Spinning Parallelogram Operator (SPO) for Light Field Depth Estimation

4D Light Field Benchmark Challenge at 2nd Workshop on LF4CV, CVPR 2017

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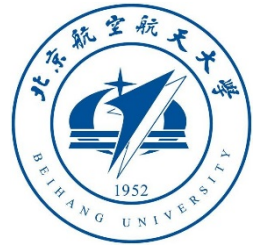
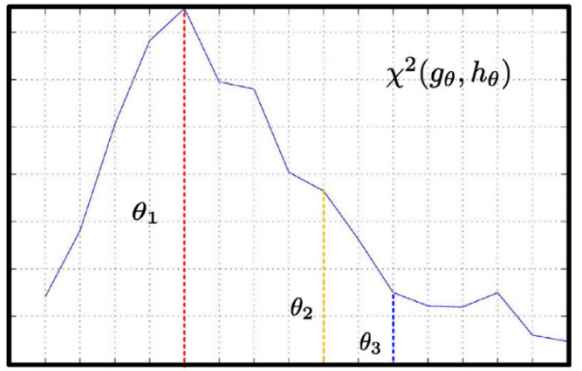
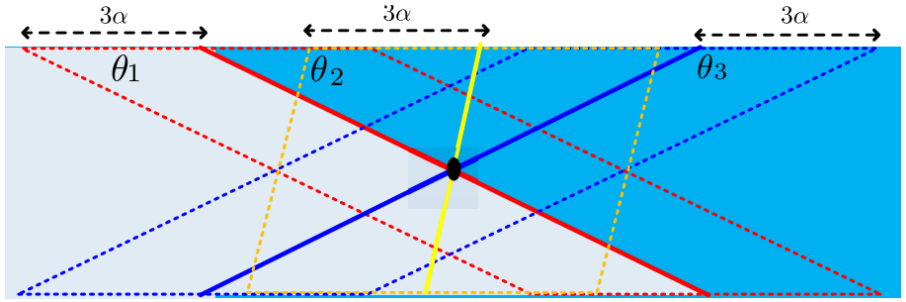


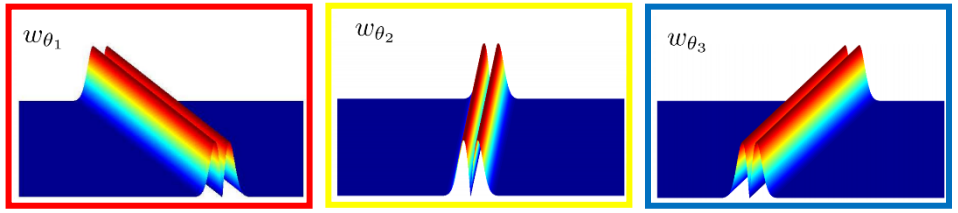
Method Comparisons

- SPO vs. Stereo Matching

Method	SPO	Stereo Matching
Theory:	• Locate lines in Epipolar Plane Images (EPIs) • By maximizing the distribution distances of separated regions.	• Locate points in sub-aperture images • By minimizing the matching cost
Volume:	• Histogram Distance: $\chi^2 = \sum_i \frac{(g_\theta(i) - h_\theta(i))^2}{g_\theta(i) + h_\theta(i)}$	• Absolute Difference • Square Difference • Gradient Difference • ……
Involved Pixels:	• Surrounding points $w_\theta(i,j) = c\, d_\theta(i,j)\, e^{\frac{-d_\theta^2(i,j)}{2\alpha^2}}$ • Horizontal and vertical views	• Reference matching points • All views
Occlusions:	• Broken lines in EPIs • Multiple local maximum distances	• Mismatching points • Large matching cost at the correct depth label

