

Efficient Large-Scale Stereo Matching

Andreas Geiger*, Martin Roser* and Raquel Urtasun**

*KARLSRUHE INSTITUTE OF TECHNOLOGY

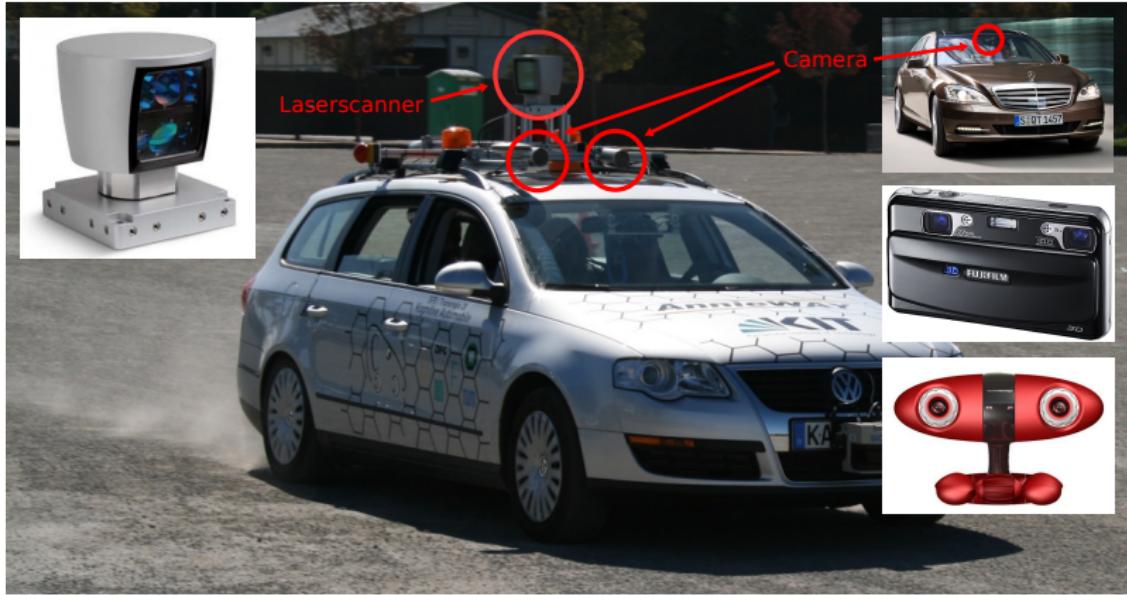
**TOYOTA TECHNOLOGICAL INSTITUTE AT CHICAGO



- 1 Motivation and Related Work
- 2 Efficient Large-Scale Stereo Matching
- 3 Experimental Evaluation
- 4 Summary and Future Work

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Motivation

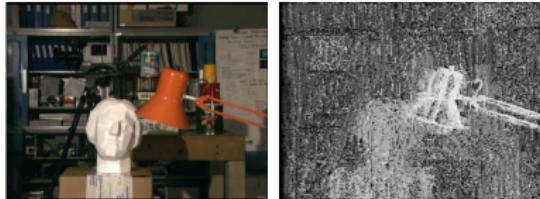


Why is 3D from Stereo hard?

- Ambiguities
- Textureless regions

- Sensor saturation
- Non-Lambertian surfaces

- Δz grows quadratically
- Computational burden



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$$|\Delta z| \approx \frac{z^2}{f \cdot b} |\Delta d|$$

