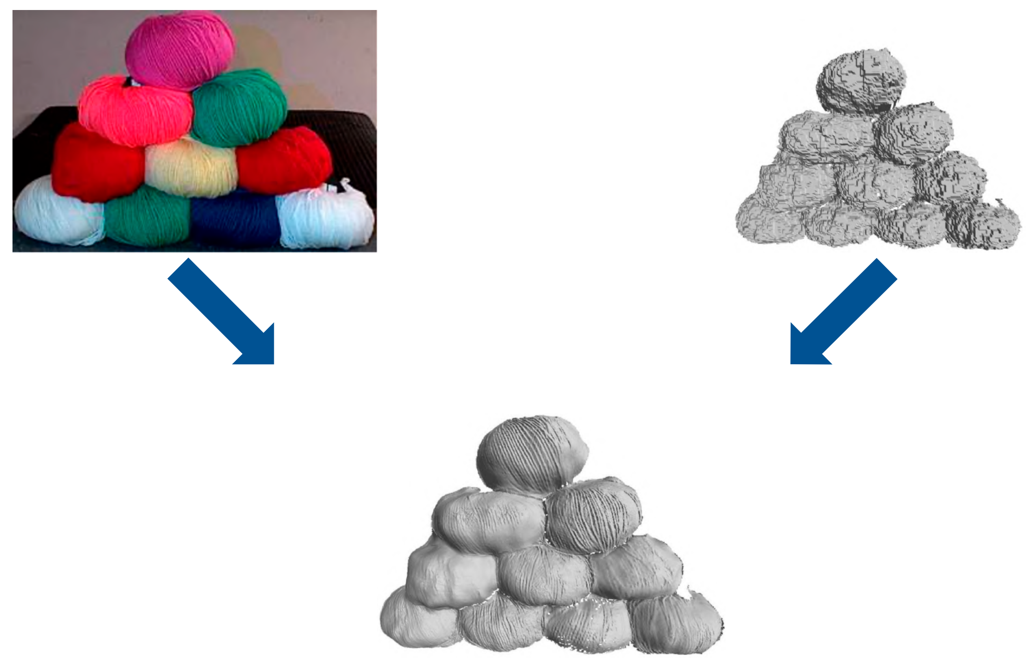
Fight Ill-Posedness with Ill-Posedness: Single-Shot Variational Depth Super-Resolution from Shading

Bjoern Haefner, Yvain Quéau, Thomas Möllenhoff, and Daniel Cremers, 2018 IEEE/CVF
Conference on Computer Vision and Pattern Recognition

Presentation by Paul Rötzer

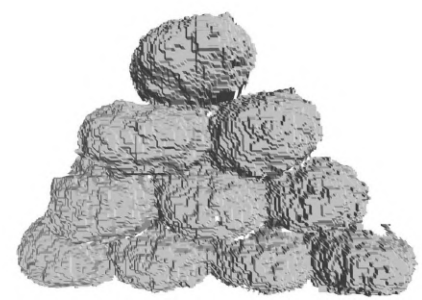
06. Oktober 2020



What are we trying to do?

One High Resolution Image

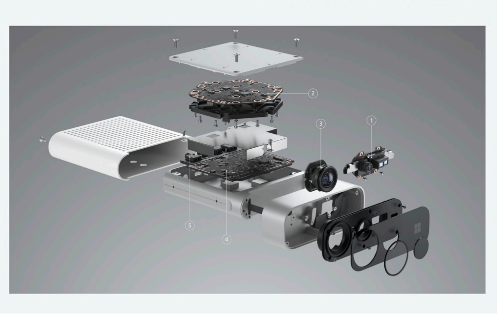
One Low Resolution Depth Map



High Resolution Depth Map

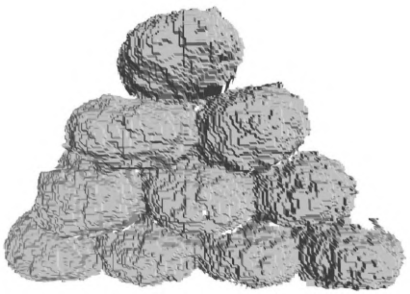
Why High Res Image and Low Res Depth Map?