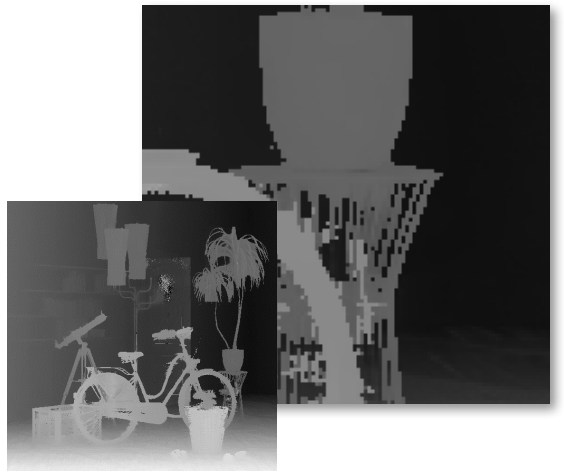


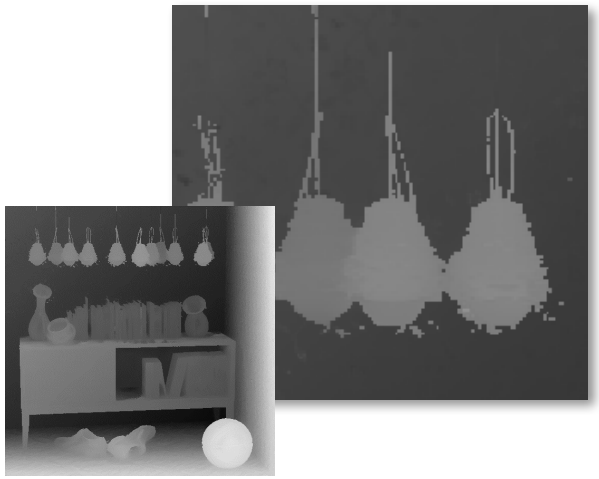


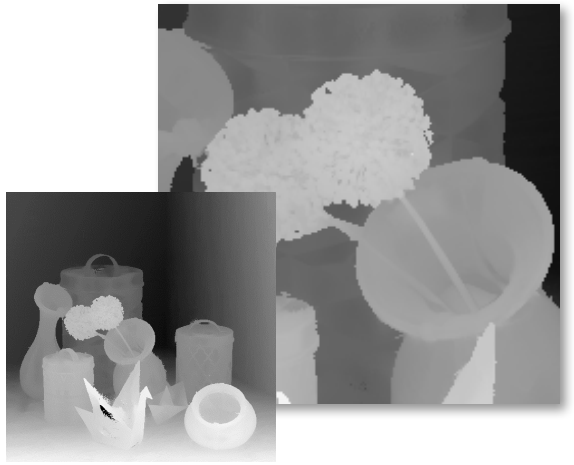


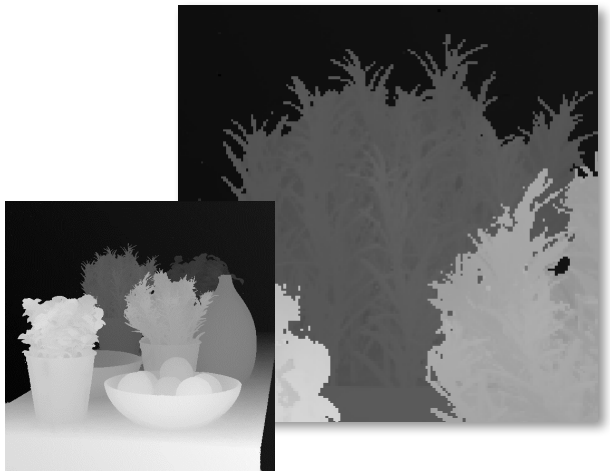
Benchmark Results Comparison

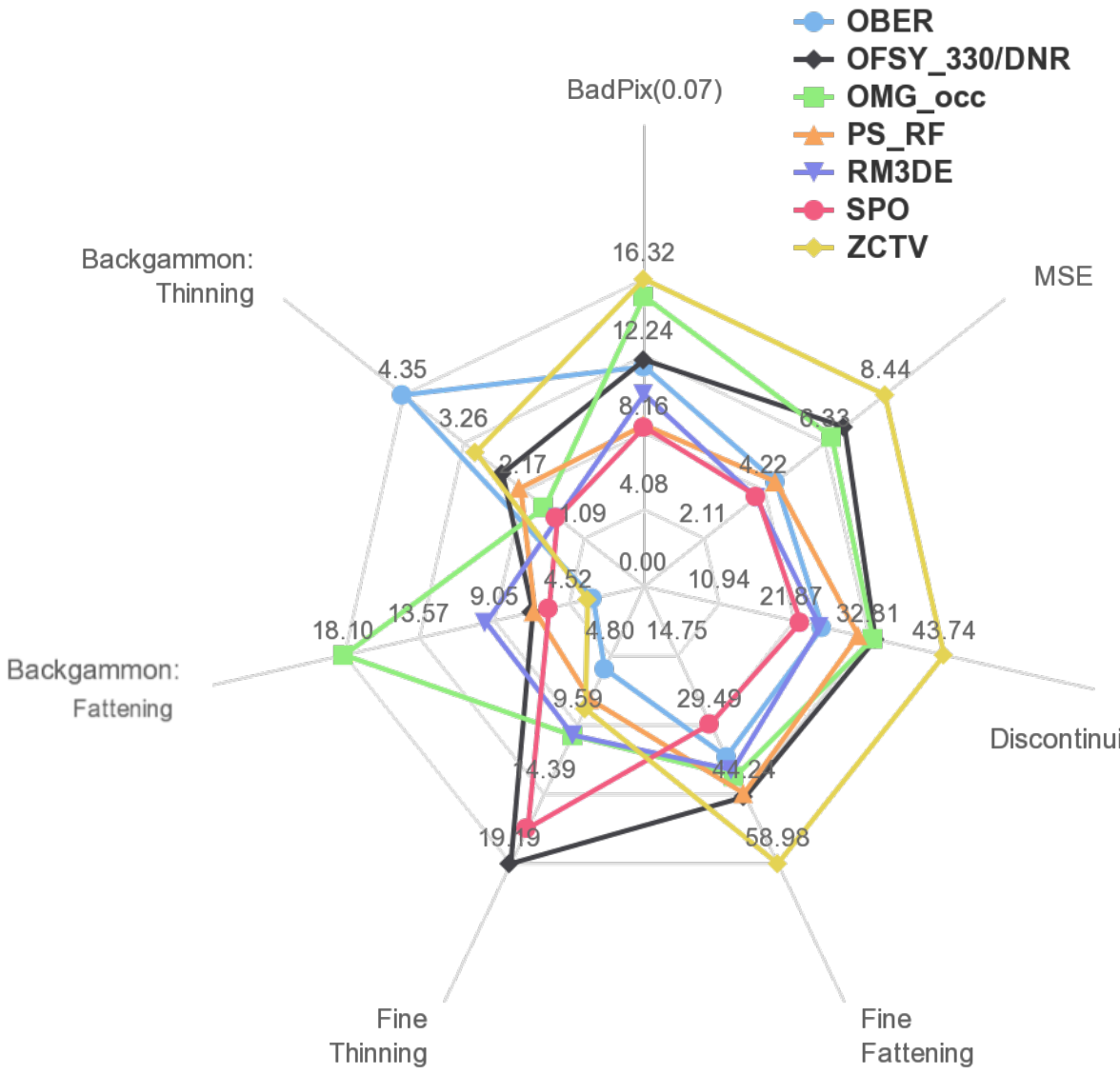
- **Occluded Regions**









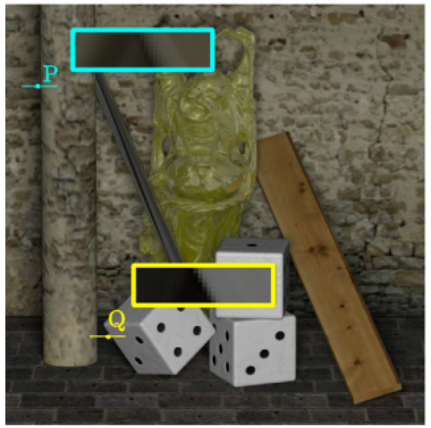