↑ distance error ↑ focal length ↑ disparity error ↑ baseline

Related Work: Local Methods

Local Methods

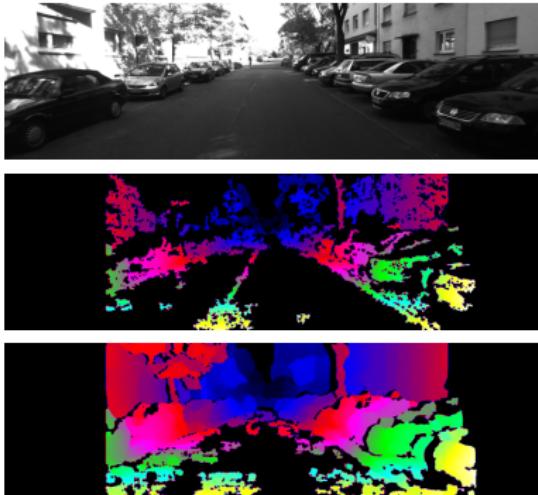
- Winner-takes-All

Examples

- Block matching
(Scharstein 02)
- Adaptive windows
(Kanade 94, Yoon 06)
- Plane-sweep
(Collins 96, Gallup 07)

Problems

- Small matching ratios
- Border bleeding



Related Work: Global Methods

Global Methods

- Minimize 1D/2D energy $E(d) = E_{\text{data}}(d) + \lambda E_{\text{smooth}}(d)$

Examples

- Graph cuts, Belief propagation
(Kolmogorov 02, Felzenszwalb 06)
- Variational methods
(Pock 07, Zach 09)
- Fusion moves
(Woodford 08, Bleyer 10)

Problems

- Computational and memory requirements
- Pairwise potentials can not model planarity



Seed-and-Grow Methods

- Grow disparity components from random seeds

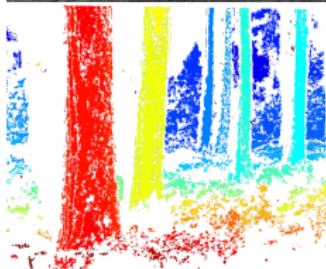
Examples

- (Cech 07)
- (Sara 03)



Problems

- Slanted/textureless surfaces
- No dense disparity maps



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- Assumption: rectified images

- Image pairs contain 'easy' and 'hard' correspondences
- Robustly match 'easy' correspondences on regular grid
- Build prior on dense search space \Rightarrow dense matching



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Idea



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Notation

- Robust support points $\mathbf{S} = \{\mathbf{s}_1, \dots, \mathbf{s}_M\}$ with $\mathbf{s}_m = (u_m \ v_m \ d_m)^T$
- Disparity $d_n \in \mathbb{N}$
- Observations $\mathbf{o}_n = (u_n \ v_n \ \mathbf{f}_n)^T$
- Local image features \mathbf{f}_n

Algorithm

- Split image domain into support points \mathbf{S} and dense pixels
- Assume factorization of distribution over disparity, observations and support points into ...