RGB-D Sensors



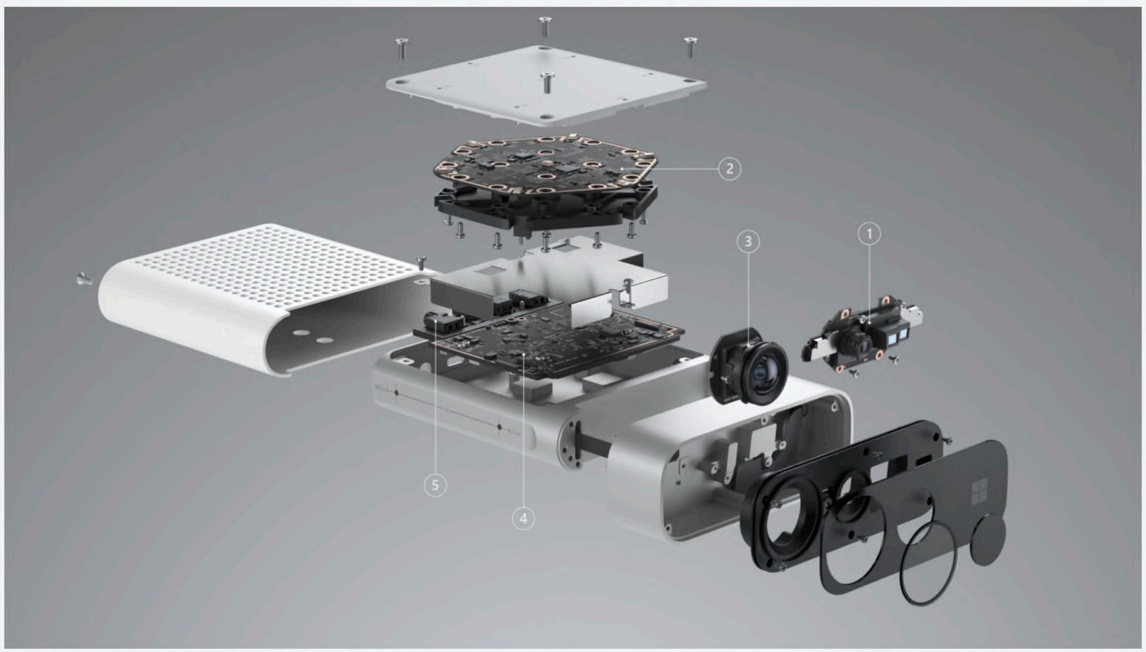
High Resolution Image

Low Resolution Depth Map



RGB-D Sensors

What's inside the Azure Kinect DK



1. 1-MP depth sensor with wide and narrow field-of-view (FOV) options that help you optimize for your application
2. 7-microphone array for far-field speech and sound capture
3. 12-MP RGB video camera for an additional color stream that's aligned to the depth stream
4. Accelerometer and gyroscope (IMU) for sensor orientation and spatial tracking
5. External sync pins to easily synchronize sensor streams from multiple Kinect devices

https://azure.microsoft.com/en-us/services/kinect-dk/#industries

RGB-D Sensors

- Low Cost
- Consumer Hardware (e.g. Xbox Kinect)
- Mobile
- Small
- Lightweight

Agenda

Related Work

Fundamentals

Analytical Derivation

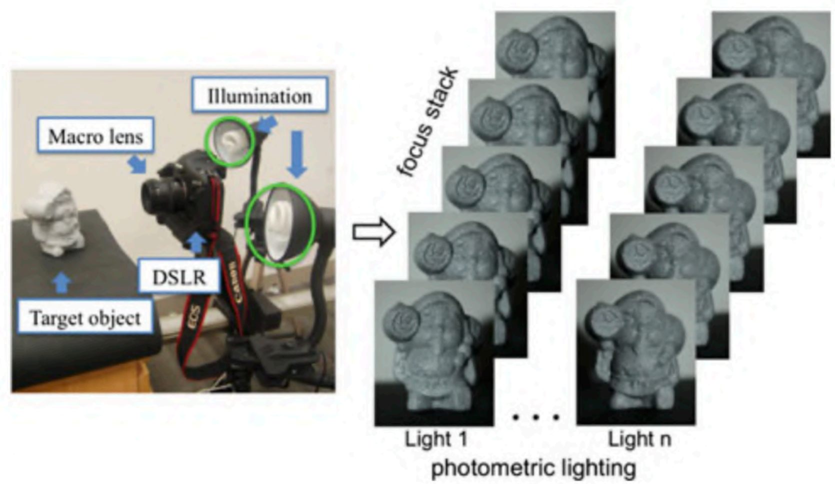
Numerical Solution

Numerical Examples

Conclusion

Related Work

Multiple Images



Multiple View Super-Resolution Depth Map

[Goldluecke, 2018]

