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Detection and Filtering of Landmark Occlusions using Terrain Spatiograms

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Overview

A team of robots cooperating to quickly produce a map needs to share landmark information between team members so that the local maps can be accurately merged. However, a landmark visible to one robot may be partially occluded to another!

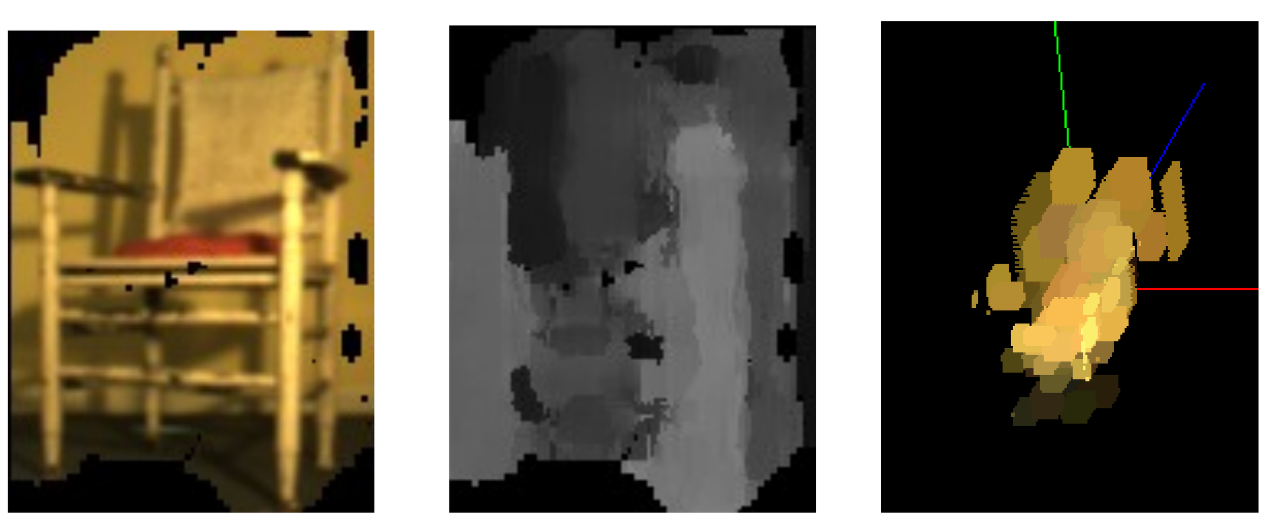
Terrain Spatiograms are a landmark representation in which the image spatial information relates to the scene rather than the image. This makes it possible to identify and filter potential landmark occlusions.

We present an approach to identifying and filtering occlusions using Terrain Spatiograms, and we report experimental results on 20 landmark datasets for varying states of occlusion. We show that occlusion can be detected and filtered, resulting in improved landmark matching scores.

Terrain Spatiograms

- A Histogram of image *I* captures the number of times each pixel value occurs in the image.
- *A Spatiogram* adds information on *where in the image t*he values occur.
- *A Terrain Spatiogram* h_I represents '*where*' as a 3D point in the field of view.

$$h_I(b) = \langle n_b, \mu_b, \Sigma_b \rangle \qquad n_b = \eta \sum_{i=1}^{|P|} \delta_{ib}$$



(a) (b) (c)

Image of chair landmark (a); monochrome stereo disparity for landmark (b); perspective view of color terrain spatiogram for landmark (c).

