Exploring Indoor Environment for a Mobile Robot

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Project Objectives

Floor Segmentation: Free space to go for a mobile robot
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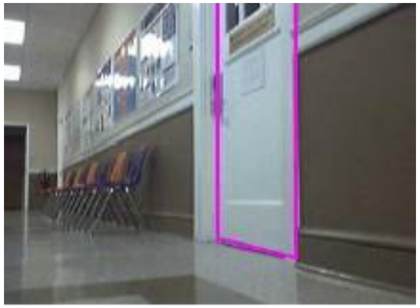

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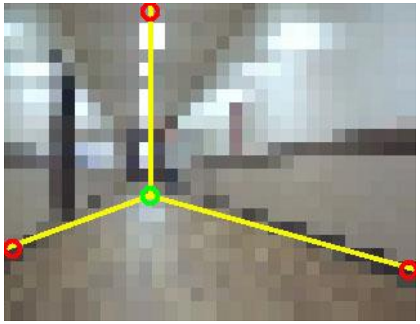

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Challenging problem: Reflections

Also:

- **variety of poses (vanishing point, ceiling not always visible)**
- **sometimes wall and floor color are nearly the same**

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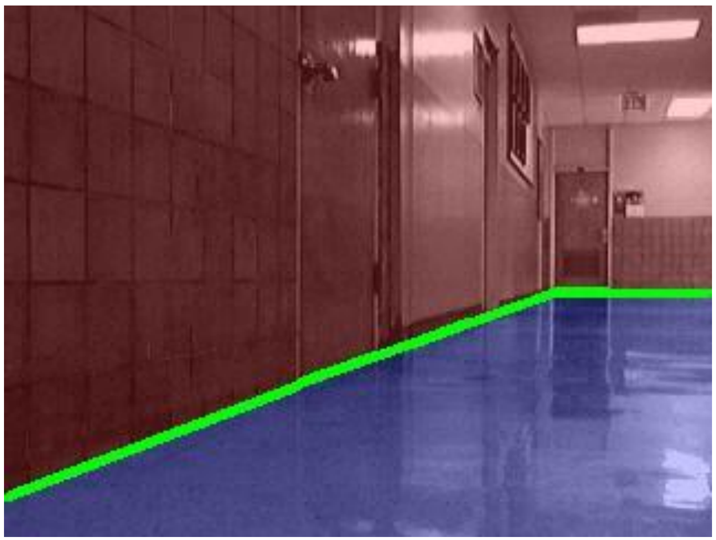
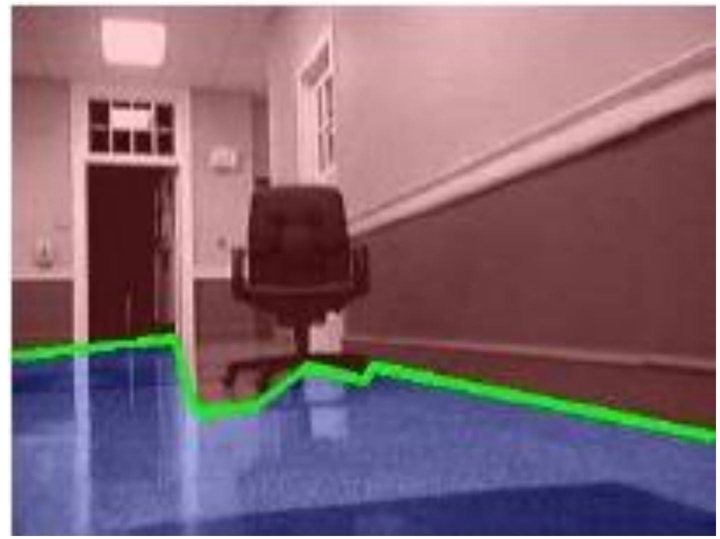
Motivation

Goal: **Segment the floor in a single corridor image**

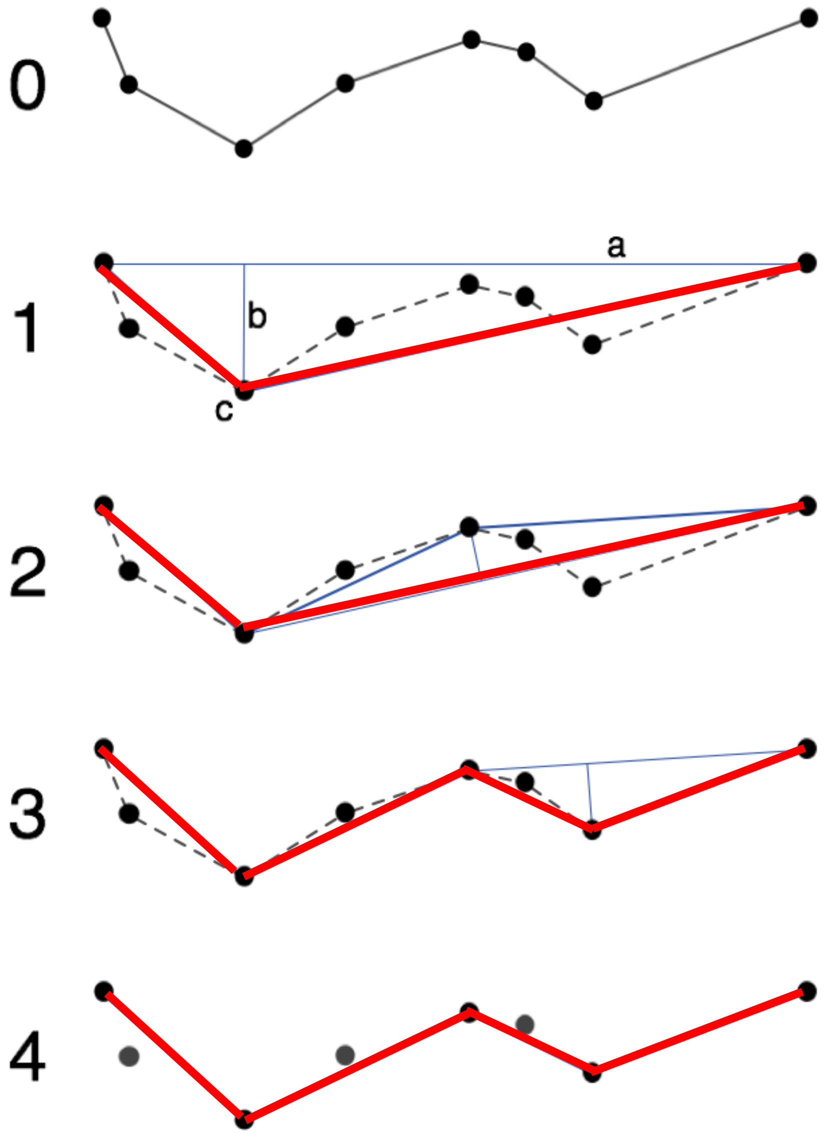




Why?