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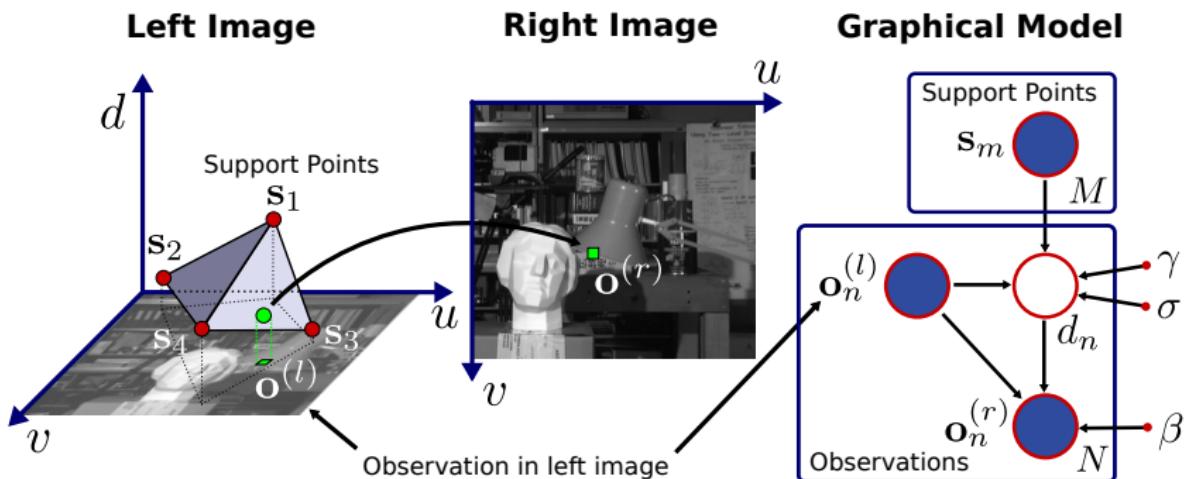
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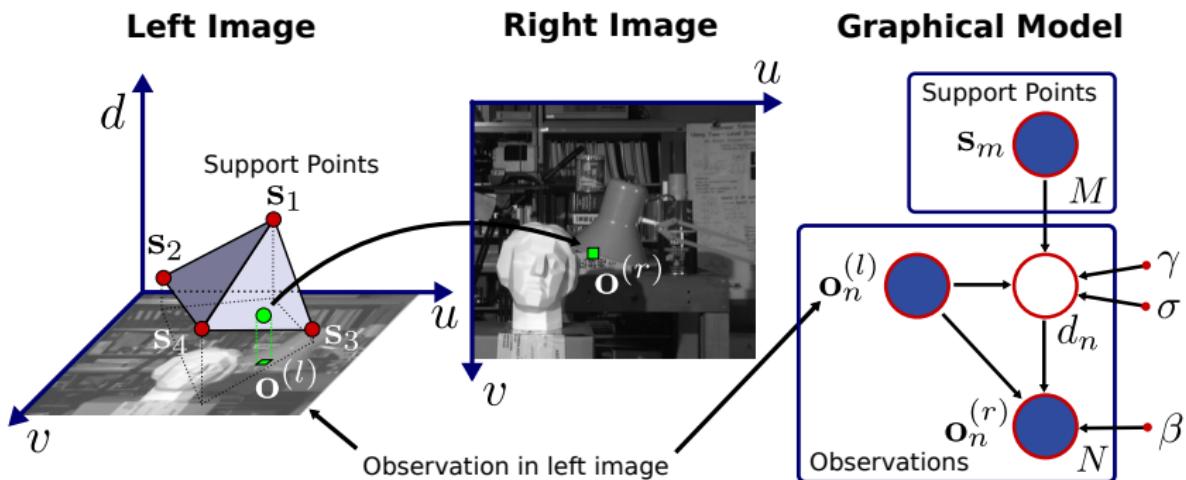
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Model



$$p(d_n, \mathbf{o}_n^{(l)}, \mathbf{o}_n^{(r)}, \mathbf{S}) \propto \underbrace{p(d_n | \mathbf{S}, \mathbf{o}_n^{(l)})}_{\text{Prior}} \underbrace{p(\mathbf{o}_n^{(r)} | \mathbf{o}_n^{(l)}, d_n)}_{\text{Likelihood}}$$

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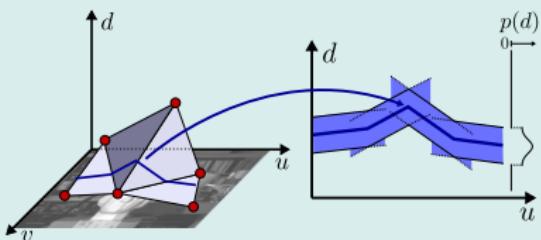


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Prior and Likelihood

Prior $p(d_n | \mathbf{S}, \mathbf{o}_n^{(l)})$

- Support pt. triangulation
- Piecew. linear manifold
- Local extrapolation



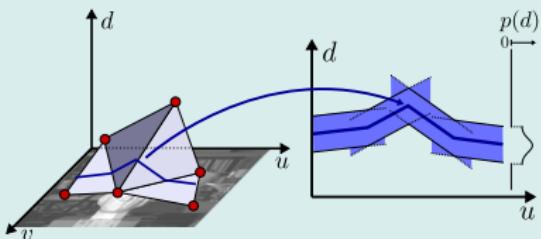
Likelihood $p(\mathbf{o}_n^{(r)} | \mathbf{o}_n^{(l)}, d_n)$

