Accurate Depth and Normal Maps from Occlusion-Aware Focal Stack Symmetry

Michael Strecke, Anna Alperovich, and Bastian Goldluecke

Computer Vision and Image Analysis
University of Konstanz

Contributions

• Novel way to handle occlusions when constructing cost volumes based on focal stack symmetry

• Joint regularization of depth and normals for smooth normal maps consistent with depth estimate

Light field structure and focal stacks

Light fields are defined as 4D function \( L : \Pi \times \Omega \rightarrow \mathbb{R} \) on ray space, where rays are given by intersection points with the focal plane \( \Pi \) and the image plane \( \Omega \).

Refocusing to disparity \( \alpha \): aperture filter \( \varphi \) over subaperture views \( v = (s, t) \),

\[
\varphi_p(\alpha) = \int_\Pi \sigma(v)L(p + \alpha v, v) \, dv.
\]

(1)

Lin et al. [6]: In absence of occlusion, the focal stack is symmetric around the ground truth disparity. Assignment cost for disparities measures symmetry,

\[
\sigma_p^\alpha(\alpha) = \int_\Pi \rho(\varphi_p(\alpha) - \varphi_p(\alpha + \delta)) \, d\delta.
\]

(2)

Joint depth and normal map optimization


Our approach: novel prior on normal maps which enforces correct relation to depth as well as smoothness of the normal field:

\[
\min_{\zeta, n} \int_{\Pi} \rho(\zeta, x) + \lambda \|N\zeta - \alpha n\|_1 \, dx + R(n) \, dx
\]

where \( R(n) \) is a regularizer for the normal field given as

\[
R(n) = \sup_{w(0,1)} \int_{\Pi} \alpha \|w - Dn\|_1 + \gamma \|Dw\|_2 \, dx
\]

and reparametrized depth \( \zeta := \nabla^2 \) is related to normals by a linear operator \( N(\zeta) \) [2].

Optimization for depth: Terms not dependent on \( \zeta \) are removed, resulting in saddle point problem:

\[
\min_{\zeta, n} \max_{\lambda > 0} \int_{\Pi} (\zeta, N\zeta - \alpha n) + \lambda \|N\zeta - \alpha n\|_1 + (\zeta, \rho_1\zeta + (\zeta, \rho_2) \zeta, \rho_2) \, dx
\]

Solved using the primal-dual algorithm [1].

Optimization for normals: Removing all terms not depending on \( n \): \( L^1 \) denoising problem

\[
\min_{n \in C_1} \int_{\Pi} \lambda \|N\zeta\|_1 \|w - n\| \, dx + R(n)
\]

Nonconvex due to \( \|n\|_1 = 1 \): adoption of ideas from [10] for solution (local parameterization of tangent space, effective linearization).

Comparison of normal maps for different methods

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carton</td>
<td>Carton</td>
<td>Carton</td>
<td>Carton</td>
<td>Carton</td>
</tr>
<tr>
<td>Door</td>
<td>Door</td>
<td>Door</td>
<td>Door</td>
<td>Door</td>
</tr>
<tr>
<td>Sideboard</td>
<td>Sideboard</td>
<td>Sideboard</td>
<td>Sideboard</td>
<td>Sideboard</td>
</tr>
<tr>
<td>Upholstered chair</td>
<td>Upholstered chair</td>
<td>Upholstered chair</td>
<td>Upholstered chair</td>
<td>Upholstered chair</td>
</tr>
<tr>
<td>Leather sofa</td>
<td>Leather sofa</td>
<td>Leather sofa</td>
<td>Leather sofa</td>
<td>Leather sofa</td>
</tr>
<tr>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
</tr>
<tr>
<td>1.93</td>
<td>1.93</td>
<td>1.93</td>
<td>1.93</td>
<td>1.93</td>
</tr>
</tbody>
</table>

Combining cost terms can improve robustness

This work was supported by the ERC Starting Grant "Light Field Imaging and Analysis" (LA 336978, FP7-2014).
Presented at the Conference on Computer Vision and Pattern Recognition (CVPR), Honolulu, USA, July 2017.
Accurate Depth and Normal Maps from Occlusion-Aware Focal Stack Symmetry

Michael Strecke, Anna Alperovich, and Bastian Goldluecke
Computer Vision and Image Analysis
University of Konstanz

Experiments

Results on benchmark [3]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>boxes</td>
<td>39.31</td>
<td>39.31</td>
<td>31.67</td>
<td>35.61</td>
<td>40.27</td>
<td>22.14</td>
</tr>
<tr>
<td>cotton</td>
<td>52.16</td>
<td>52.16</td>
<td>44.19</td>
<td>40.27</td>
<td>48.95</td>
<td>30.11</td>
</tr>
<tr>
<td>dino</td>
<td>32.73</td>
<td>32.73</td>
<td>27.64</td>
<td>37.57</td>
<td>48.95</td>
<td>22.14</td>
</tr>
<tr>
<td>sideboard</td>
<td>39.31</td>
<td>39.31</td>
<td>35.61</td>
<td>40.27</td>
<td>48.95</td>
<td>22.14</td>
</tr>
</tbody>
</table>

References


Real-world results