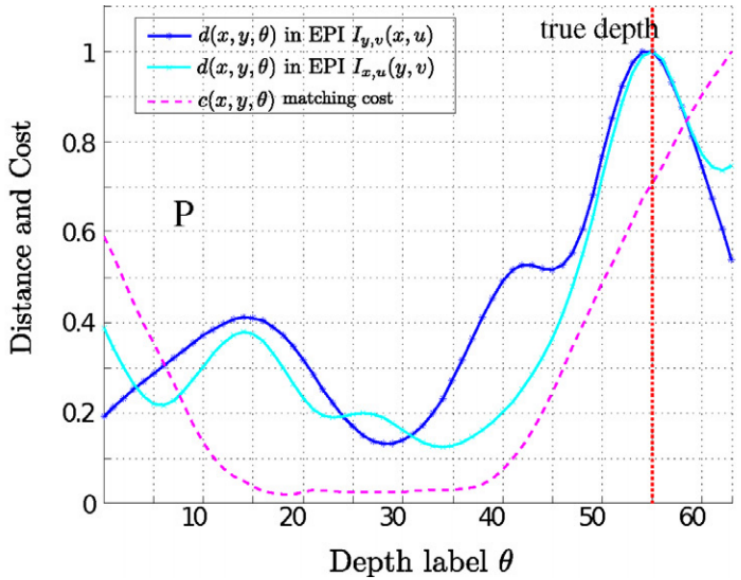
Benchmark Results Comparison

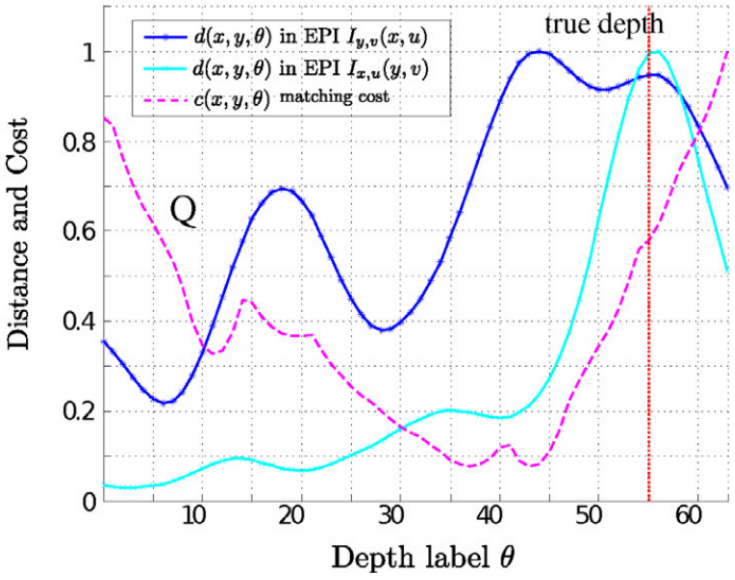
- **Occluded Regions**

Reason 1: SPO for Local Estimation

- The histogram distance is robust to occlusions, which keeps at a local maximum value for the occluded points.







