Enhanced Depth Estimation for Hand-held Light Field Cameras

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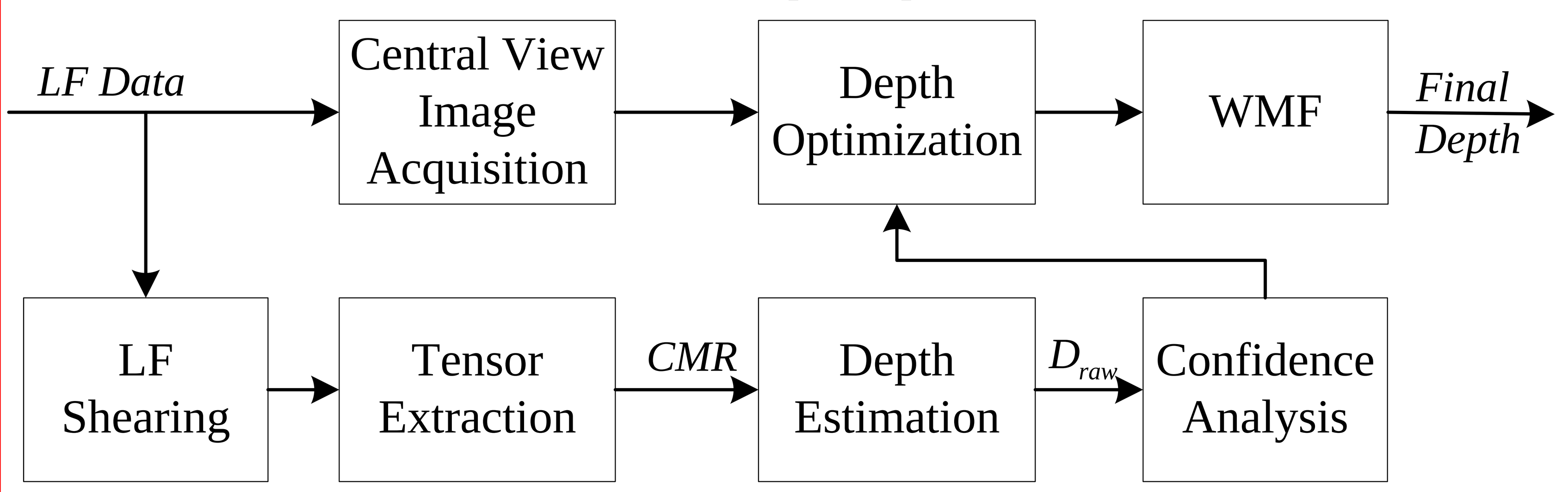
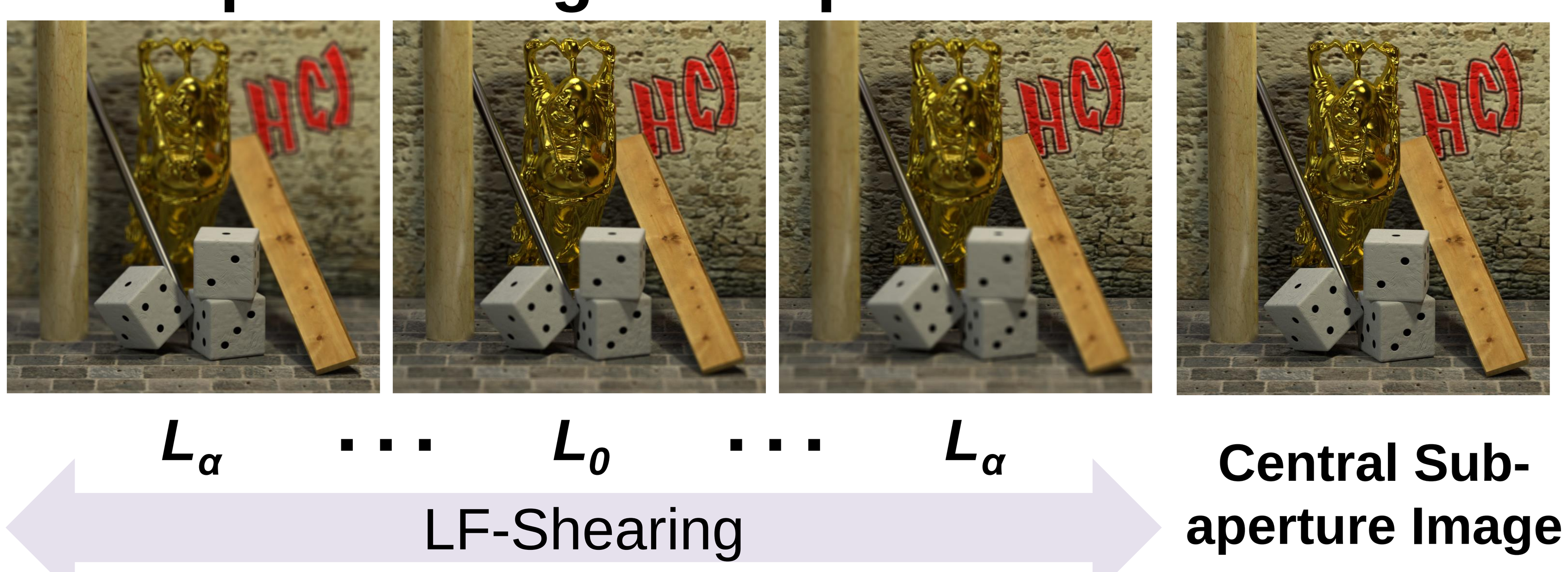
1. Abstract