Recognizing a Landmark

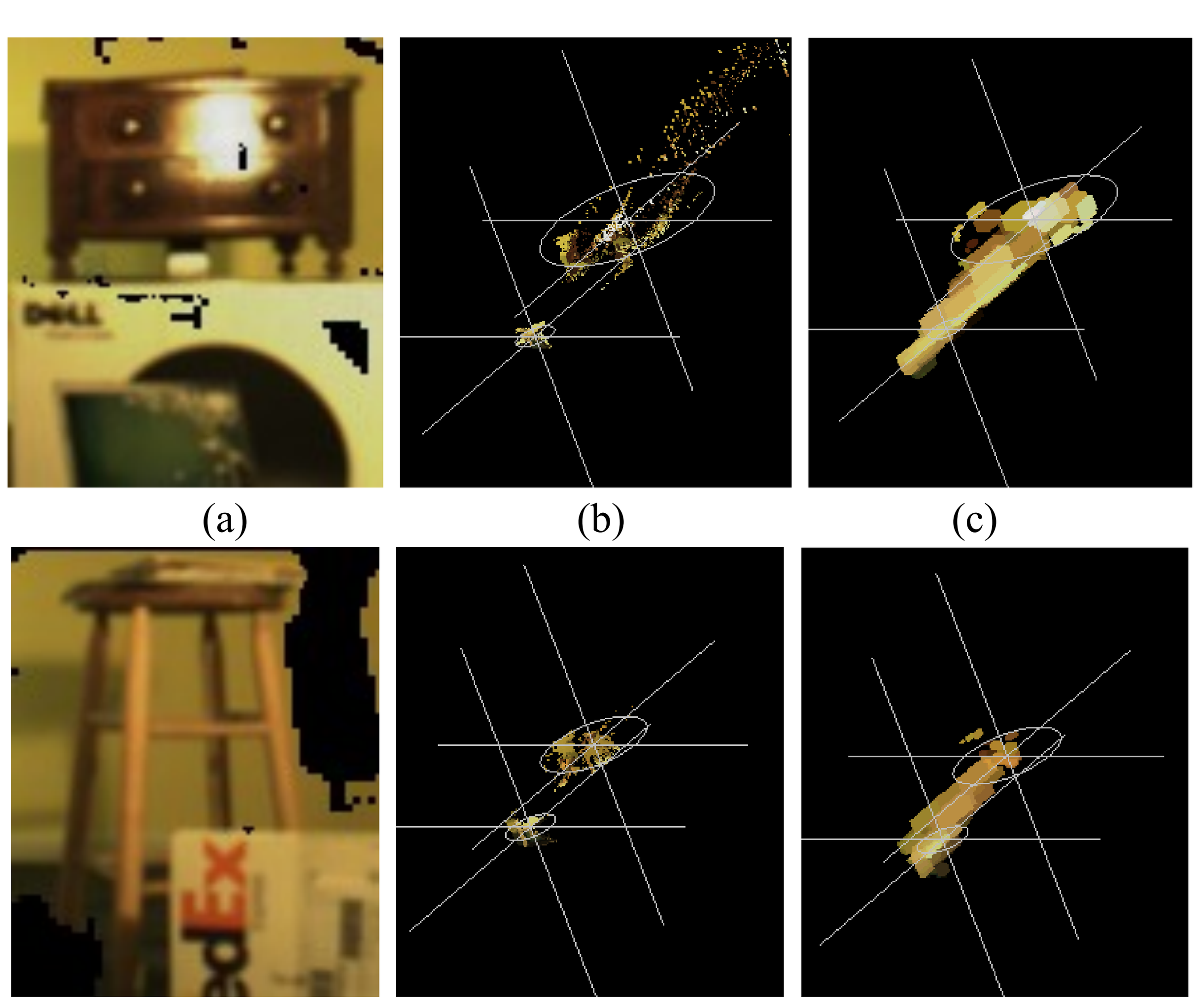
- Compute the terrain spatiogram of the landmark
- Compare with the terrain spatiograms of a list of stored landmarks.
- To compare *h* and *h'* : $\rho(h,h') = \sum_{b=1}^{|B|} \psi_b \sqrt{n_b n'_b}$

where

$$\psi_b = 2(2p)^{0.5}|S_b S'_b|^{0.25}\, N(m_b\,;\, m'_b, 2(S_b+S'_b))$$

Identifying Landmark Occlusions

- For any occluded landmark h_o *K-means clustering* performed in the XZ plane → cluster centers C_i , weights W_i
- Largest, rear-most cluster is identified as the candidate landmark cluster
  $C_o = argmax\,(W_i)\ \&\ argmaxZ(C_i)$
- and *any other clusters* are considered occlusions.