Multiple Lighting Super-Resolution Depth Map

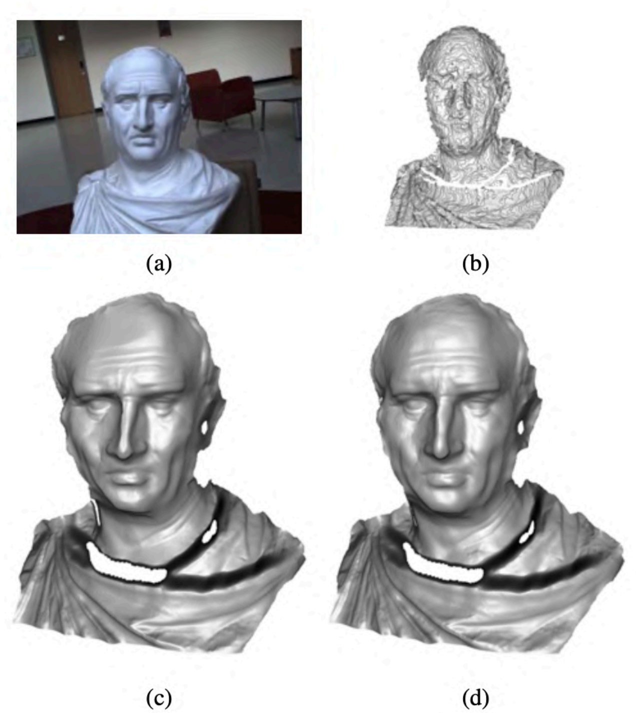
[Lu, 2013]

Single RGB-D Images

[Han, 2013]

- Input: single RGB-D image
- Constant albedo

  => Computation time: ~ 20 min



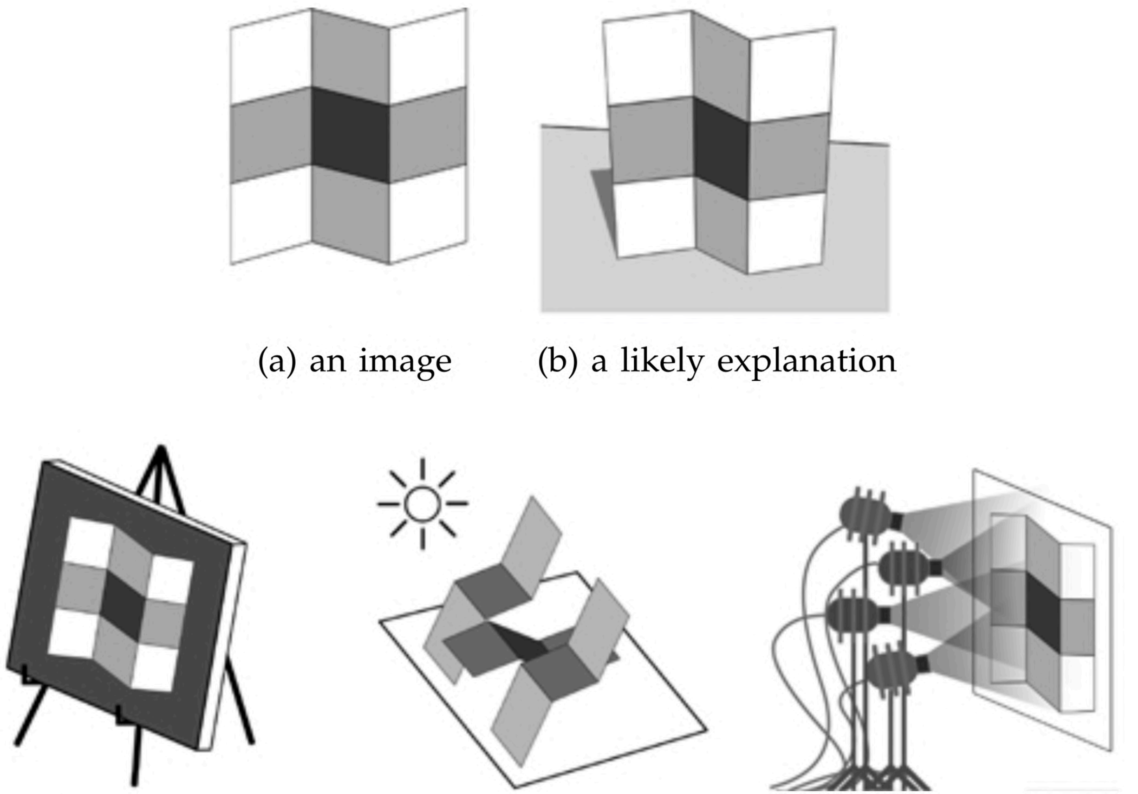
Single RGB-D Images

(a) Input image (b) Input depth (c) Our result

[Han, 2013]

Fundamentals: Ill-Posedness in 3D Reconstruction (Single-Shot)

How do physical objects look which produce an image?



