Photometric Segmentation

Simultaneous Photometric Stereo and Masking

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Photometric Stereo (PS)

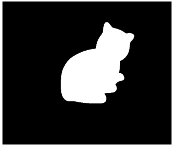
 $+\cdots+$  $=$

PS Images

Needed for PS:

- Differently illuminated images

Photometric Stereo (PS)

 $+ \cdots +$  $+$  $=$

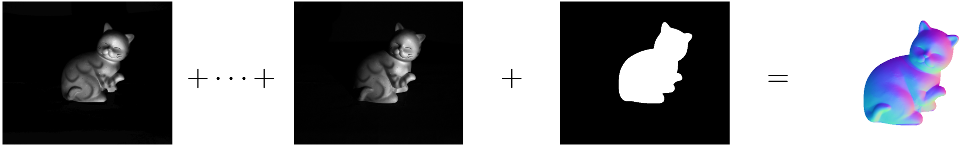
PS Images

Segmented Object

Needed for PS:

- Differently illuminated images
- Mask of object

Photometric Stereo (PS)



PS Images

Segmented Object

Surface Normals

Needed for PS:

- Differently illuminated images
- Mask of object

$\Longrightarrow$ Estimate fine-scale geometry

Photometric Stereo (PS)

PS Images

Segmented Object

Surface Normals

Needed for PS:

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$\Longrightarrow$ Estimate fine-scale geometry

Goal:

- Perform PS without given mask
- Jointly segment object

Segmentation

Active contours approach [Chan and Vese; TIP 2001]:

$$\min_{\mu_1,\mu_2,C} \int_{\text{inside}(C)} \mathcal{P}_1(\mu_1, I(x))\,\mathrm{d}x + \int_{\text{outside}(C)} \mathcal{P}_2(\mu_2, I(x))\,\mathrm{d}x + \nu\,\text{length}(C)$$

- minimal length curve C
- $\mathcal{P}_j(\mu_j, I(x)) = \frac{1}{m}\sum_{i=1}^{m}(\mu_j - I_i(x))^2$, $j \in \{1,2\}$
- graylevel images I
- μ_j, $j \in \{1,2\}$, resembles mean intensity

Photometric Stereo Mathematically

$$I_i(x) = \rho(x)\,\langle \mathbf{s}_i, \mathbf{n}(x)\rangle,\ i \in \{1,\dots,m\}, \text{ with } \mathbf{n}(x) = \frac{[\nabla z(x), -1]^\top}{\sqrt{|\nabla z(x)|^2+1}}$$

- albedo ρ
- lighting vectors $\mathbf{s}_i = \left[s_i^1, s_i^2, s_i^3\right]^\top$
- normal field $\mathbf{n}$
- depth map z

Using image ratios (e.g. [Quéau et al.; CVPR 2016]):

$$\underset{\binom{m}{2}\text{ ratios}}{\rightsquigarrow} \frac{I_i(x)}{[\nabla z(x), -1]^\top \cdot \mathbf{s}_i} = \frac{\rho(x)}{\sqrt{|\nabla z(x)|^2+1}} = \frac{I_j(x)}{[\nabla z(x), -1]^\top \cdot \mathbf{s}_j}$$

Photometric Stereo Mathematically

$$I_i(x) = \rho(x) \langle \mathbf{s}_i, \mathbf{n}(x) \rangle, \ i \in \{1, \dots, m\}, \text{ with } \mathbf{n}(x) = \frac{[\nabla z(x), -1]^\top}{\sqrt{|\nabla z(x)|^2 + 1}}$$

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$$\overset{\rightsquigarrow}{\binom{m}{2} \text{ ratios}} \quad I_i(x) \, [\nabla z(x), -1]^\top \cdot \mathbf{s}_j = I_j(x) \, [\nabla z(x), -1]^\top \cdot \mathbf{s}_i$$

Photometric Stereo Mathematically

Further algebraic simplifications lead to system of linear PDEs:

$$\rightsquigarrow \mathbf{a}_{ij}(x)\nabla z(x) = b_{ij}(x), \text{ with } \mathbf{a}_{ij}(x) \in \mathbb{R}^{1\times 2} \text{ and } b_{ij}(x) \in \mathbb{R}$$

Use $\binom{m}{2}$ linear PDEs and solve for z:

$$\mathcal{P}_{\mathrm{PS}}(z(x)) := \frac{1}{\binom{m}{2}} \sum_{ij} \left(\mathbf{a}_{ij}(x)\nabla z(x) - b_{ij}(x)\right)^2 + \lambda(z(x) - z_0(x))^2$$

$$\min_z \int_\Omega \mathcal{P}_{\mathrm{PS}}(z(x))\,\mathrm{d}x$$

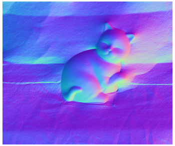
Motivation

Photometric Segmentation to

jointly solve image segmentation and photometric stereo (PS)

PS images

Segmentation only



PS only (without mask)

Segmentation + PS

Proposed Variational Model

$$\min_{z,\phi} \int_\Omega H(\phi(x))\mathcal{P}_{\text{PS}}(z(x))\,\mathrm{d}x + \int_\Omega (1 - H(\phi(x)))\mathcal{P}_{\text{PS}}(z_0(x))\,\mathrm{d}x + \nu \int_\Omega |\nabla H(\phi(x))|\,\mathrm{d}x$$