- **obstacle avoidance**
- **mapping**
- **autonomous exploration and navigation**

Douglas-Peucker Algorithm



<u>Purpose</u>: Reduce the number of points in a curve (polyline)

<u>Algorithm</u>:

1. **Connect farthest endpoints**
2. ***Repeat***
   1. **Find maximum distance between the original curve and the simplified curve**
   2. **Split curve at this point**

   Until **max distance is less than threshold**

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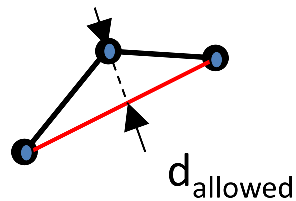
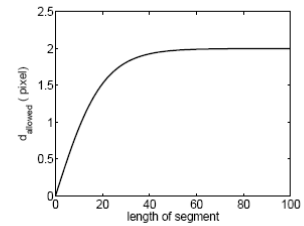
Detecting Line Segments (LS)

1. **Compute Canny edges**
2. **Modified Douglas-Peucker algorithm to detect line segments**





Vertical LS: slope within ±5° of vertical direction
Horizontal LS: Slope within ±45° of horizontal direction

3. **Pruning line segments (320x240)**
   Vertical LS: minimum length 60 pixels
   Horizontal LS: minimum length 15 pixels
   Vanishing point (height selection): The vanishing point is computed as the mean of the intersection of pairs of non-vertical lines. It is used for throwing away horizontal line segments coming from windows, ceiling lights, etc.

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Score Model

Weights

horizontal line

$$\Phi_{total}(\ell_h) = w_s\overline{\phi}_s(\ell_h) + w_b\overline{\phi}_b(\ell_h) + w_h\overline{\phi}_h(\ell_h)$$

Structure Score

Bottom Score

Homogeneous Score

$\Phi_{total}(\ell_h)$ is assigned to each horizontal line ℓ_h

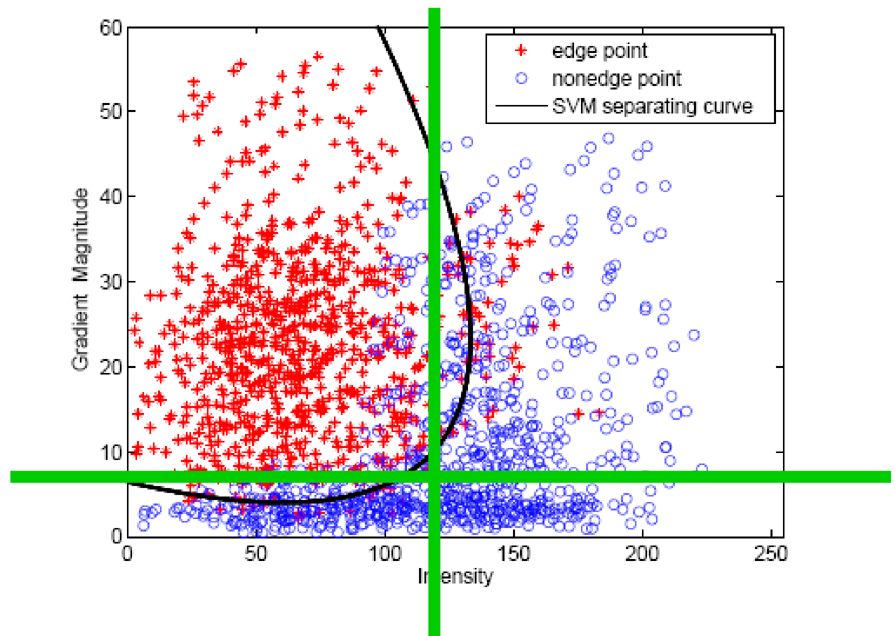
Score Model – Structure

$|\nabla I(x,y)| > T_1$ and $I(x,y) < T_2$

Given a typical corridor image

1. $|\nabla I(x,y)| > T_1$ **(gradient magnitude)**
   (How to set threshold T_1?)
2. $I(x,y) < T_2$ **(image intensity)**
   (How to set threshold T_2?)

Approximate using two thresholds:



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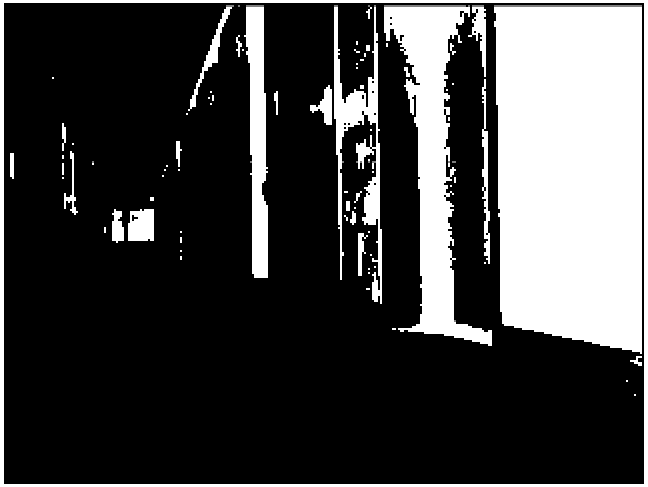
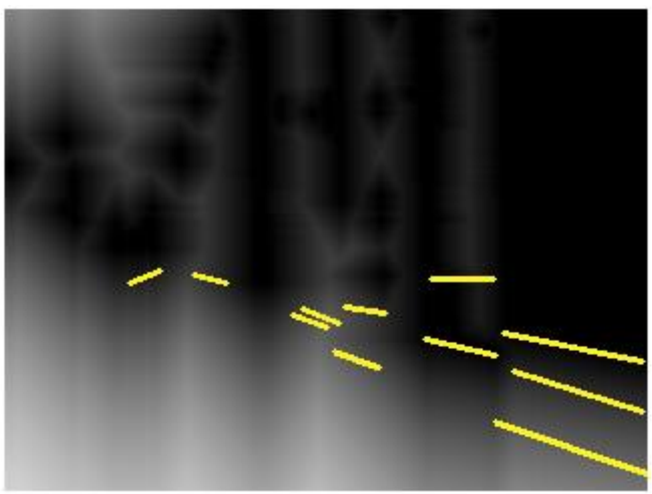
Score Model – Structure