Depth estimation of the existing approaches with light field cameras is severely affected by homogenous regions in the scene. In this paper, we propose a new depth estimation and enhancement method. The raw depth is calculated from analyzing the Consistency Metric Range (CMR) in the angular patch. Confident depth map is obtained by analyzing the variation of CMR within a neighborhood around the lowest CMR curves. Confident depth points are propagated to the whole image by global optimization with weighted neighborhood smoothness, gradient and second derivative constraints. Finally, depth is enhanced by using weighted median filter.

Architecture of the proposed scheme



2. Pre-processing for Depth Estimation



$$L_\alpha(x,y,u,v) = L_o\left(x+u\left(1-\frac{1}{\alpha}\right), y+v\left(1-\frac{1}{\alpha}\right), u, v\right),$$

L_0: rectification of the captured image; L_α: refocused image at depth level α; x, y: spatial coordinates, u, v: angular coordinates on the image plane.

3. Depth estimation & Optimization

3.1. Angular patch analysis

Tensor Extraction

$$R_{avg}(\mathbf{p},\alpha) = \sqrt{\frac{\left(R_R^2(\mathbf{p},\alpha)+R_G^2(\mathbf{p},\alpha)+R_B^2(\mathbf{p},\alpha)\right)}{3}}$$

$$R_{max}(\mathbf{p},\alpha) = max\left(R_R(\mathbf{p},\alpha), R_G(\mathbf{p},\alpha), R_B(\mathbf{p},\alpha)\right)$$

