = \frac{agr(m_1, m_2') \times 100\%}{agr(m_1, m_2') + dis(m_1, m_2')},$$

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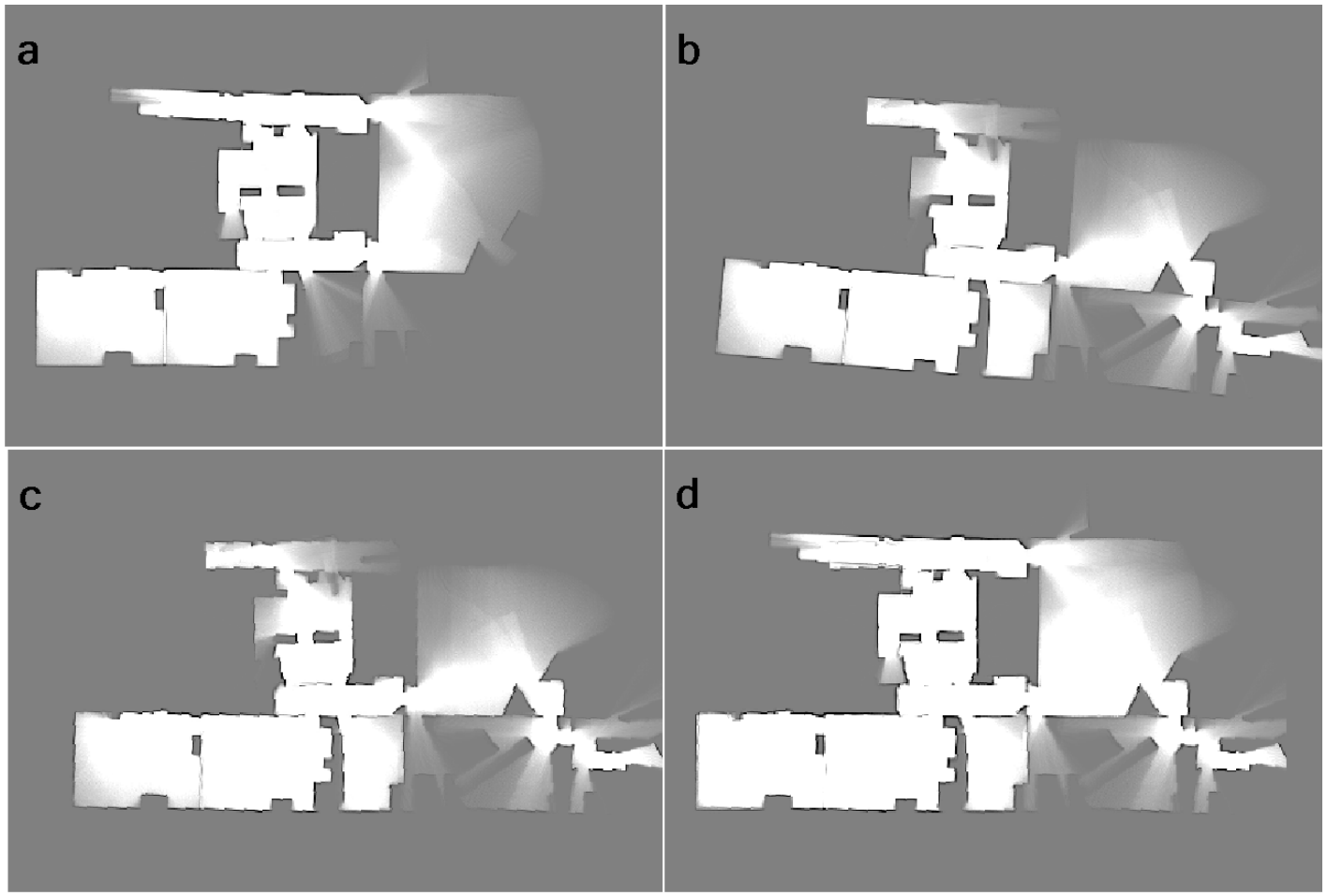
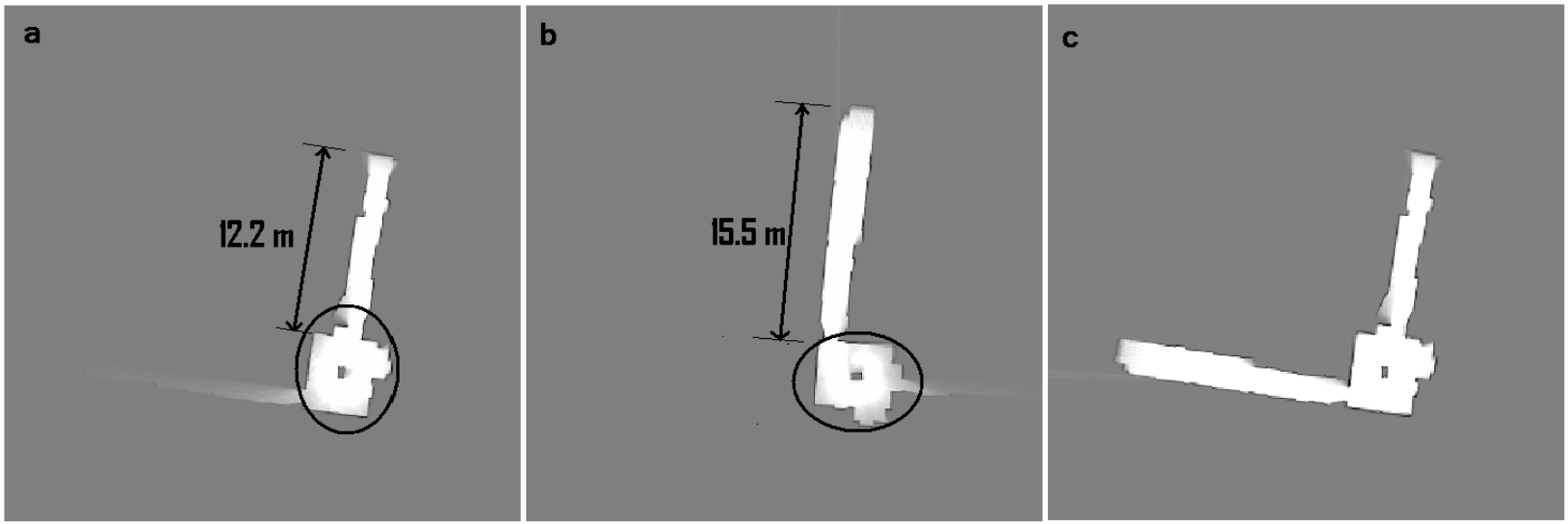
Experimental Results