(a) an image (b) a likely explanation

(c) painter's explanation (d) sculptor's explanation (e) gaffer's explanation

[Adelson, 1996]

How do physical objects look which produce an image?

- Ill-Posed Problem

- Humans address this problem with priors
  - Depends on the individual Background (e.g. Painter, Sculptor)

- RGB-D sensors
  - Provide an initial guess

- Different Approaches
  - Shape from Shading
  - Single Depth Super-Resolution

Ill-Posedness in **Shape from Shading**

Ill-Posedness in **Shape from Shading**

$$I = \mathcal{R}(z|l, \rho) + \eta_I$$

$$\begin{aligned} I &: Image \\ \mathcal{R}(z|l,\rho) &: Scene \\ z &: Depth\ Map \\ l &: Lighting \\ \rho &: Surface\ Reflectance \\ \eta_I &: Noise \end{aligned}$$

Ill-Posedness in **Shape from Shading**

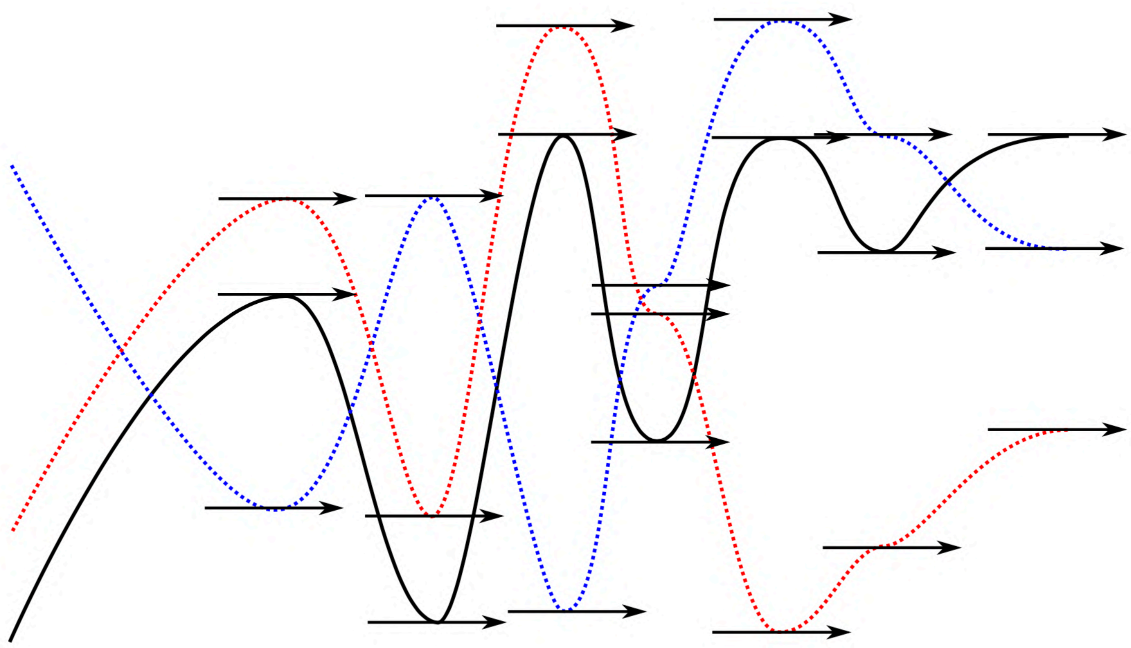
$$I = \mathcal{R}(z|l, \rho) + \eta_I$$

Solution provides only magnitude of depth gradient and not direction

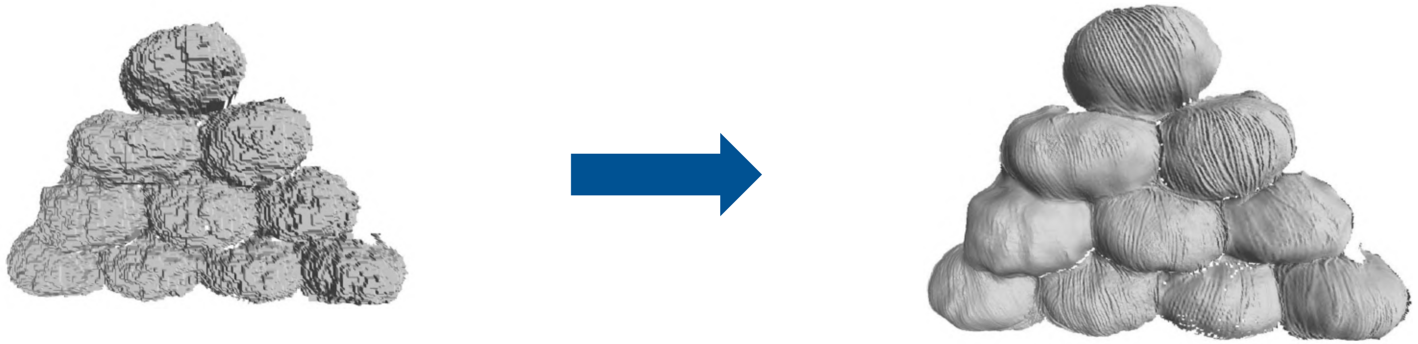
$$\begin{aligned} I &: Image \\ \mathcal{R}(z|l,\rho) &: Scene \\ z &: Depth\ Map \\ l &: Lighting \\ \rho &: Surface\ Reflectance \\ \eta_I &: Noise \end{aligned}$$