$d[(x,y),\mathcal{S}]$

Given a typical corridor image

1. **$|\nabla I(x,y)| > T_1$** (gradient magnitude)
2. **$I(x,y) < T_2$** (image intensity)
3. **Now threshold original image using T_{LC} (average gray level of pixels satisfying #1 and #2)**
4. **Compute the chamfer distance between the line segments and structure blocks**

$$\phi_s(\ell_h) = \sum_{(x,y)\in\ell_h} d[(x,y),\mathcal{S}]$$

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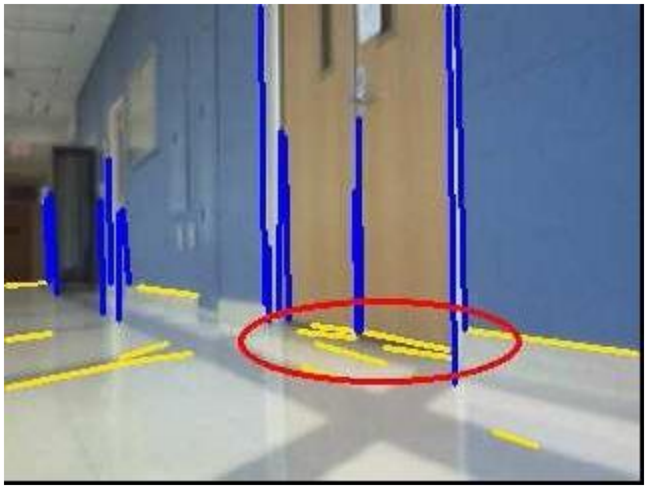
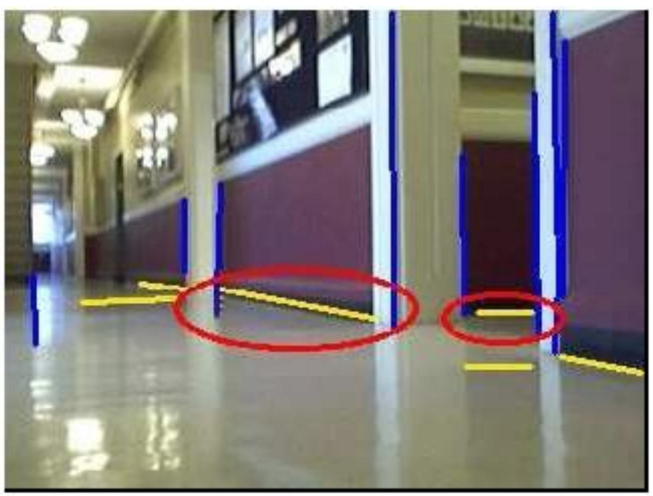
Score Model – Bottom





1. **Connect the bottom points of consecutive vertical line segments to create "bottom" wall-floor boundary**
2. **Compute the distance of each horizontal line segment to the "bottom" wall-floor boundary**

(red circled horizontal line segments indicates a positive contribution)

$$\phi_b(\ell_h) = \sum_{(x,y)\in\ell_h} d[(x,y),\ell_b]$$

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Score Model – Homogeneous

Idea: **The floor tends to have larger regions (due to decorations, posters, windows on the wall).**

Algorithm:

1. **Color-based segmentation of the image (using Felzenszwalb-Huttenlocher's minimum spanning tree algorithm)**
2. **For each horizontal line segment, compute**

$$\bar{\phi}_h(\ell_h) = \frac{|\mathcal{R}|}{|\mathcal{R}_{\max}|}$$

size of region just below segment

size of largest segment

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Segmenting the floor

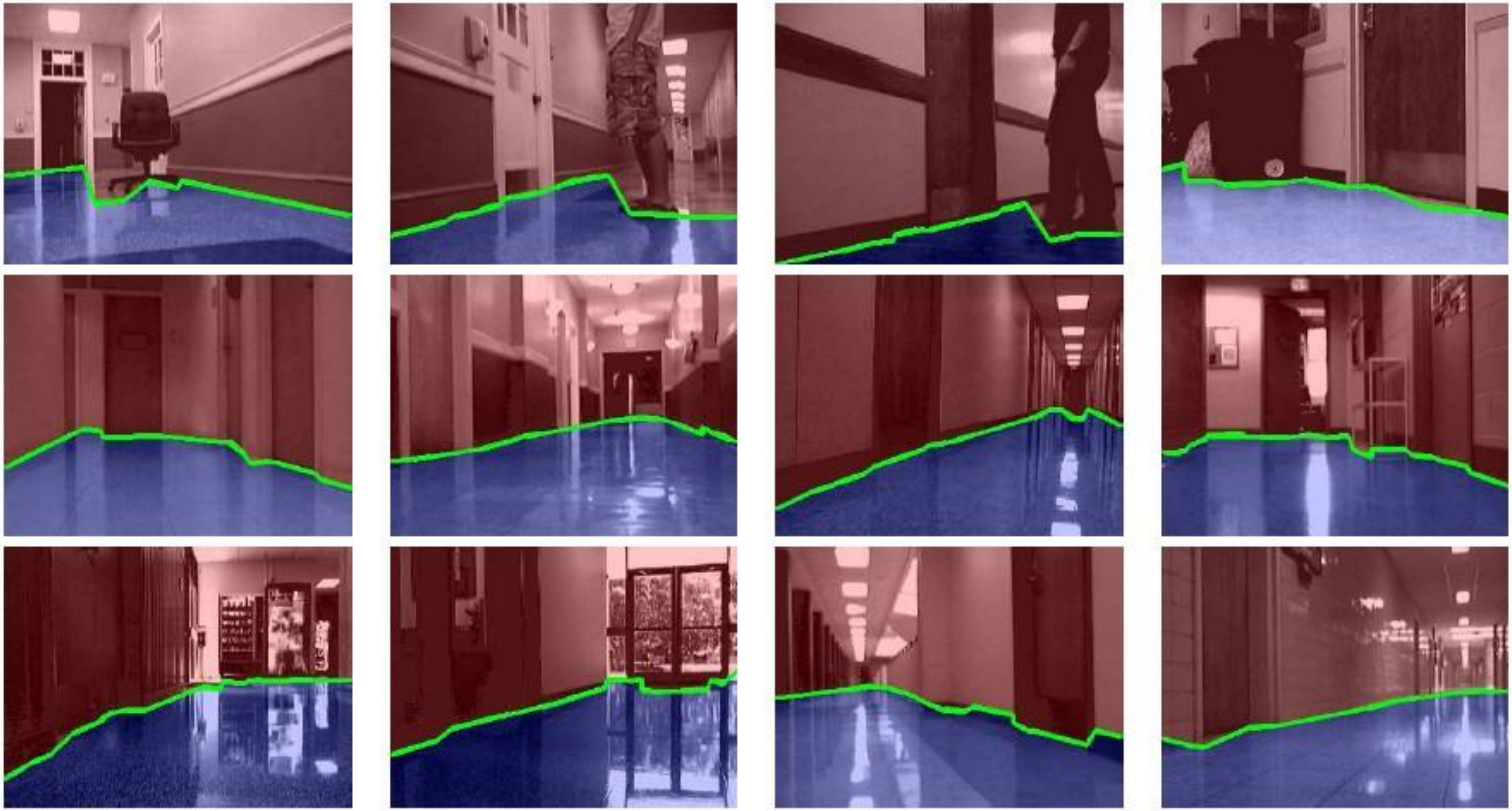
- **Normalize the scores and sum**
- **Threshold the final score:**