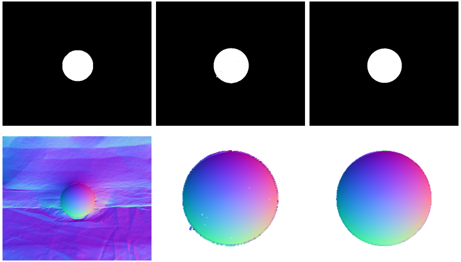
Curve parameterization using level-sets [Osher and Sethian; JCP 1988]:

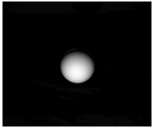
Level-set function: $\phi : \Omega \to \mathbb{R};\ x \mapsto \phi(x) = \begin{cases} > 0, & x \in \text{inside}(C)\ (\text{“foreground”}) \\ 0, & x \in C \\ < 0, & x \in \text{outside}(C)\ (\text{“background”}) \end{cases}$

Heaviside step function: $H : \mathbb{R} \to \{0,1\};\ x \mapsto H(x) = \begin{cases} 1, & x \geq 0 \\ 0, & x < 0. \end{cases}$

Evaluation and Comparison

	Solved separately	Solved jointly	Ground truth
Segmentation result			
PS result	(without mask)		
IoU			
MAE			





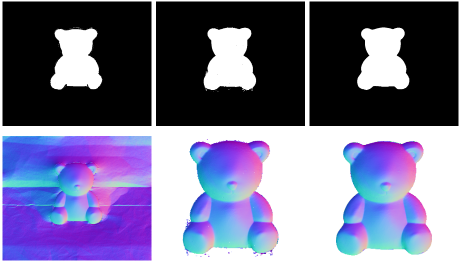
Input images

Evaluation and Comparison

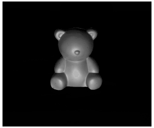
Solved separately | Solved jointly | Ground truth

Segmentation result

PS result



(without mask)



Input images

IoU
MAE

Evaluation and Comparison

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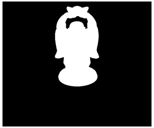
Segmentation result





PS result


(without mask)



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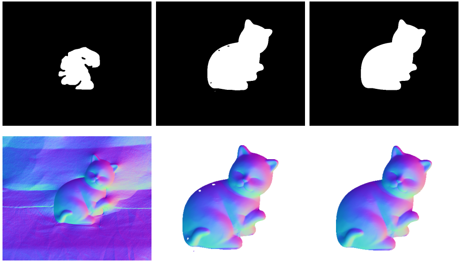

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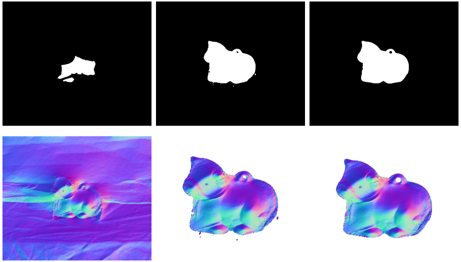

(without mask)

IoU

MAE

Input images

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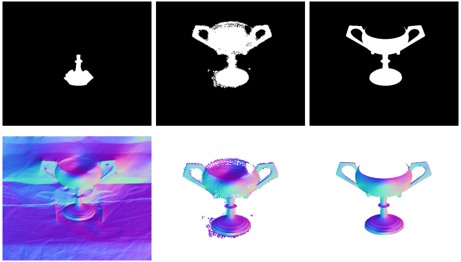

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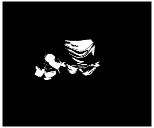
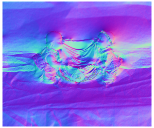
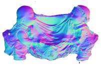
Segmentation result			
PS result	 (without mask)		
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MAE			

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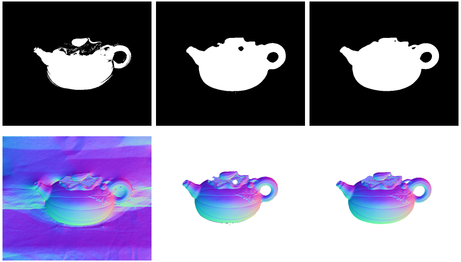
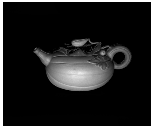


(without mask)



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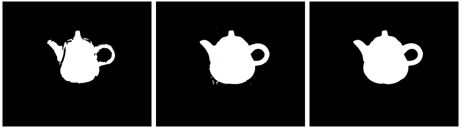

PS result

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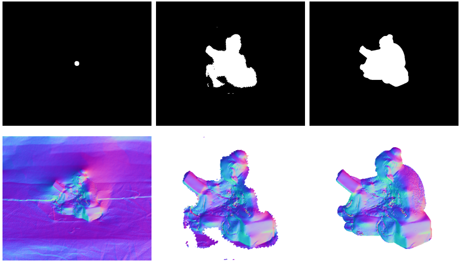

(without mask)

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See you at our poster $\#74$