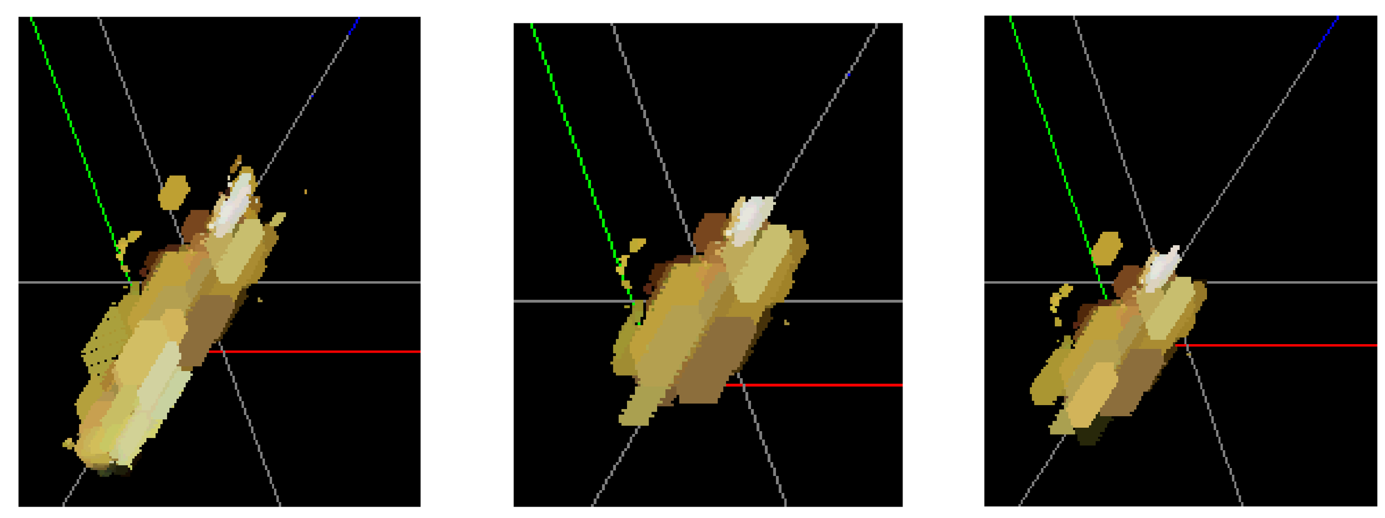


(a) (b) (c)
(d) (e) (f)

Occluded Landmark left image of stereo pair (a, d); perspective view of image pixels mapped to absolute depth (b, e); perspective view of terrain spatiogram with XZ cluster center and 1SD circle (c, f). We will assume: *occlusions fall outside this circle.*

Matching Occluded Landmarks

- A visibility vector V_o is calculated to trim away the occlusions
- Both landmark spatiograms h_l and candidate landmark spatiogram h_o are translated to the origin for comparison, h'_l and h'_o respectively.
- Only the depth (z) information is used to translate the candidate landmark:
- Each is renormalized about the location of intersection of their visibility vectors.
- The filtered candidate and landmark are compared using the normalized comparison.