$$\Phi_{total}(\ell_h) > \tau_\phi$$

- **Connect the remaining line segments and extend the endpoints to the edges of the image**

Sample Results

89.1% success on database of 426 images:



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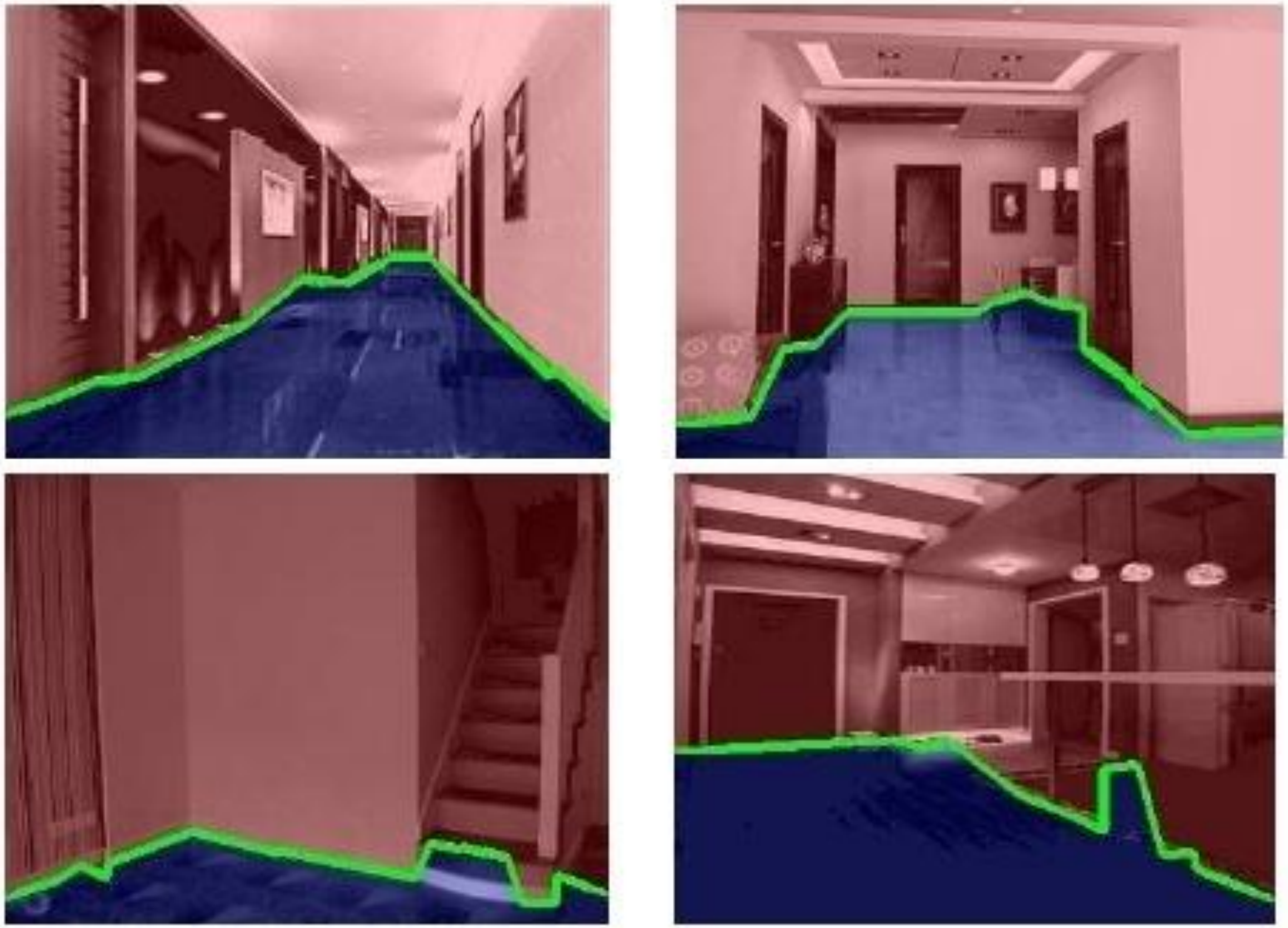
Sample Results

Images downloaded from the internet:



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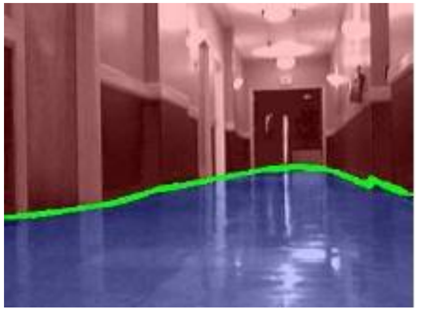