Ill-Posedness in **Shape from Shading**

Solution provides only magnitude of depth gradient and not direction



Ill-posedness in **Single Depth Image Super-Resolution**



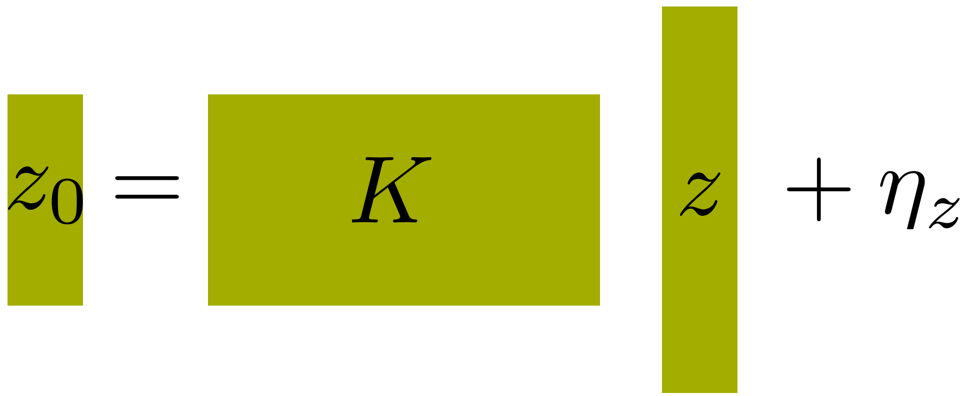
Ill-posedness in **Single Depth Image Super-Resolution**

$$z_0 = Kz + \eta_z$$

$z_0 : Depth\ Map\ (low\ res)$
$z : Depth\ Map\ (high\ res)$
$K : Warping,\ Blurring,\ Downsampling$
$\eta_z : Noise$

Ill-posedness in **Single Depth Image Super-Resolution**

$$z_0 = Kz + \eta_z$$



$z_0 : Depth\ Map\ (low\ res)$
$z : Depth\ Map\ (high\ res)$
$K : Warping,\ Blurring,\ Downsampling$
$\eta_z : Noise$

Ill-posedness in **Single Depth Image Super-Resolution**

$$z_0 = Kz + \eta_z$$

$$\cancel{K^{-1}}$$

K not square ➤ K not invertible

z_0 : *Depth Map (low res)*
z : *Depth Map (high res)*
K : *Warping, Blurring, Downsampling*
η_z : *Noise*

Fight Ill-Posedness with Ill-Posedness:
Derivation of the Variational Approach

Derivation of the Variational Approach

$$\max_{z,\rho,l} \mathcal{P}(z, \rho, l | z_0, I)$$

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

$$\mathcal{P}(z, \rho, l | z_0, I) = \frac{\mathcal{P}(z_0, I | z, \rho, l)\mathcal{P}(z, \rho, l)}{\mathcal{P}(z_0, I)}$$

$$\propto \underbrace{\mathcal{P}(z_0, I | z, \rho, l)}_{\text{likelihood}} \underbrace{\mathcal{P}(z, \rho, l)}_{\text{prior}}$$

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

$$\max_{z,\rho,l} \mathcal{P}(z,\rho,l|z_0,I) = -\min_{z,\rho,l} \log\left(\mathcal{P}(z,\rho,l|z_0,I)\right)$$

$$\begin{aligned} z_0 &: Depth\ Map\ (low\ res) \\ I &: Image \\ z &: Depth\ Map\ (high\ res) \\ \rho &: Surface\ Reflectance \\ l &: Lighting \end{aligned}$$

