Fight Ill-Posedness With Ill-Posedness

Single-Shot Variational Depth Super-Resolution From Shading

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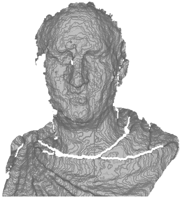
CVPR 2018
Salt Lake City

19. June 2018

Problem of Depth Super-Resolution

Input RGB image

Depth image



3D shape

Depth misses fine geometric details due to

- noise and quantization effects
- coarse resolution of the depth

$\Longrightarrow$ Perform super-resolution of depth (ill-posed problem!)

Shape-from-shading

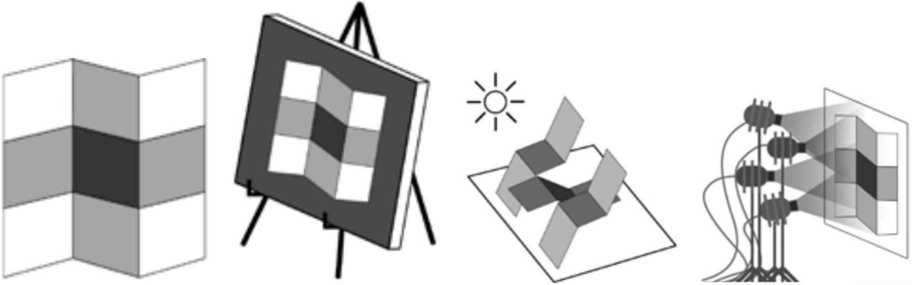
Shape-from-Shading (SfS) tries to solve

$$I = \mathcal{R}(z|\ell, \rho),$$

- RGB image $I : \Omega \to \mathbb{R}^3$
- image formation model $\mathcal{R}$
- depth map $z : \Omega \to \mathbb{R}$
- lighting ℓ
- surface reflectance $\rho : \Omega \to \mathbb{R}^3$

$\Longrightarrow$ Shape-from-shading is an ill-posed problem!

Shape-from-shading



Some image | Painter's explanation | Sculptor's explanation | Gaffer's explanation

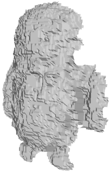
[Adelson & Pentland; PBI 1996]

Motivation

Fight ill-posedness with ill-posedness to

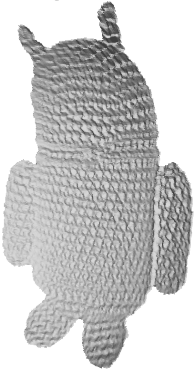
jointly solve depth super-resolution (SR) and shape-from-shading (SfS)

Input RGB

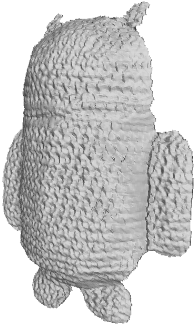


Input depth

Depth SR



SfS



SR + SfS

Parametrize $\mathcal{R}$

Using spherical harmonics for the image formation model $\mathcal{R}$ (e.g. [Basri & Jacobs; PAMI 2003]),

$$I = \mathcal{R}(z|\ell,\rho) = \rho \left\langle \ell, \begin{bmatrix} \mathbf{n}(z) \\ 1 \end{bmatrix} \right\rangle .$$

With a pinhole camera model $\mathbf{n}$ can be written wrt. to z,

$$\mathbf{n}(z) = \frac{1}{\sqrt{|f\nabla z|^2 + (-z - \langle \mathbf{p}, \nabla z \rangle)^2}} \begin{bmatrix} f\nabla z \\ -z - \langle \mathbf{p}, \nabla z \rangle \end{bmatrix},$$

- focal length f,
- pixel coordinates $\mathbf{p} : \Omega \to \mathbb{R}^2$ wrt. to the principal point.