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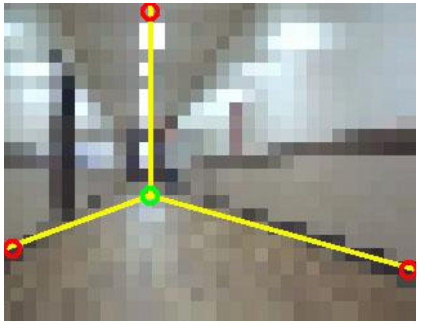

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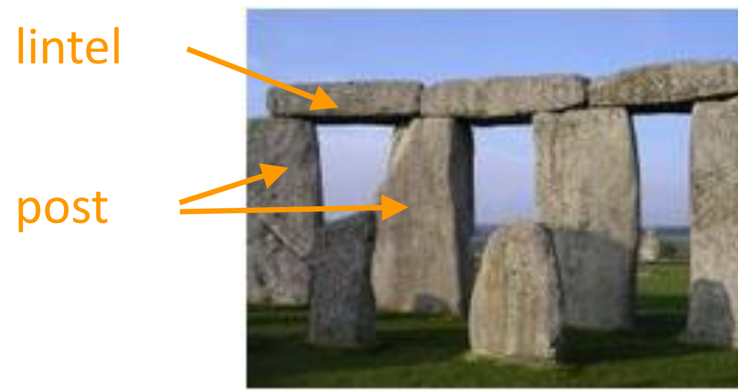
What is Lintel-Occluded?

Lintel-occluded

- post-and-lintel architecture
- camera is low to ground
- cannot point upward b/c obstacles



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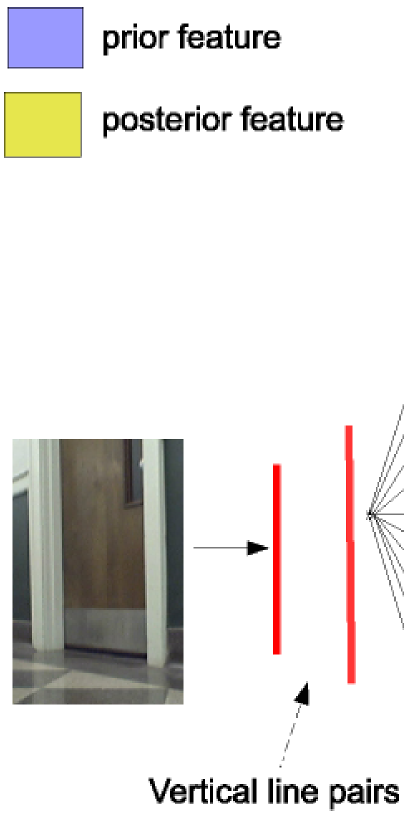
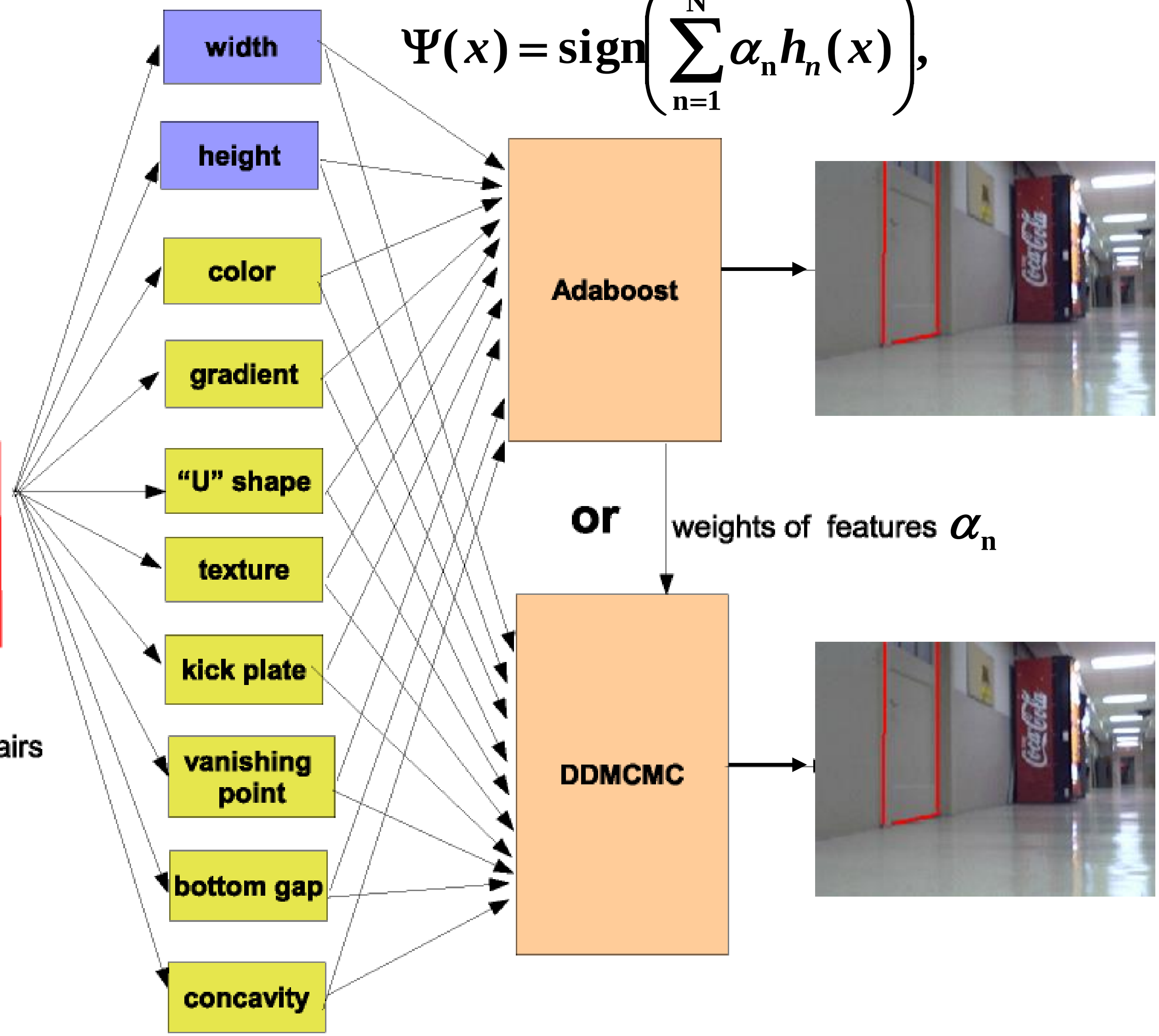
Slides from Z. Chen