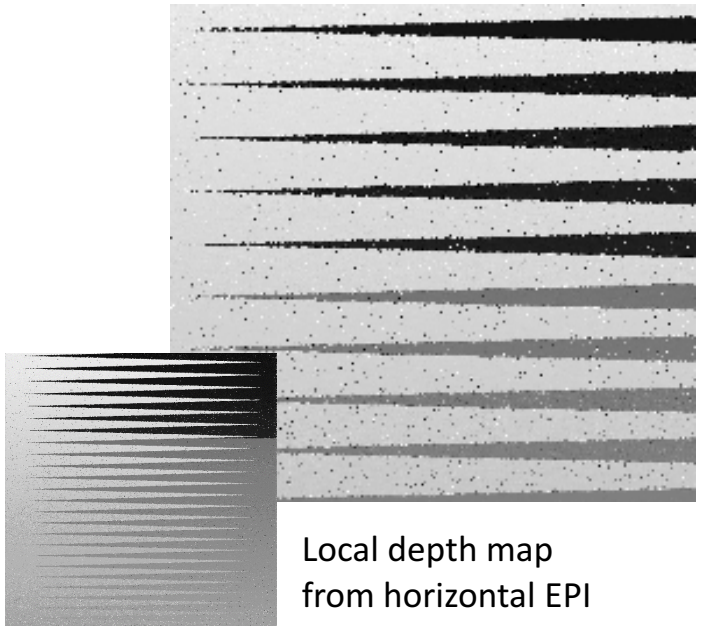
Benchmark Results Comparison

- **Occluded Regions**

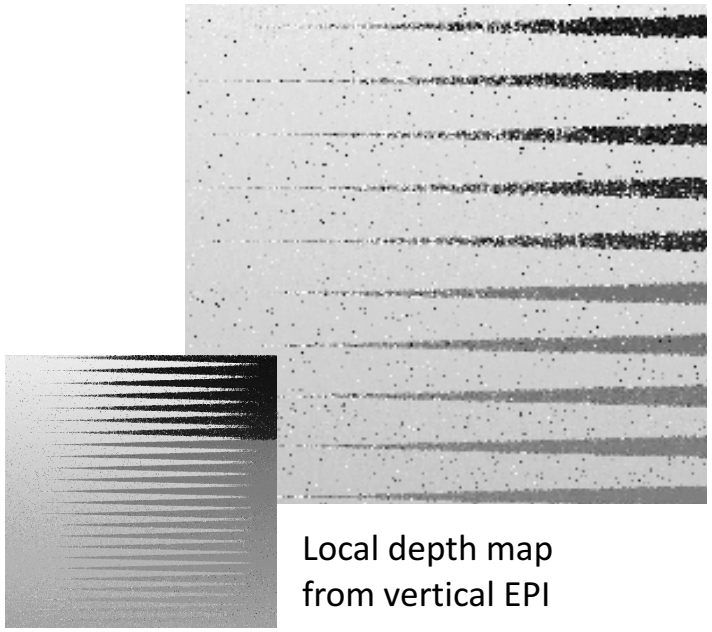
Reason 2: Cost Integration

- The local volumes from different EPIs are integrated based on the confidence:

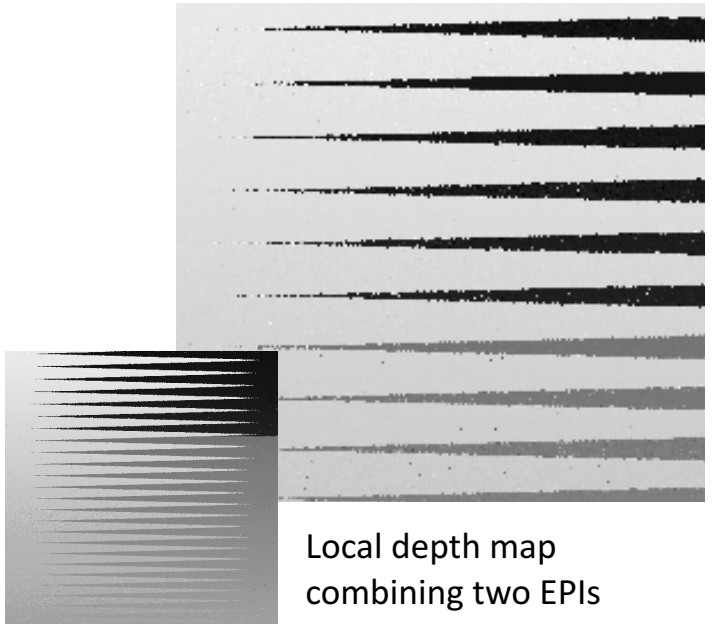
$$d_{u,v}(x,y,\theta) = c_{y,v^*}(x,u^*)\, d_{y,v^*}(x,u^*,\theta) + c_{x,u^*}(y,v^*)\, d_{x,u^*}(y,v^*,\theta)$$, where $$c = e^{-\frac{\bar{d}/d_{max}}{2\sigma^2}}$$