Derivation of the Variational Approach

$$\mathcal{P}(z, \rho, l | z_0, I) = \frac{\mathcal{P}(z_0, I | z, \rho, l)\mathcal{P}(z, \rho, l)}{\mathcal{P}(z_0, I)}$$
$$\propto \mathcal{P}(z_0, I | z, \rho, l)\mathcal{P}(z, \rho, l)$$

$$\max_{z,\rho,l} \mathcal{P}(z, \rho, l | z_0, I) = -\min_{z,\rho,l} \log\left(\mathcal{P}(z, \rho, l | z_0, I)\right)$$

z_0 : *Depth Map (low res)*
I : *Image*
z : *Depth Map (high res)*
ρ : *Surface Reflectance*
l : *Lighting*

Derivation of the Variational Approach

$$\mathcal{P}(z,\rho,l|z_0,I) = \frac{\mathcal{P}(z_0,I|z,\rho,l)\mathcal{P}(z,\rho,l)}{\mathcal{P}(z_0,I)}$$
$$\propto \mathcal{P}(z_0,I|z,\rho,l)\mathcal{P}(z,\rho,l)$$

$$\max_{z,\rho,l} \mathcal{P}(z,\rho,l|z_0,I) = -\min_{z,\rho,l} \log\left(\mathcal{P}(z,\rho,l|z_0,I)\right)$$

$$\max_{z,\rho,l} \mathcal{P}(z,\rho,l|z_0,I) = -\min_{z,\rho,l} \log\left(\mathcal{P}(z_0,I|z,\rho,l)\right) + \log\left(\mathcal{P}(z,\rho,l)\right)$$

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

Assumptions

$$\begin{aligned} z_0 &: Depth\ Map\ (low\ res) \\ I &: Image \\ z &: Depth\ Map\ (high\ res) \\ \rho &: Surface\ Reflectance \\ l &: Lighting \end{aligned}$$

Derivation of the Variational Approach

Assumptions

- RBG-D Sensors: Image and Depth measurement are independent (by construction)

$$\mathcal{P}(z_0, I|z, \rho, l) = \mathcal{P}(z_0|z)\mathcal{P}(I|z, \rho, l)$$

  - ➢ Depth is independent from reflectance and lighting

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

Assumptions

- RBG-D Sensors: Image and Depth measurement are independent (by construction)

$$\mathcal{P}(z_0, I|z, \rho, l) = \mathcal{P}(z_0|z)\mathcal{P}(I|z, \rho, l)$$

  - ➢ Depth is independent from reflectance and lighting

- Independence of Depth, Reflectance and Lighting

$$\mathcal{P}(z, \rho, l) = \mathcal{P}(z)\mathcal{P}(\rho)\mathcal{P}(l)$$

  - ➢ Lambertian Surfaces
  - ➢ Distant-Light

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

Assumptions

$$\mathcal{P}(z_0, I|z, \rho, l) = \mathcal{P}(z_0|z)\mathcal{P}(I|z, \rho, l)$$

z_0 : *Depth Map (low res)*
I : *Image*
z : *Depth Map (high res)*
ρ : *Surface Reflectance*
l : *Lighting*

Derivation of the Variational Approach

Assumptions

$$\mathcal{P}(z_0, I|z, \rho, l) = \mathcal{P}(z_0|z)\mathcal{P}(I|z, \rho, l)$$

Homoskedastic, zero-mean Gaussian noise

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

Assumptions

$$\mathcal{P}(z_0, I|z, \rho, l) = \mathcal{P}(z_0|z)\mathcal{P}(I|z, \rho, l)$$

Homoskedastic, zero-mean Gaussian noise

Achromatic lighting, first-order spherical harmonics, homoskedastic, zero-mean Gaussian noise

$$\begin{aligned} z_0 &: Depth\ Map\ (low\ res) \\ I &: Image \\ z &: Depth\ Map\ (high\ res) \\ \rho &: Surface\ Reflectance \\ l &: Lighting \end{aligned}$$

Derivation of the Variational Approach

Assumptions

$$\mathcal{P}(z, \rho, l) = \mathcal{P}(z)\mathcal{P}(\rho)\mathcal{P}(l)$$

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

Assumptions

$$\mathcal{P}(z, \rho, l) = \mathcal{P}(z)\mathcal{P}(\rho)\mathcal{P}(l)$$

Minimal surface

- Robustness

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

Assumptions

$$\mathcal{P}(z,\rho,l) = \mathcal{P}(z)\mathcal{P}(\rho)\mathcal{P}(l)$$

Minimal surface
- Robustness

Piecewise constant
- Reflactance must fit this prior

$z_0 : Depth\ Map\ (low\ res)$
$I : Image$
$z : Depth\ Map\ (high\ res)$
$\rho : Surface\ Reflectance$
$l : Lighting$