Variational formulation

$$\min_{\substack{\rho:\,\Omega_{HR}\to\mathbb{R}^3\\ \ell\in\mathbb{R}^4\\ z:\,\Omega_{HR}\to\mathbb{R}}} \|\overbrace{\rho\,\langle \ell, \mathbf{m}_{z,\nabla z}\rangle - I}^{\text{SfS term}}\|^2_{\ell^2(\Omega_{HR})} + \mu\|\overbrace{Kz - z_0}^{\text{SR term}}\|^2_{\ell^2(\Omega_{LR})} + \nu\mathcal{P}_1(z) + \lambda\mathcal{P}_2(\rho),$$

$\mathcal{P}_1(z)$ being a minimal surface prior [Graber et al.; CVPR 2015],

$$\mathcal{P}_1(z) = \|\mathrm{d}\mathcal{A}(z,\nabla z)\|_{\ell^1(\Omega_{HR})} = \left\| \frac{z}{f^2}\sqrt{|f\nabla z|^2 + (-z - \langle \mathbf{p}, \nabla z\rangle)^2} \right\|_{\ell^1(\Omega_{HR})}$$

and $\mathcal{P}_2(\rho)$ being a piecewise constant albedo prior,

$$\mathcal{P}_2(\rho) = \|\nabla\rho\|_{\ell^0(\Omega_{HR})} = \sum_{p\in\Omega_{HR}} \begin{cases} 0, & \text{if } |\nabla\rho(p)|_2 = 0, \\ 1, & \text{otherwise.} \end{cases}$$

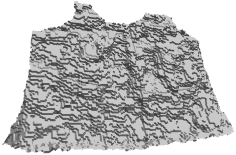
Numerical solution

$$\min_{\substack{\rho:\,\Omega_{HR}\to\mathbb{R}^3\\ \ell\in\mathbb{R}^4\\ z:\,\Omega_{HR}\to\mathbb{R}\\ \theta:\,\Omega_{HR}\to\mathbb{R}^3}} E(\rho,\ell,\theta,z) := \left\|\rho\left\langle \ell,\mathbf{m}_\theta\right\rangle - I\right\|^2_{\ell^2(\Omega_{HR})} + \mu\left\|Kz - z_0\right\|^2_{\ell^2(\Omega_{LR})} + \nu\left\|\mathrm{d}\mathcal{A}_\theta\right\|_{\ell^1(\Omega_{HR})} + \lambda\left\|\nabla\rho\right\|_{\ell^0(\Omega_{HR})}$$

$$\text{s.t. } \theta = (z, \nabla z).$$

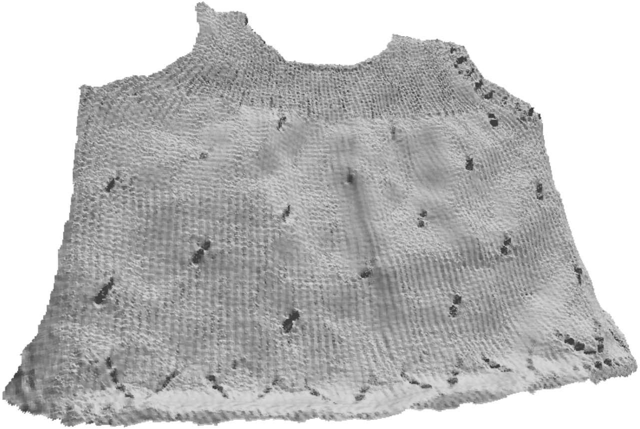
Can be solved using a multi-block variant of ADMM.