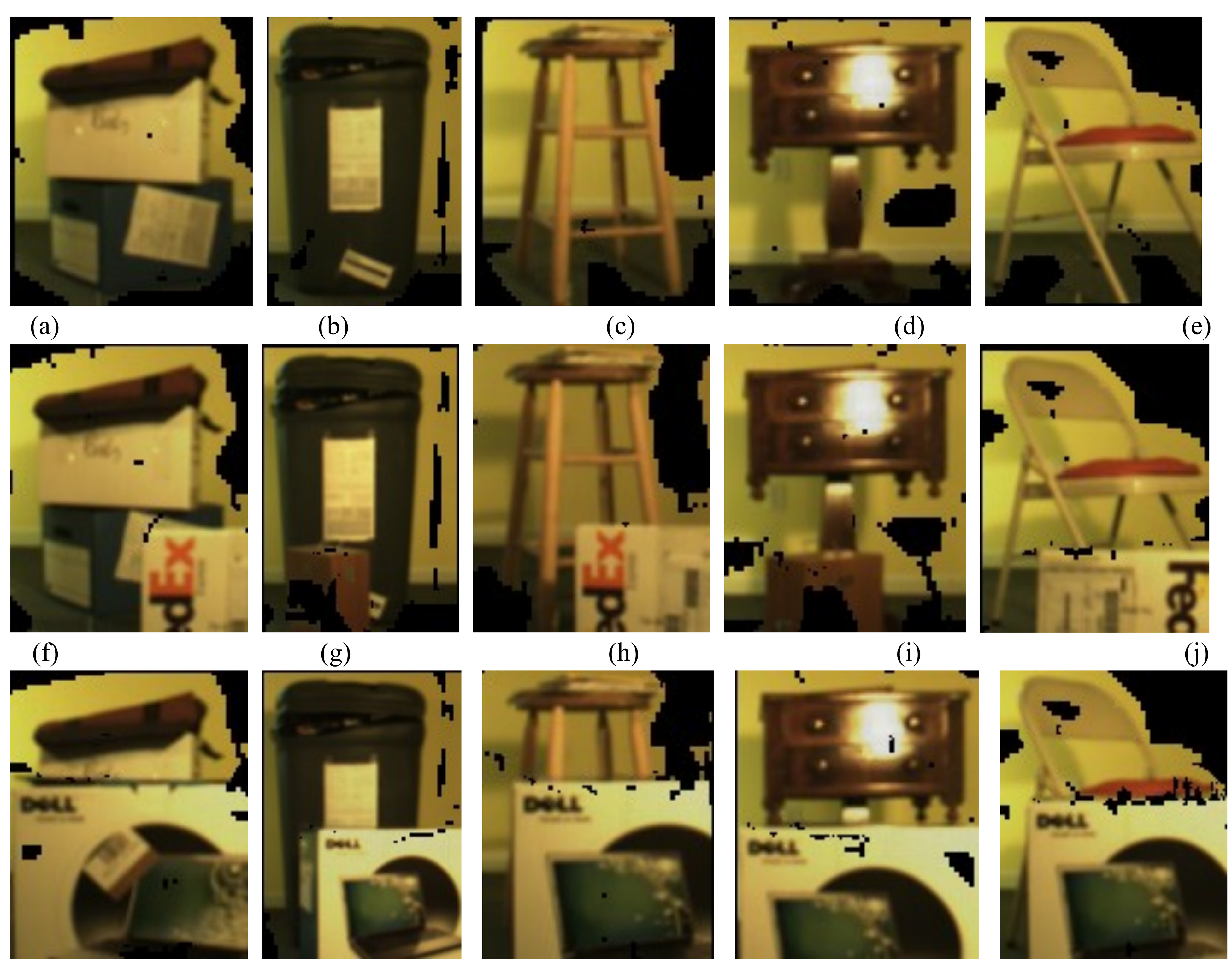


(a) (b) (c)

Candidate landmark spatiogram showing landmark cluster center (a); trimmed to landmark moments (b); and translated (c).

Results

This landmark occlusion detection and filtering method was evaluated on a collection of occluded and unoccluded landmarks (show in the image table below). Terrain spatiograms of corresponding unoccluded and occluded landmarks were compared before and after occlusion filtering.



(a) (b) (c) (d) (e)
(f) (g) (h) (i) (j)
(k) (l) (m) (n) (o)

Five landmarks used in occlusion experiments: top row (a-e), unoccluded objects; middle row (f-j), small occlusions; bottom row (k-o), larger occlusions.

	ρ11	ρ22	ρ33	ρ12	ρ13
a	1	1	1	0.815	0.485
b	1	1	1	0.828	0.697
c	1	1	1	0.571	0.405
d	1	1	1	0.868	0.632
e	1	1	1	0.835	0.483

Comparison *before* occlusion filtering.
(ρ12 compares landmark in row 1 with same occluded landmark in row 2, etc.)

	ρ1'2'	ρ'3'	ρ1'2' % change	ρ1'3' %change
a	0.905	0.694	11.113	42.86
b	0.893	0.885	7.871	26.92
c	0.632	0.549	10.721	35.628
d	0.917	0.812	5.687	28.574
e	0.914	0.611	9.536	26.455

Comparison *after* occlusion filtering..

Conclusions

- Introduced an approach to identifying landmark occlusions using Terrain Spatiograms.
- Presented a procedure to match occluded landmarks against candidate landmarks.
- Demonstrated results showing the method is effective for a set of indoor landmarks with a range of occlusions.