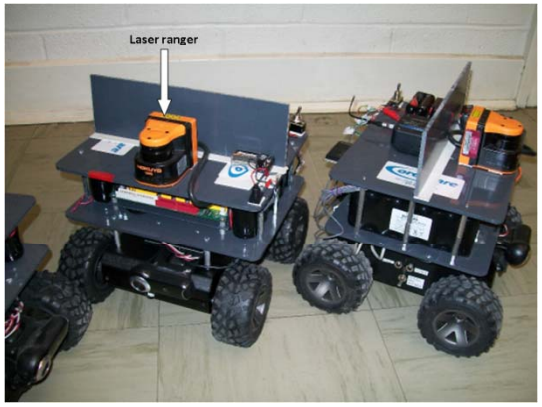
- Experiment1: RADISH data set, Fort AP Hill



Experimental Results

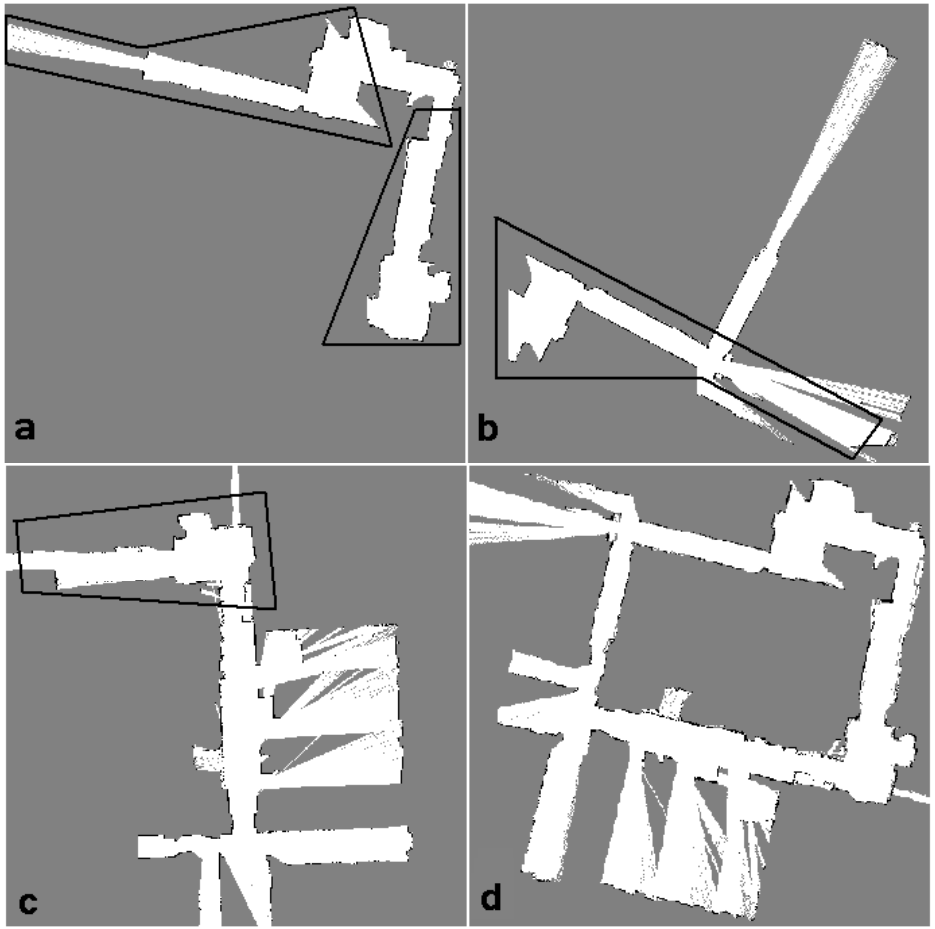
- Experiment2: Real Experiment with Two Vehicles





Experimental Results

- Experiment3: Real Experiment with Three Vehicles



Experimental Results

- Comparisons

Normalized processing time and efficiency comparison of the experiments with two other methods (Map segmentation and Adaptive Random Walk):

PROCESSING TIME AND EFFICIENCY OF THREE EXPERIMENTS, (1) RADISH DATA SET, (2) TWO COROBOTS, (3) THREE COROBOTS.

Experiment	(1)	(2)	(3)	(1)	(2)	(3)
Method	Processing (sec)			Verification (%)		
Hough peak matching	14	11	14	94	92	94
Map segmentation [21]	105	83	106	95	92	94
ARW map merging [4]	168	150	152	93	88	92

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Conclusions

- Multiple robot map merging:
  - Hough peak matching
  - Fast
  - Robust

- Future works:
  - Extending the work to 3D map merging
  - Iterative peak matching

Thank You.