- Laplace distribution
- 5×5 block window
- 3×3 Sobel filter

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$$\begin{matrix} \nabla_u \\ \nabla_v \end{matrix} + \begin{matrix} \nabla_u \\ \nabla_v \end{matrix} = \longrightarrow \exp(-\beta \|\begin{matrix} \nabla_u \\ \nabla_v \end{matrix}\|_1)$$

Sampling from the model

Left image



Sample mean



Sampling from the model

Left image



Sample mean



Right image



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Middlebury Benchmark



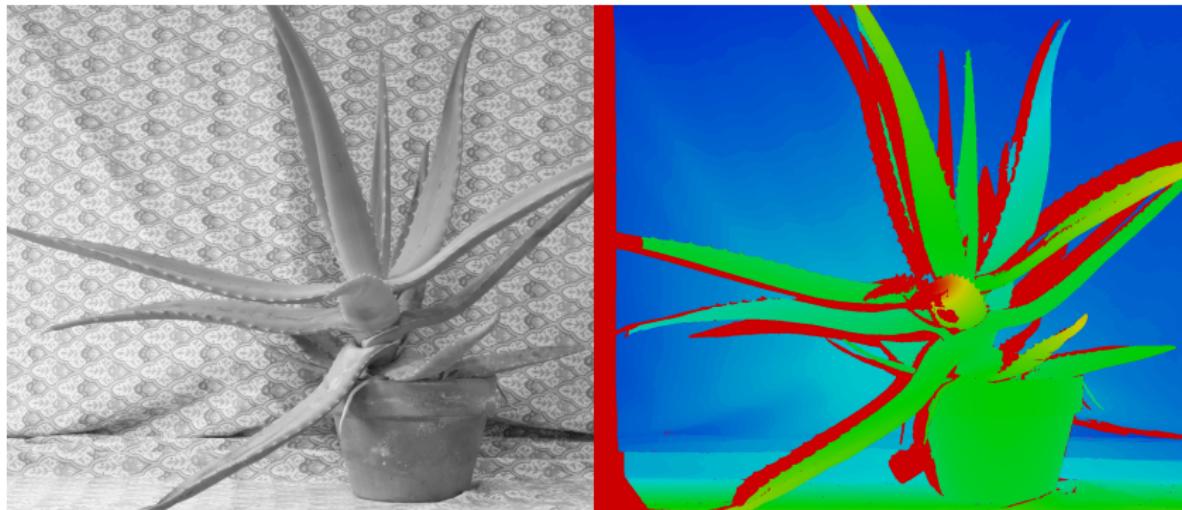
900 x 750 pixels, ground truth

Middlebury Benchmark



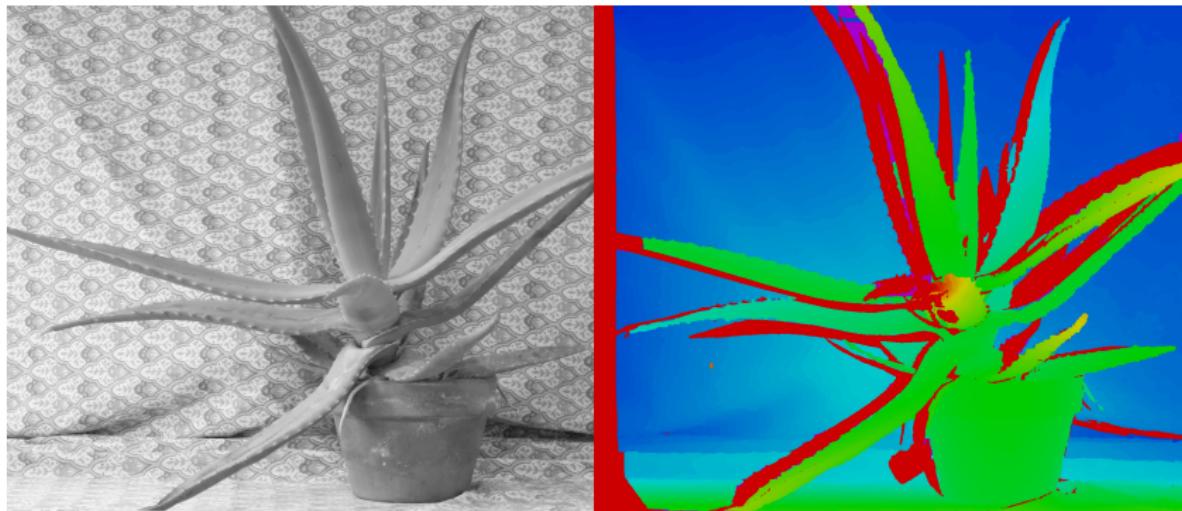
900 x 750 pixels, 0.4 seconds

Middlebury Benchmark



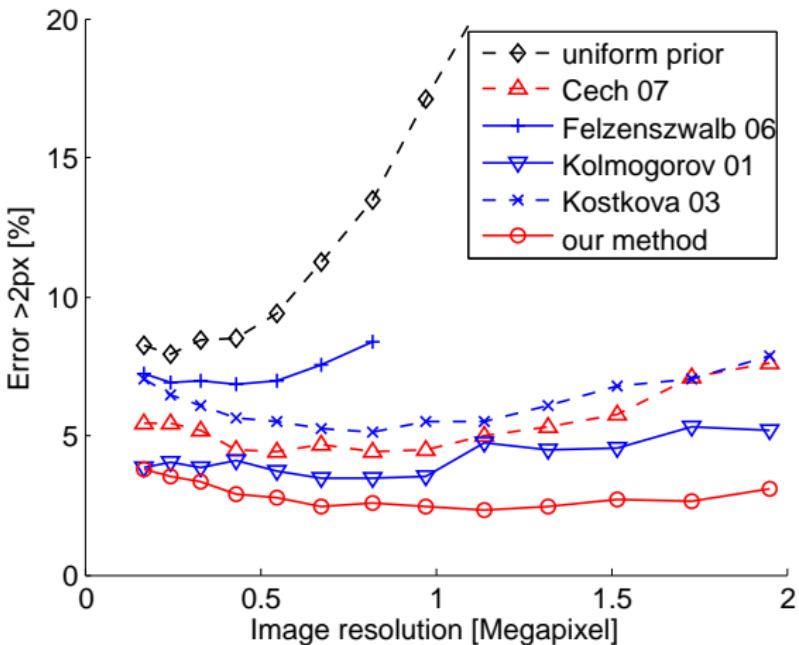
1300 x 1100 pixels, ground truth

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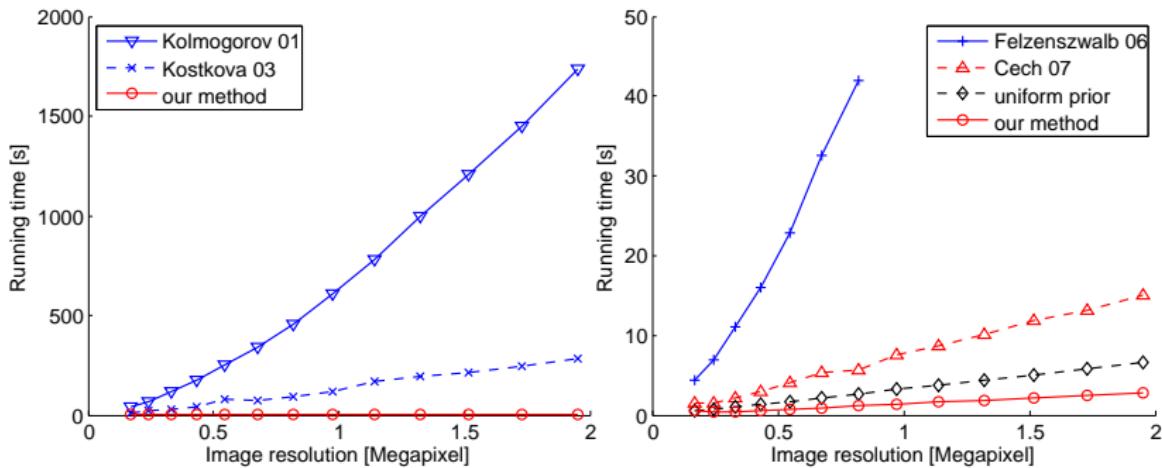