Local depth map
from horizontal EPI



Local depth map
from vertical EPI



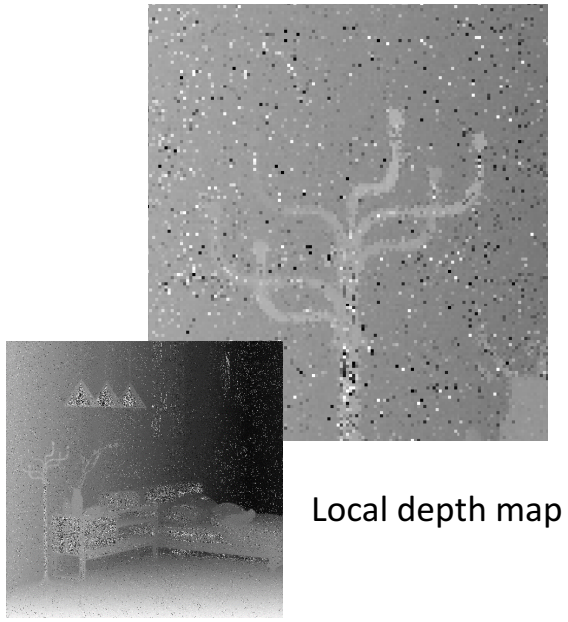
Local depth map
combining two EPIs

Benchmark Results Comparison

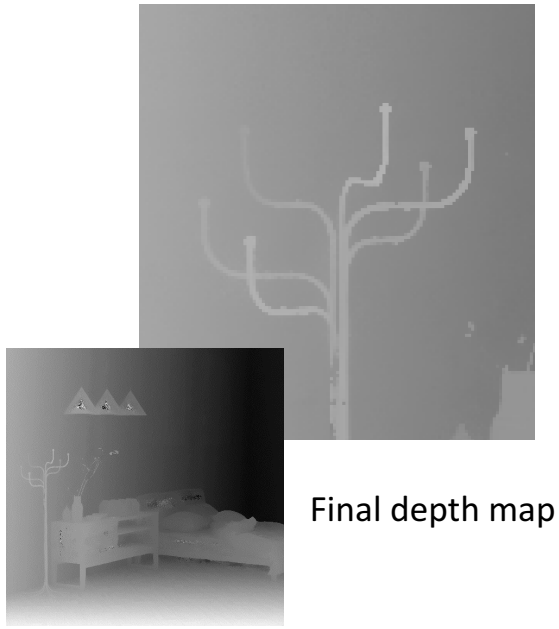
- **Occluded Regions**

Reason 3: Cost Filtering

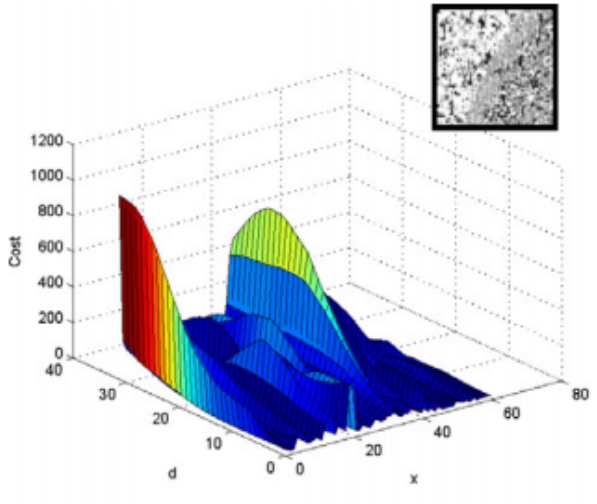
- The effective information is propagated to surrounding similar points using the guided filter, where the occluded points are recovered more accurately.