Derivation of the Variational Approach

Assumptions

$$\mathcal{P}(z, \rho, l) = \mathcal{P}(z)\mathcal{P}(\rho)\mathcal{P}(l)$$

Minimal surface
- Robustness

Piecewise constant
- Reflectance must fit this prior

constant

$$z_0 : Depth\ Map\ (low\ res)$$
$$I : Image$$
$$z : Depth\ Map\ (high\ res)$$
$$\rho : Surface\ Reflectance$$
$$l : Lighting$$

Derivation of the Variational Approach

$$\mathcal{P}(z_0, I|z, \rho, l) = \mathcal{P}(z_0|z)\mathcal{P}(I|z, \rho, l)$$

constant

$$\mathcal{P}(z, \rho, l) = \mathcal{P}(z)\mathcal{P}(\rho)\mathcal{P}(l)$$

$z_0 : Depth\ Map\ (low\ res)$

$I : Image$

$z : Depth\ Map\ (high\ res)$

$\rho : Surface\ Reflectance$

$l : Lighting$

Derivation of the Variational Approach

constant

$$\mathcal{P}(z_0, I|z, \rho, l) = \mathcal{P}(z_0|z)\mathcal{P}(I|z, \rho, l)$$

$$\mathcal{P}(z, \rho, l) = \mathcal{P}(z)\mathcal{P}(\rho)\mathcal{P}(l)$$

$$\max_{z,\rho,l} \mathcal{P}(z, \rho, l|z_0, I) =$$

$$-\min_{z,\rho,l} \log\left(\mathcal{P}(I|z, \rho, l)\right) + \log\left(\mathcal{P}(z_0|z)\right) + \log\left(\mathcal{P}(z)\right) + \log\left(\mathcal{P}(\rho)\right)$$

z_0 : *Depth Map (low res)*
I : *Image*
z : *Depth Map (high res)*
ρ : *Surface Reflectance*
l : *Lighting*

Derivation of the Variational Approach

$$\mathcal{P}(z_0, I | z, \rho, l) = \overbrace{\mathcal{P}(z_0|z)}^{\text{single depth super-resolution}} \qquad \underbrace{\mathcal{P}(I|z,\rho,l)}_{\text{shape from shading}}$$

z_0 : *Depth Map (low res)*
I : *Image*
z : *Depth Map (high res)*
ρ : *Surface Reflectance*
l : *Lighting*

Derivation of the Variational Approach

$$\mathcal{P}(z_0, I|z,\rho,l) = \overbrace{\mathcal{P}(z_0|z)}^{\text{single depth super-resolution}} \quad \underbrace{\mathcal{P}(I|z,\rho,l)}_{\text{shape from shading}}$$

$$\max_{z,\rho,l} \mathcal{P}(z,\rho,l|z_0,I) =$$

$$-\min_{z,\rho,l} \underbrace{\log\left(\mathcal{P}(I|z,\rho,l)\right)}_{\text{shape from shading}} + \overbrace{\log\left(\mathcal{P}(z_0|z)\right)}^{\text{single depth super-resolution}} + \log\left(\mathcal{P}(z)\right) + \log\left(\mathcal{P}(\rho)\right)$$

z_0 : *Depth Map (low res)*
I : *Image*
z : *Depth Map (high res)*
ρ : *Surface Reflectance*
l : *Lighting*

Fighting Ill-Posedness with Ill-Posedness: **Numerical Solution** of the Variational Approach

Numerical Solution of the Variational Approach

Alternating Direction Method of Multipliers (ADMM)

[Boyd, 2010]

Numerical Solution of the Variational Approach

Alternating Direction Method of Multipliers (ADMM)

Problem
$$\min f(x) + g(z)$$
$$\text{s.t. } x = z$$

[Boyd, 2010]

Numerical Solution of the Variational Approach

Alternating Direction Method of Multipliers (ADMM)

Problem
$$\min f(x) + g(z)$$
$$\text{s.t. } x = z$$

Lagrangian
$$\mathcal{L}_\rho(x, z, y) = f(x) + g(x) + u^{\mathrm{T}}\big(Ax - z\big) + \frac{\rho}{2}\|Ax - z\|_2^2$$

[Boyd, 2010]

Numerical Solution of the Variational Approach

Alternating Direction Method of Multipliers (ADMM)

Problem
$$\min f(x) + g(z)$$
$$\text{s.t. } x = z$$

Lagrangian
$$\mathcal{L}_\rho(x, z, y) = f(x) + g(x) + u^{\mathrm{T}}\big(Ax - z\big) + \frac{\rho}{2}\|Ax - z\|_2^2$$