1300 x 1100 pixels, 1 second

Accuracy (on cones image pair)

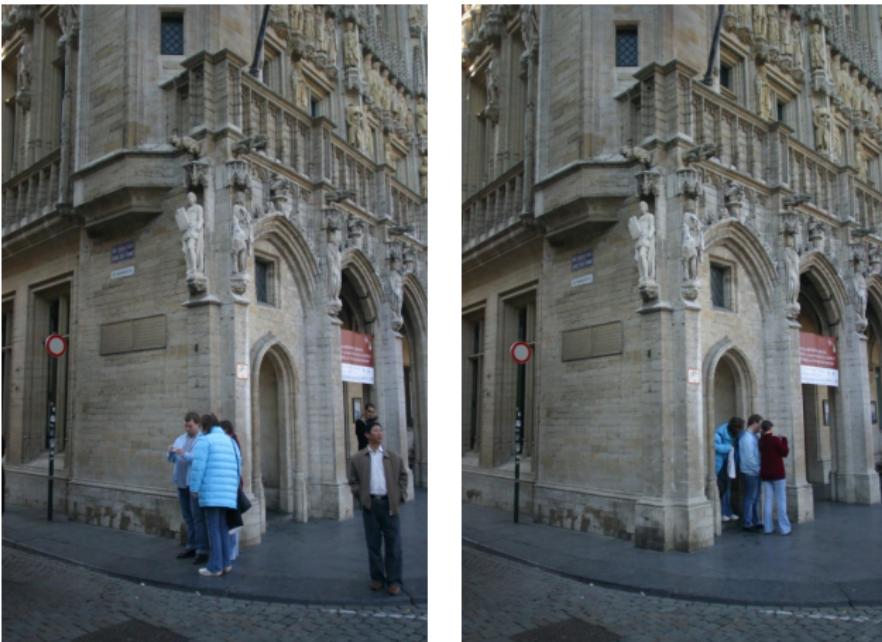


Running times (on cones image pair)



[For more details see: Geiger et al., ACCV 2010]

3D Reconstruction: Brussels



2 seconds

[<http://cvlab.epfl.ch/data/strechamvs/>]

3D Face Reconstruction



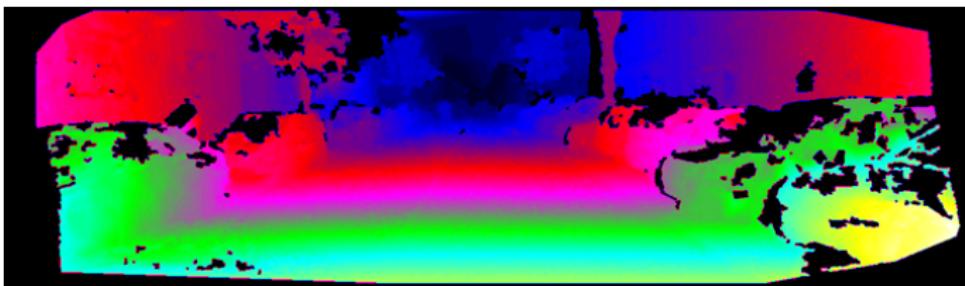
[<http://www.fujifilm.com/products/3d>]