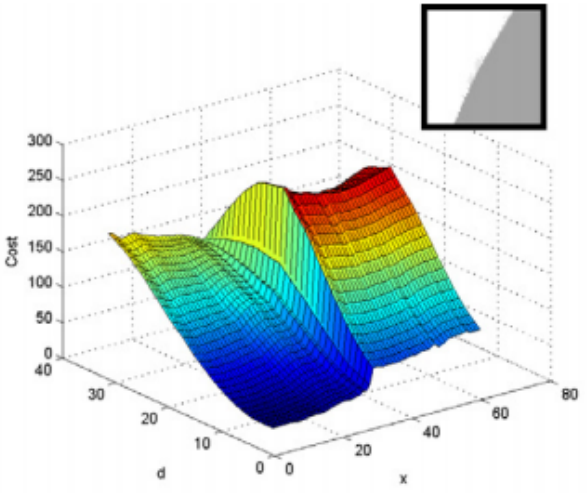
Local depth map



Final depth map



Local cost volume

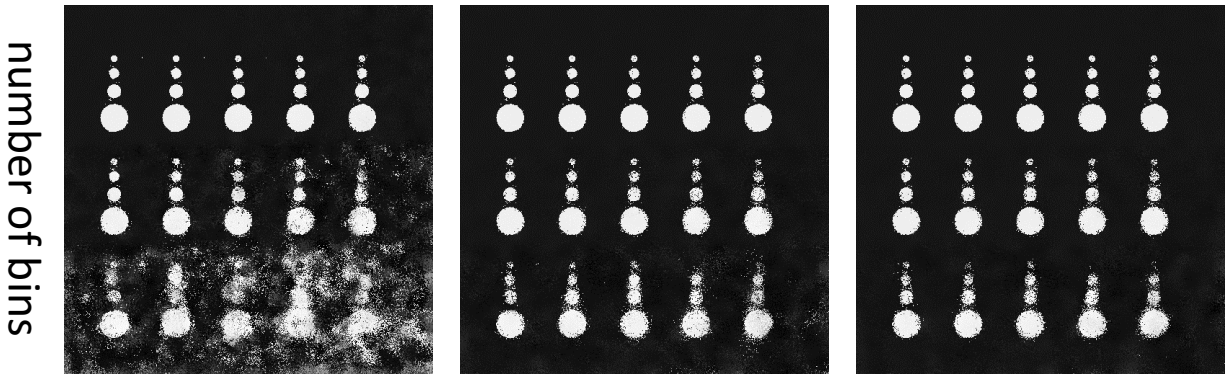


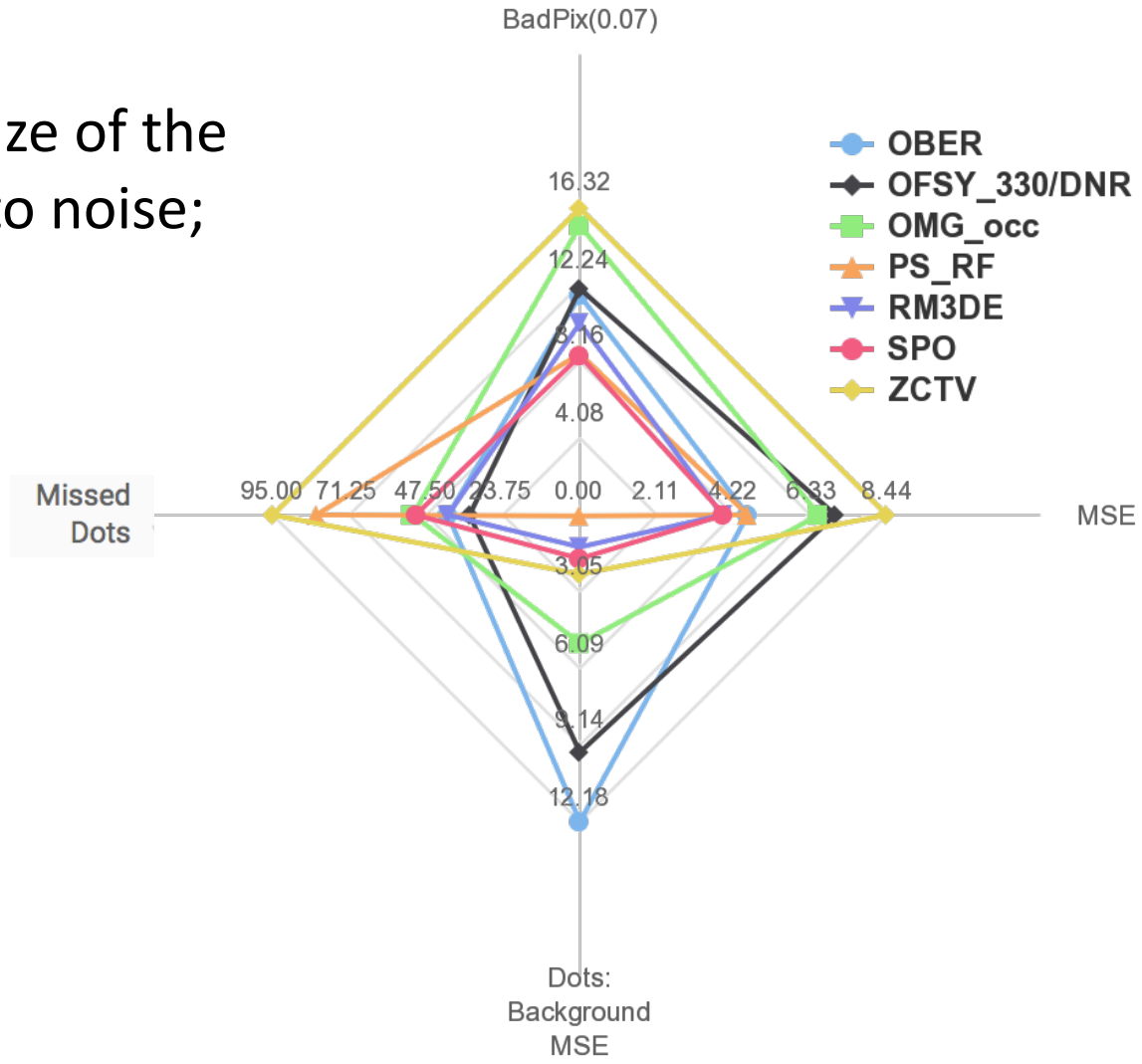
Filtered cost volume

Benchmark Results Comparison

- **Noisy Regions**

  - The histogram distance is influenced by the size of the bins, where the bins with large size are robust to noise;