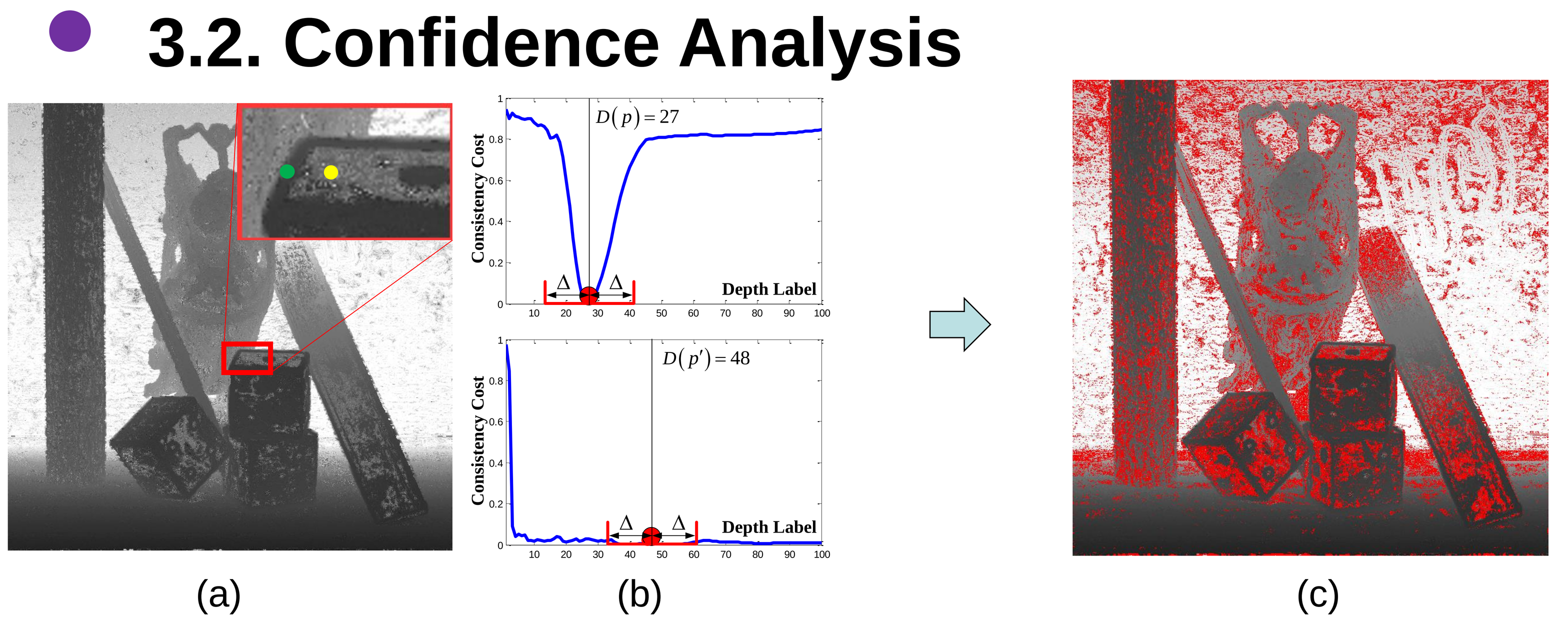
$$C(\mathbf{p},\alpha) = \beta R_{max}(\mathbf{p},\alpha) + (1-\beta) R_{avg}(\mathbf{p},\alpha)$$

Raw depth

$$D_{raw}(\mathbf{p}) = \underset{\alpha}{\operatorname{argmin}}\, C(\mathbf{p},\alpha)$$

Variation of intensity in the angular patch with different depth level is analyzed. Angular patch comparison in different positions exhibit same tendency with the variation of depth level α.

3.2. Confidence Analysis



Confidence analysis. (a) Raw depth map. (b) The CMR curves of two points: top one for the green point in (a) and bottom one for the yellow point in (a). (c)

$$\operatorname{var}\left(C(\mathbf{r})\right)\Big|_{\mathbf{r}\in M(\mathbf{p})} \le \tau \quad \text{where} \quad M(\mathbf{p}) = [D_{raw}(\mathbf{p})-\Delta, D_{raw}(\mathbf{p})+\Delta]$$