Qualitative Evaluation



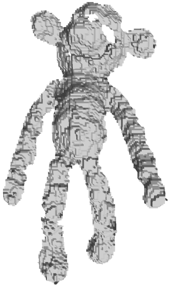
Input depth

Input RGB

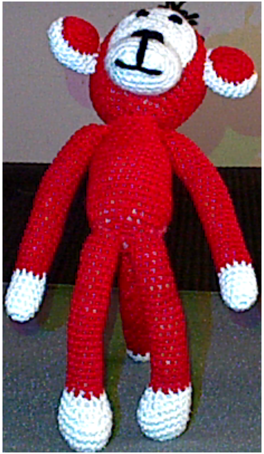


Estimated depth

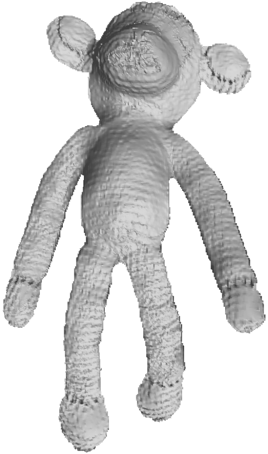
Qualitative Evaluation



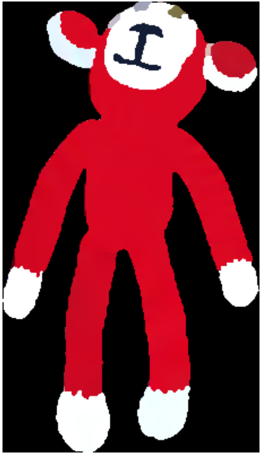
Input depth



Input RGB

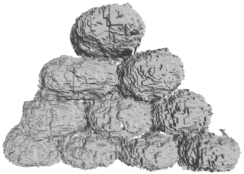


Estimated depth



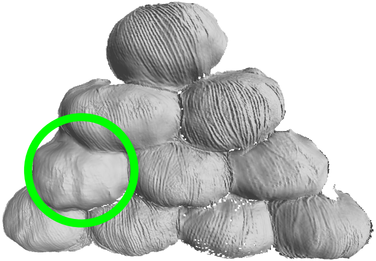
Estimated albedo

Qualitative Evaluation



Input depth

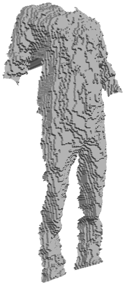
Input RGB



Estimated depth

Estimated Albedo

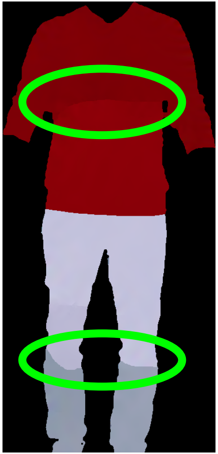
Qualitative Evaluation



Input depth

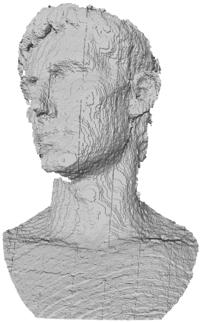
Input RGB

Estimated depth



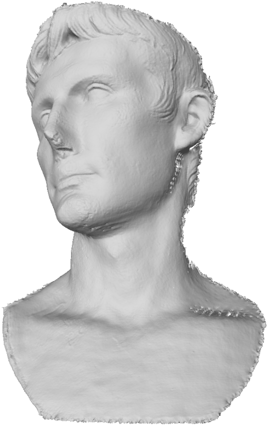
Estimated Albedo

Comparison with multi-view approaches

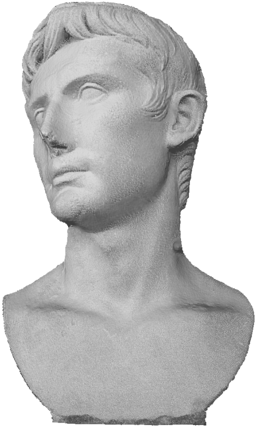


Input depth

Input RGB



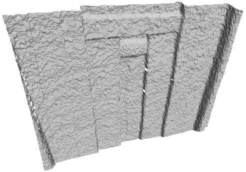
[Zollhöfer et al.; ToG 2015]



Ours

Comparison with multi-view approaches


Input RGB


Input depth


[Maier et al.; ICCV 2017]


Ours

See you at our poster C19 on Tuesday 10:10a.m.-12:30p.m.

Code will be available online