Our Approach

$$\Psi(x) = \mathbf{sign}\left(\sum_{n=1}^{N} \alpha_n h_n(x)\right),$$





Assumptions:

- Both door posts are visible
- Posts appear nearly vertical
- The door is at least a certain width

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Key idea: Multiple cues are necessary for robustness (pose, lighting, …)

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Bayesian Formulation

door

image

$$p(\mathrm{d} \mid I) \propto p(I \mid \mathrm{d})\, p(\mathrm{d})$$

Taking the log likelihood,

$$E(\mathrm{d}) = \Psi_{\mathrm{data}}(I \mid \mathrm{d}) + \Psi_{\mathrm{prior}}(\mathrm{d})$$

Data model

Prior model

$$\Psi_{\mathrm{data}}(\mathrm{d}, I) = \sum_{i=1}^{N_{\mathrm{data}}} \alpha_i f_i(\mathrm{d}) \qquad \Psi_{\mathrm{prior}}(\mathrm{d}) = \sum_{j=1}^{N_{\mathrm{prior}}} \beta_j g_j(\mathrm{d})$$

$$\text{where } f_i(\mathrm{d}) \text{ and } \mathrm{g_j}(\mathrm{d}) \in [0,1]$$

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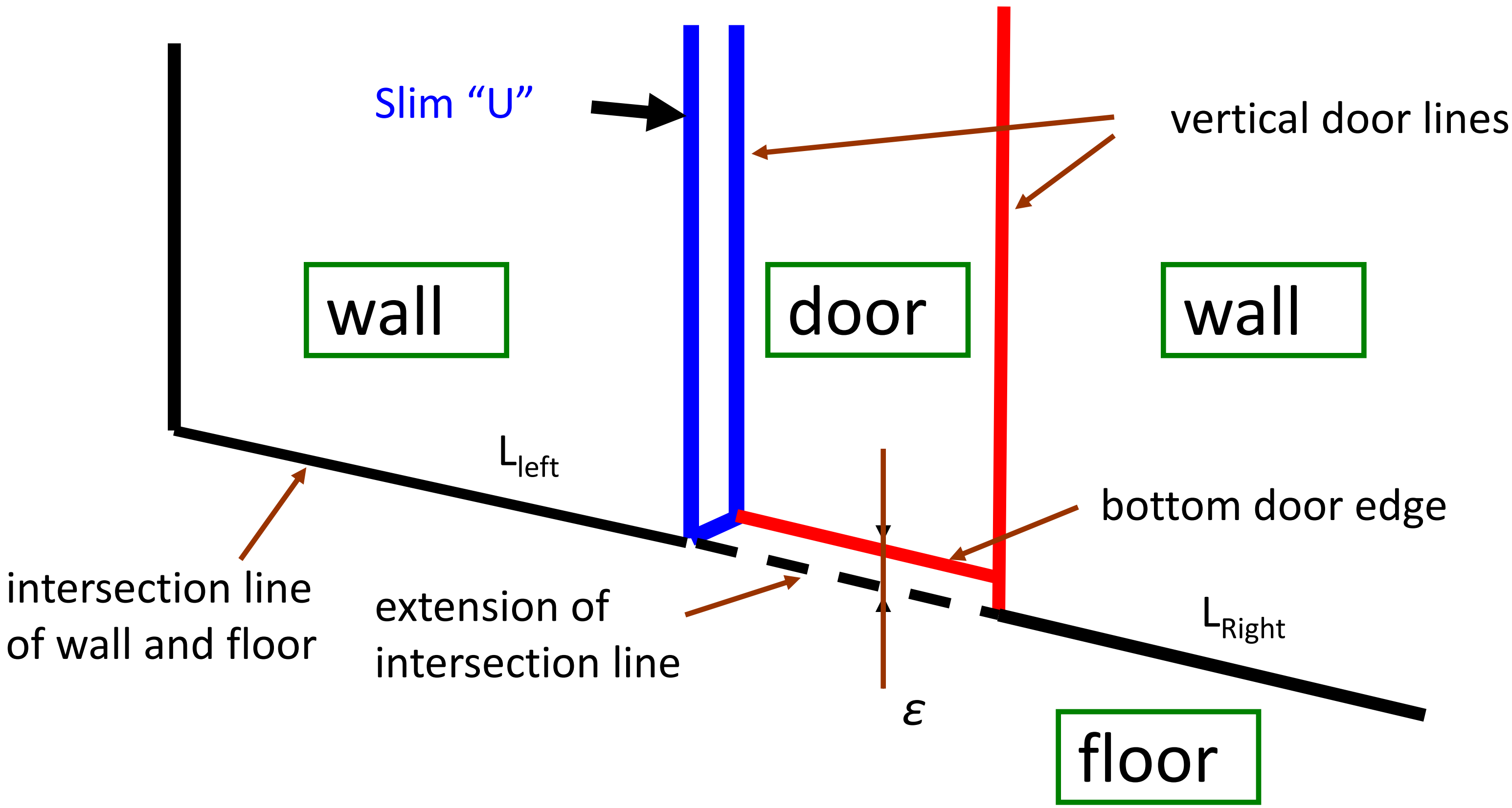
Data Model Features (cont.)



Concavity(g_9)