Urban Scene Reconstruction



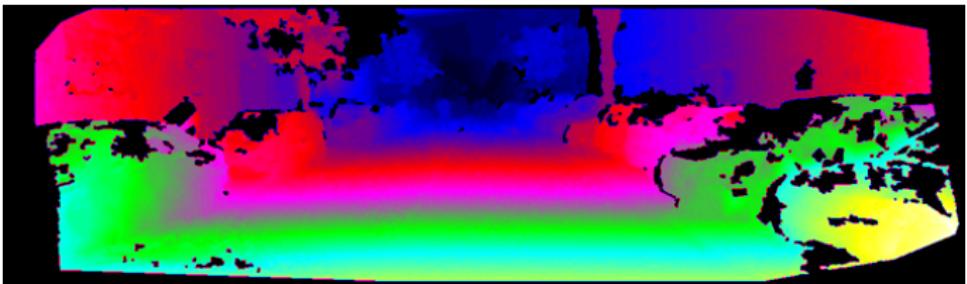
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Summary



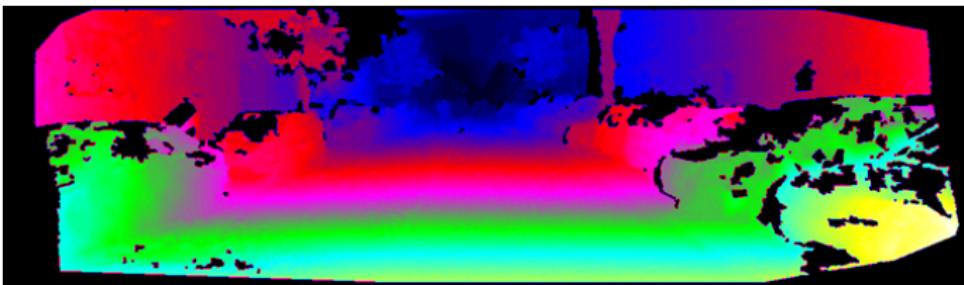
- Simple prior based on sparse feature matches
- Reduced ambiguities and run-time
- Takes into account slanted surfaces
- Real-time 3D reconstruction of static scenes on CPU
- C++ / MATLAB code available at <http://cvlibs.net>

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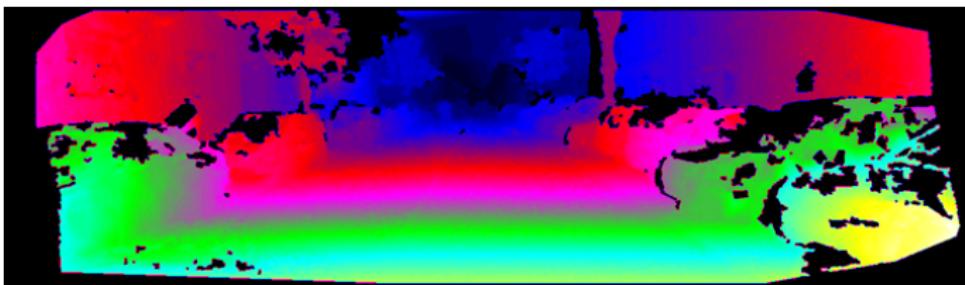
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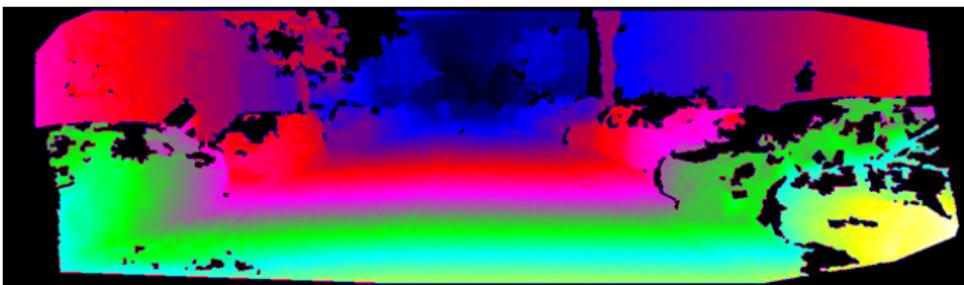
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- Develop better priors
- Incorporate segmentation / global reasoning on lines
- GPU implementation
(goal: 20 fps at 1-2 megapixels)
- Employ as unitary potentials on global methods
⇒ smaller label sets
- Thank you!

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