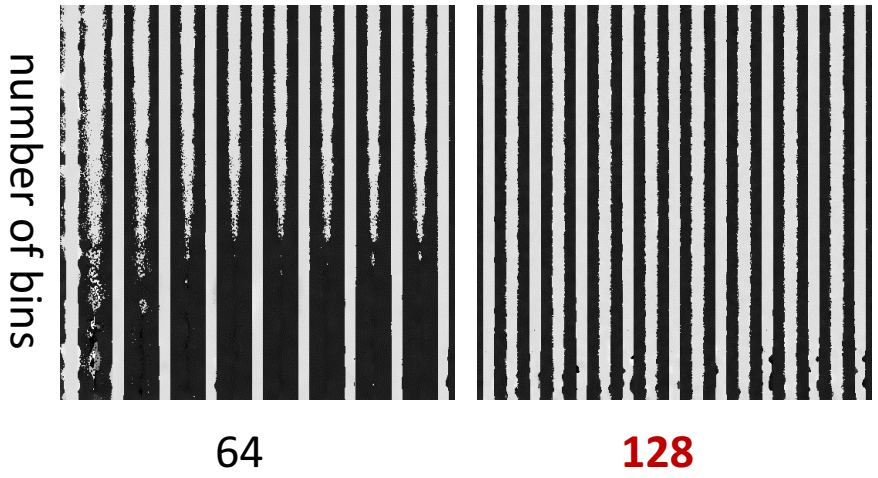


✓ number of bins: the smaller the better

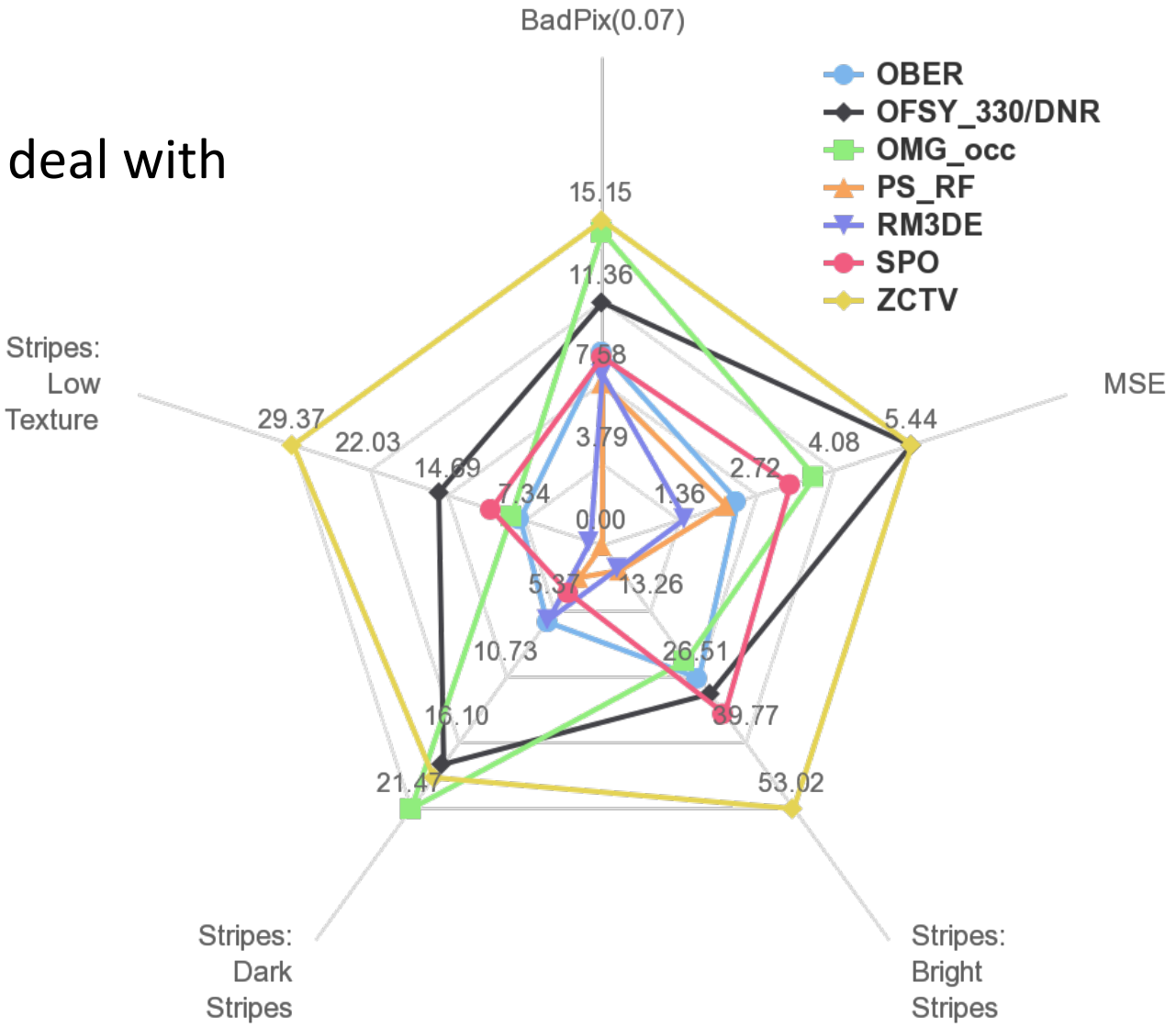
Benchmark Results Comparison

- **Low-texture Regions**

  - The histogram with small bins is able to deal with low texture regions;