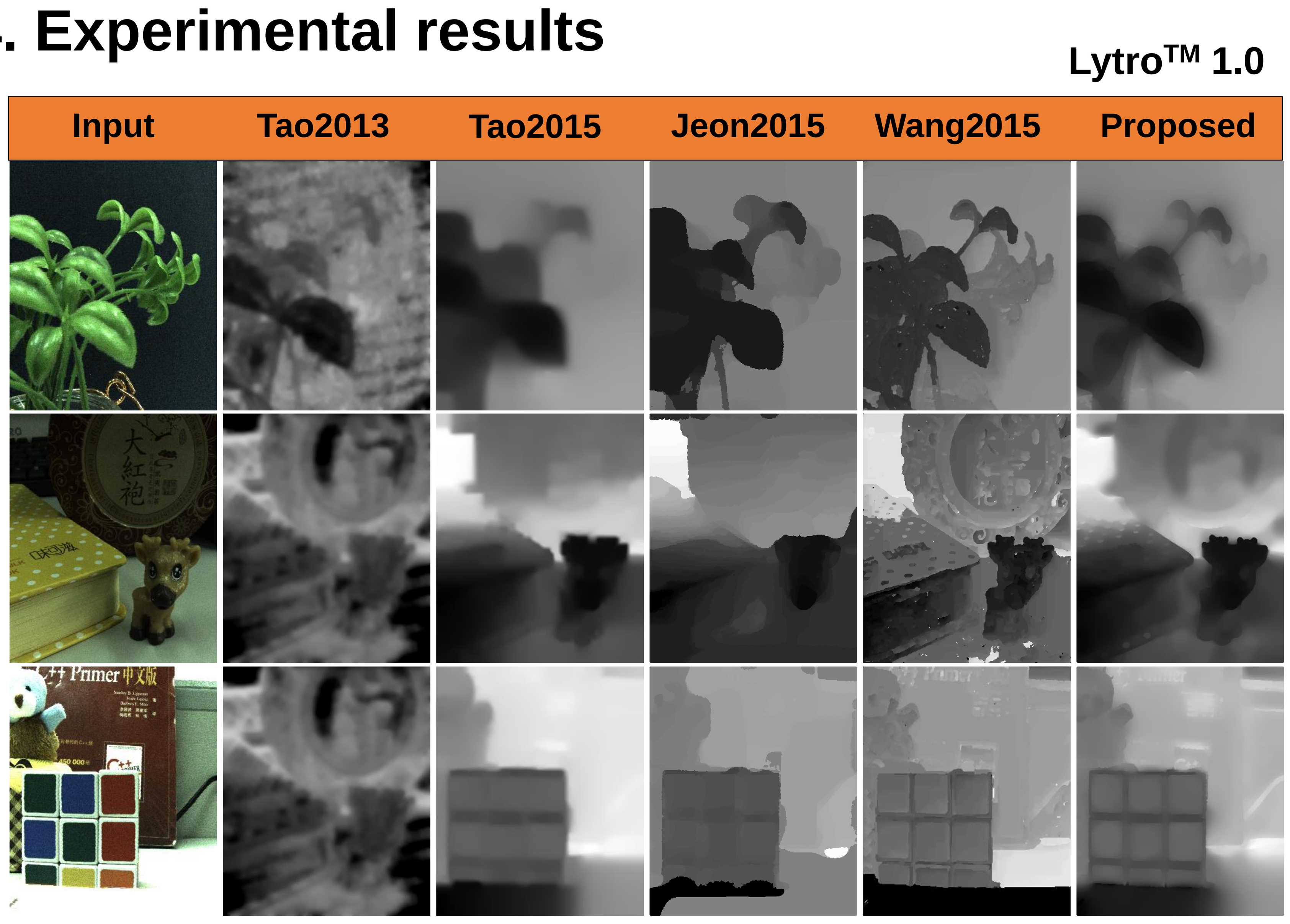
Confident depth regions: $\Omega = \left\{\mathbf{p} \,\middle|\, \operatorname{var}\left(R(\mathbf{r})\right)\Big|_{\mathbf{r}\in M(\mathbf{p})} > \tau\right\}$