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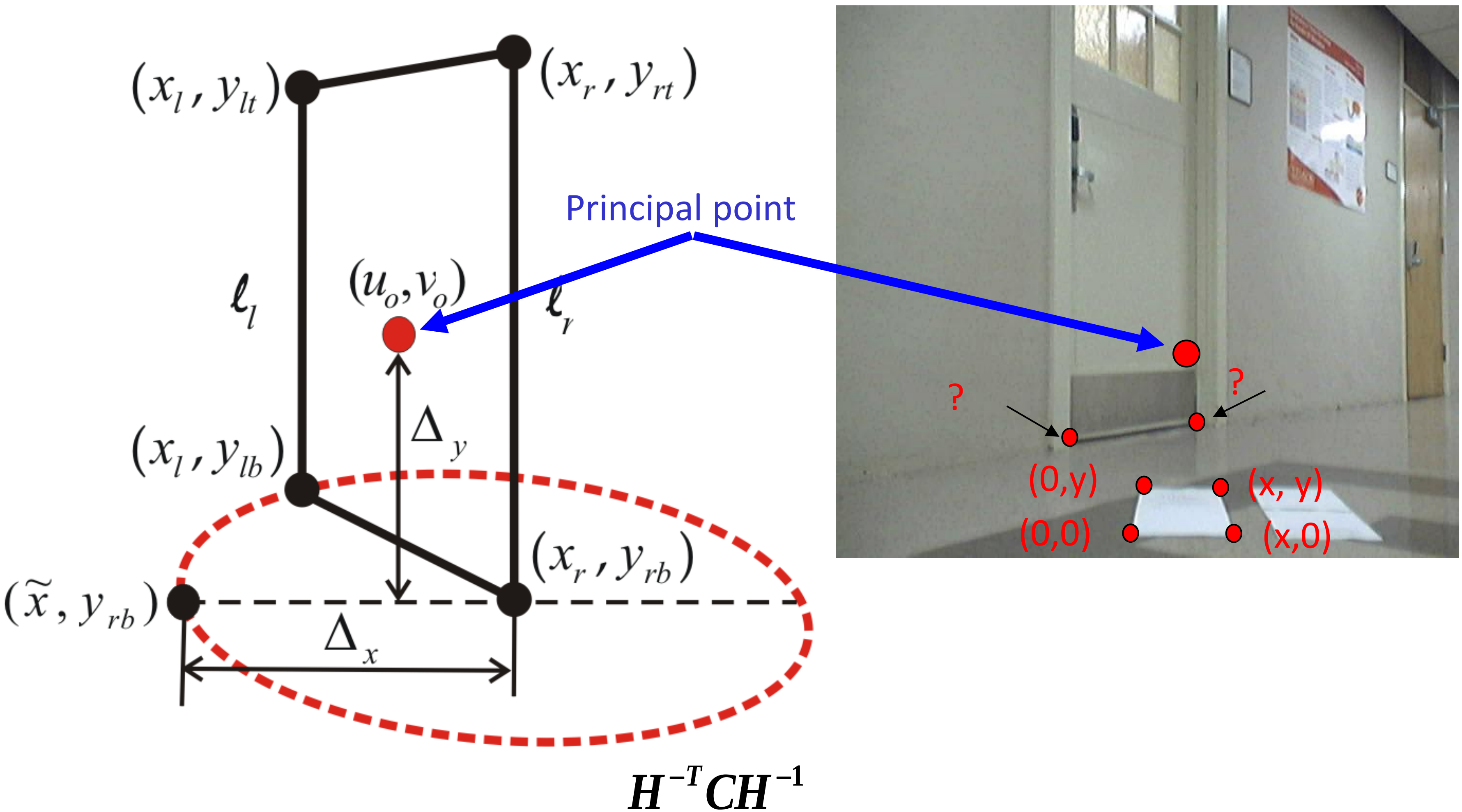
Prior Model Features: Width and Height



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Data Model (Posterior) Features

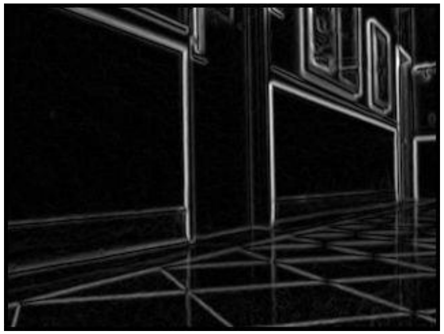
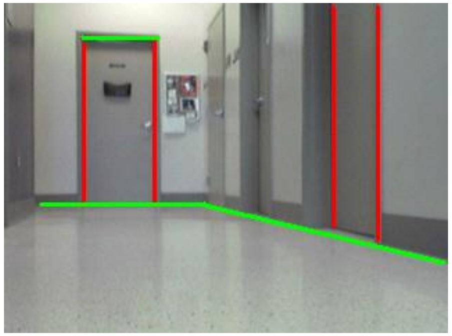


Image gradient along edges (g_1)



Placement of top and bottom edges (g_2, g_3)

Color (g_4)

texture (g_5)

Kick plate (g_6)

Vanishing point (g_7)

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Experimental Results: High Reflection / Textured Floors

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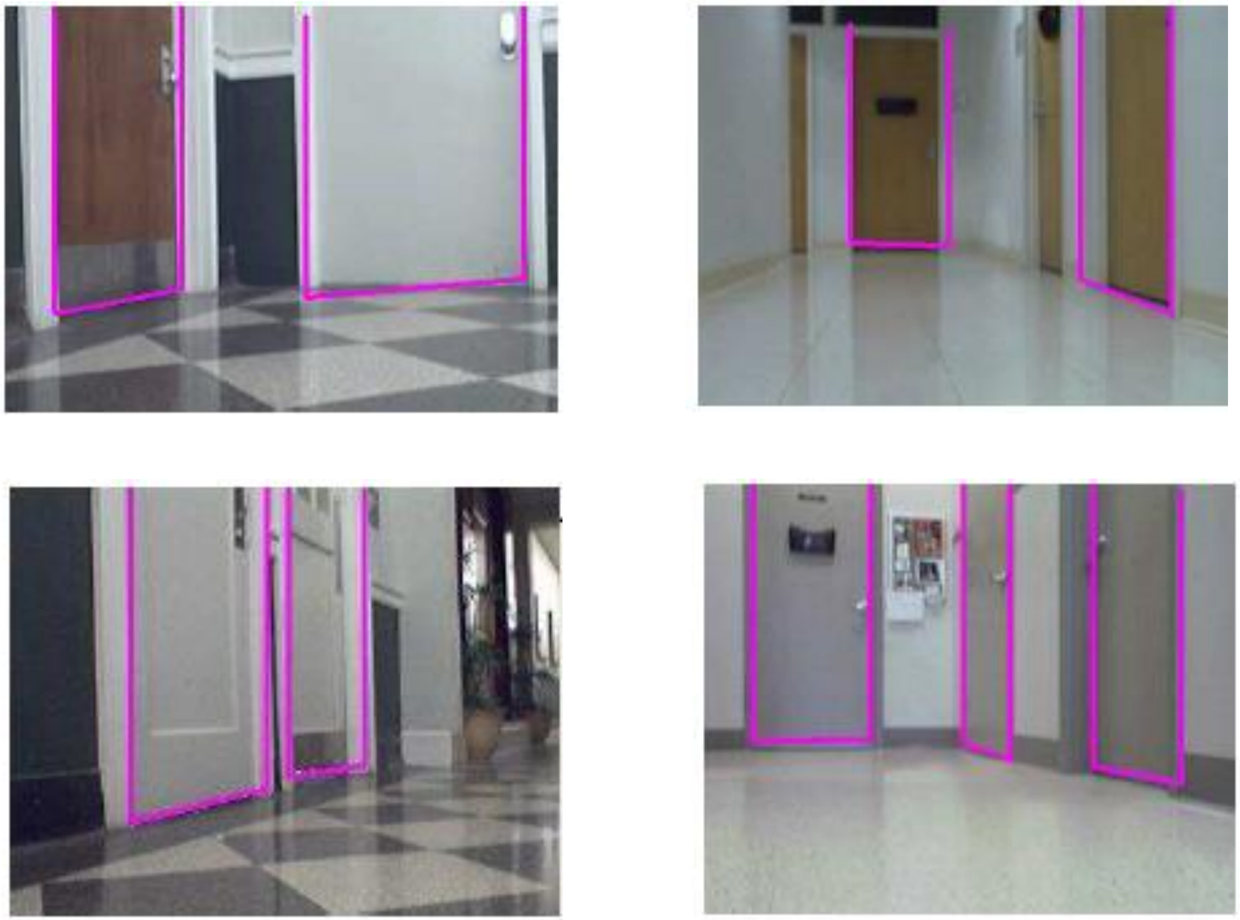
Experimental Results: Different Viewpoints