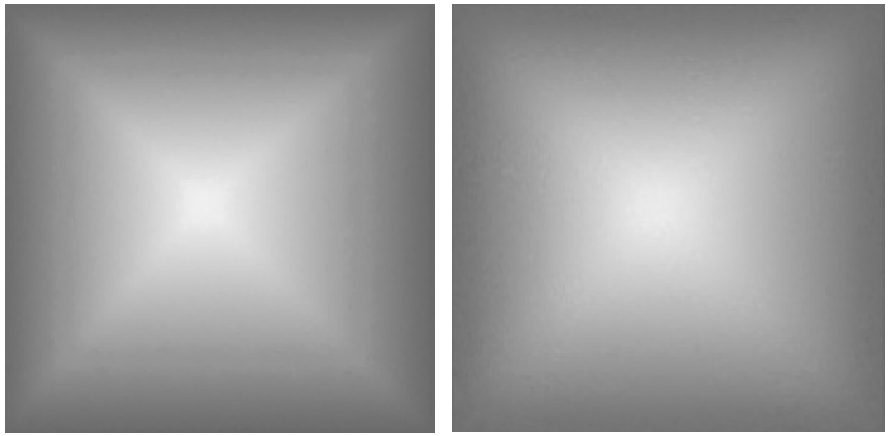
✓ number of bins: the larger the better



Benchmark Results Comparison

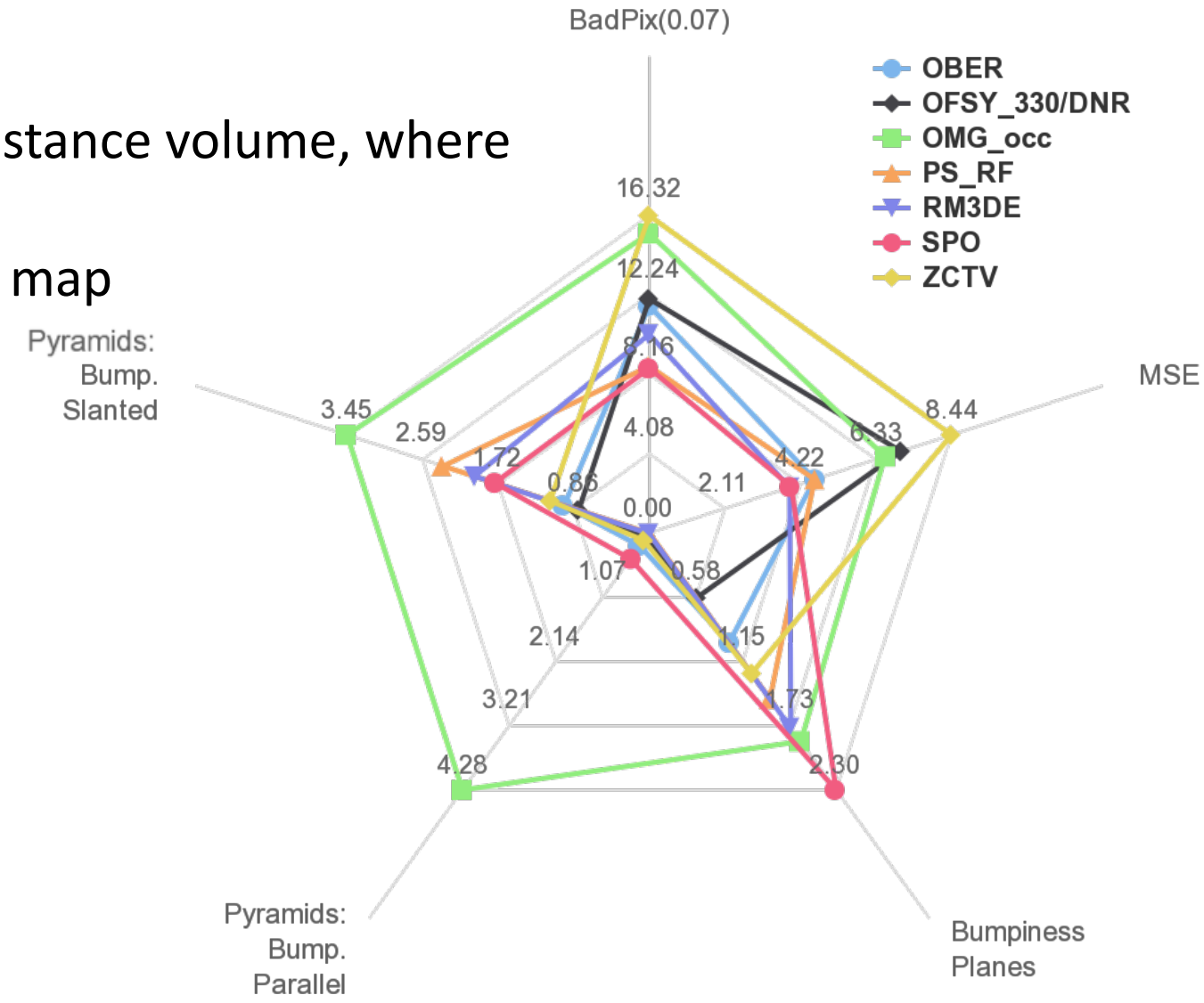
- **Surface reconstruction:**

  - Only the guided filter is used for the distance volume, where
    - Small radius -> noisy depth map
    - Large radius -> over-smooth depth map



radius = 3

radius = 9



Implementation

- Procedure:
  1. Construct histogram image in different bins;
  2. SPO -> Convolution kernel;
  3. Add up the histogram distance in different bins;

- Analyses:
  - Images: B bins, N channels and D depth label
  - NBD convolution operations for each pixel

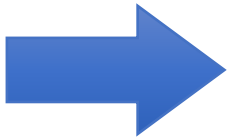
- Time:
  - Matlab, Intel i7 3.60 GHz CPU and 8 GB RAM
  - 328*328 images, 64 labels, 64 number of bins : 65s (local estimation), 63s (guided filter)

Summary

- Strengths:
  - Histogram distance
  - Maximum response
  - Surrounding points
  - No occlusion modeling

  - Fine structure
  - Discontinuities, robust to occlusion
  - Adapt to noisy and low-texture images
  - No requirement for depth scope and angular resolution
  - Simple and effective Algorithm

- Drawbacks:
  - Simple optimization
  - Surrounding points



  - Unreliable Surface Reconstruction
  - Maximum accuracy: Badpix (0.01) is high

Reference

- Paper
  - Shuo Zhang, Hao Sheng, Chao Li, Jun Zhang and Zhang Xiong, Robust Depth Estimation for Light Field via Spinning Parallelogram Operator, Computer Vision and Image Understanding, 2016, 145(C), 148-159
- Benchmark Results & Code
  - https://github.com/shuozh/Spinning-Parallelogram-Operator
- Contact
  - shuo zhang (shuo.zhang@buaa.edu.cn)

Thank you!