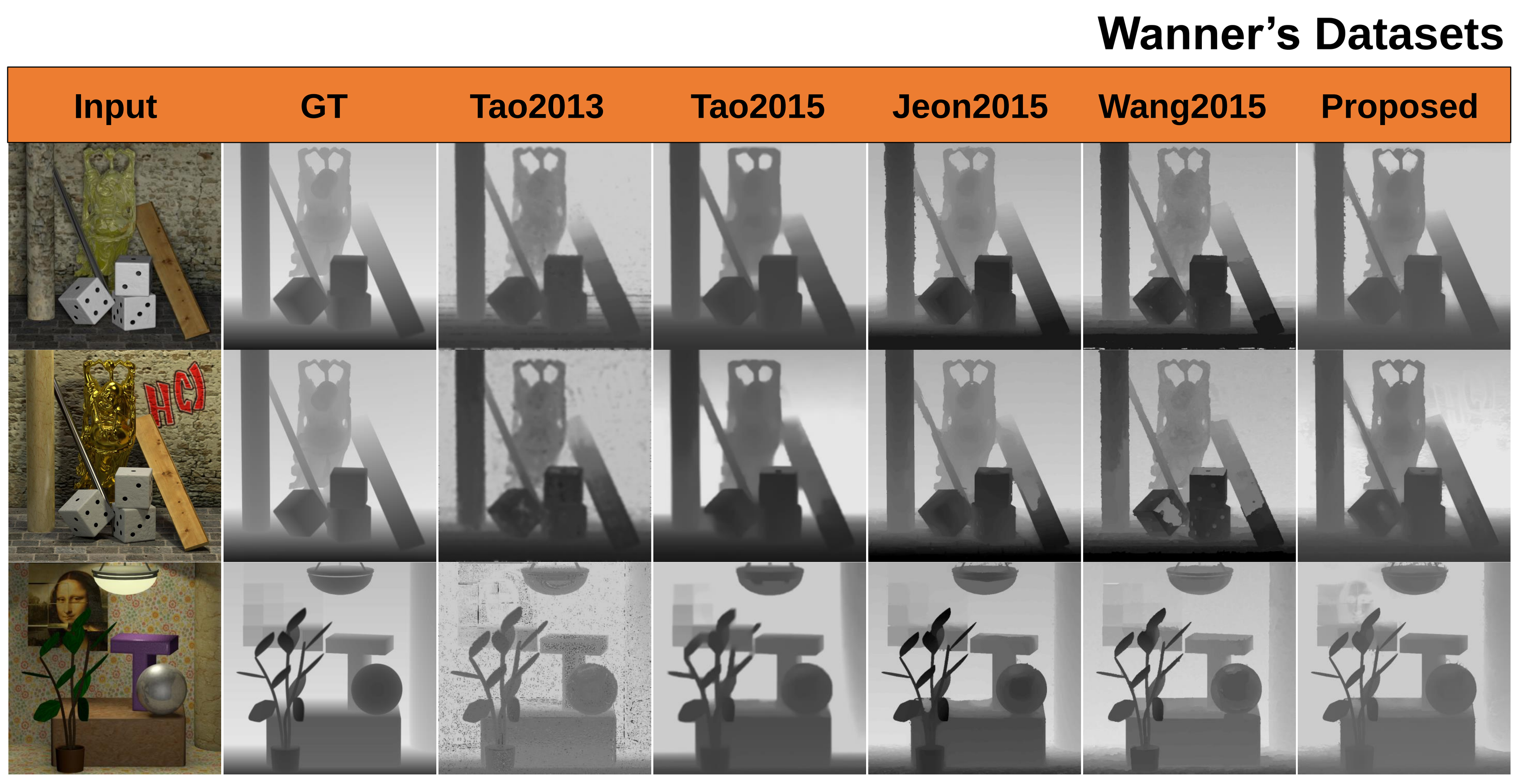
3.3. Depth Map Optimization and Enhancement

$$D^* = \underset{D}{\arg\min} \sum_{\mathbf{p}} \left(D(\mathbf{p}) - \sum_{\mathbf{s}\in N(\mathbf{p})} w_{\mathbf{ps}} D(\mathbf{s})\right)^2 + \lambda \sum_{\mathbf{p}} \left(G_D(\mathbf{p}) - G_{I_c}(\mathbf{p})\right)^2 + \eta \sum_{\mathbf{p}} \left(\Delta D(\mathbf{p})\right)^2, \quad s.t.\ D(\Omega) = D_{raw}(\Omega)$$

we minimize the difference between the depth D(***p***) and the weighted average of the depth of pixels belonging to the neighborhood of ***p***; ***λ*** and ***η*** control the Laplacian constraint and the second derivative kernel respectively. ***G***: gradient extracted from the central sub-aperture image

4. Experimental results





Much clearer transitions of texture regions and much smoother homogenous regions.