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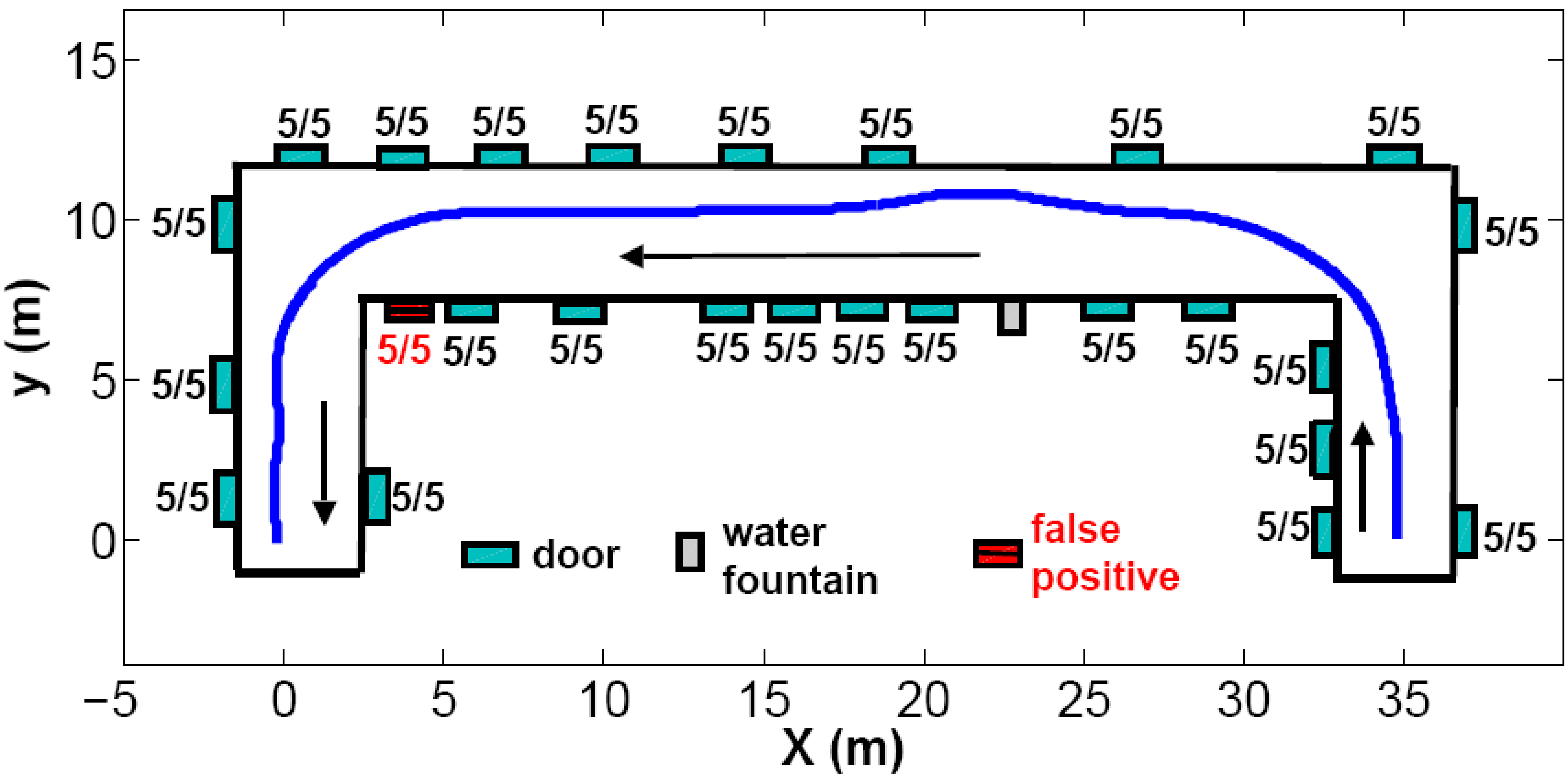
Navigation in a Corridor

- Doors were detected and tracked from frame to frame.
- Fasle positives are discarded if doors were not repeatedly detected.



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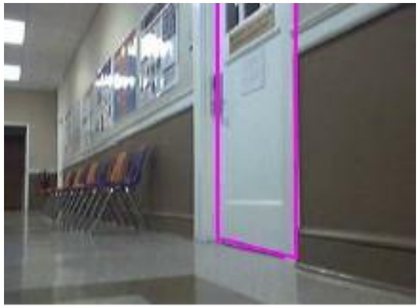

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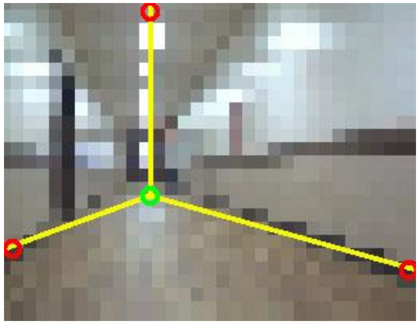

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Q & A

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