Iterations
$$x^{k+1} := \underset{x}{\operatorname{argmin}}\, \mathcal{L}_\rho(x, z^k, y^k)$$
$$z^{k+1} := \underset{z}{\operatorname{argmin}}\, \mathcal{L}_\rho(x^{k+1}, z, y^k)$$
$$u^{k+1} := u^k + x^{k+1} - z^{k+1}$$

[Boyd, 2010]

Numerical Solution of the Variational Approach

$$\max_{z,\rho,l} \mathcal{P}(z, \rho, l | z_0, I) =$$

$$- \min_{z,\rho,l} \log\left(\mathcal{P}(I | z, \rho, l)\right) + \log\left(\mathcal{P}(z_0 | z)\right) + \log\left(\mathcal{P}(z)\right) + \log\left(\mathcal{P}(\rho)\right)$$

$z_0 : Depth\ Map\ (low\ res)$

$I : Image$

$z : Depth\ Map\ (high\ res)$

$\rho : Surface\ Reflectance$

$l : Lighting$

Numerical Solution of the Variational Approach

$$\max_{z,\rho,l} \mathcal{P}(z,\rho,l|z_0,I) =$$

$$-\min_{z,\rho,l} \underbrace{\log\big(\mathcal{P}(I|z,\rho,l)\big)}_{:=-f(z,\nabla z,\rho,l)} + \underbrace{\log\big(\mathcal{P}(z_0|z)\big)}_{:=-\mu g(z)} + \underbrace{\log\big(\mathcal{P}(z)\big)}_{:=-\nu h(z,\nabla z)} + \underbrace{\log\big(\mathcal{P}(\rho)\big)}_{:=-\lambda p(\rho)}$$

z_0 : *Depth Map (low res)*
I : *Image*
z : *Depth Map (high res)*
∇z : *Gradient of Depth Map*
ρ : *Surface Reflectance*
l : *Lighting*
μ, ν, λ : *Weights*

Numerical Solution of the Variational Approach

$$\max_{z,\rho,l} \mathcal{P}(z,\rho,l|z_0,I) =$$

$$\min_{z,\rho,l} f\left(z,\nabla z,\rho,l\right) + \mu g\left(z\right) + \nu h\left(z,\nabla z\right) + \lambda p\left(\rho\right)$$

$z:$ *Depth Map (high res)*
$\nabla z:$ *Gradient of Depth Map*
$\rho:$ *Surface Reflectance*
$l:$ *Lighting*
$\mu,\nu,\lambda:$ *Weights*

Numerical Solution of the Variational Approach

$$\max_{z,\rho,l} \mathcal{P}(z,\rho,l|z_0,I) =$$

$$\min_{z,\rho,l} f\left(z,\nabla z,\rho,l\right) + \mu g\left(z\right) + \nu h\left(z,\nabla z\right) + \lambda p\left(\rho\right)$$

Introducing

$$\theta := \left(z,\nabla z\right)$$

$$\begin{aligned} z &: Depth\ Map\ (high\ res) \\ \nabla z &: Gradient\ of\ Depth\ Map \\ \rho &: Surface\ Reflectance \\ l &: Lighting \\ \mu,\nu,\lambda &: Weights \end{aligned}$$

Numerical Solution of the Variational Approach

$$\max_{z,\rho,l} \mathcal{P}(z, \rho, l | z_0, I) =$$

$$\min_{z,\rho,l} f(z, \nabla z, \rho, l) + \mu g(z) + \nu h(z, \nabla z) + \lambda p(\rho)$$

Introducing

$$\theta := (z, \nabla z)$$

To obtain

$$\min_{z,\rho,l,\theta} f(\theta, \rho, l) + \mu g(z) + \nu h(\theta) + \lambda p(\rho)$$

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

z : *Depth Map (high res)*
∇z : *Gradient of Depth Map*
ρ : *Surface Reflectance*
l : *Lighting*
μ, ν, λ : *Weights*

Numerical Solution of the Variational Approach

$$\min_{z,\rho,l,\theta} f(\theta, \rho, l) + \mu g(z) + \nu h(\theta) + \lambda p(\rho)$$

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

$$\begin{aligned} z &: Depth\ Map\ (high\ res) \\ \nabla z &: Gradient\ of\ Depth\ Map \\ \rho &: Surface\ Reflectance \\ l &: Lighting \\ \mu, \nu, \lambda &: Weights \\ u &: Langrange\ Multiplier \\ \kappa &: Step\ Size \end{aligned}$$

Numerical Solution of the Variational Approach

$$\min_{z,\rho,l,\theta} f(\theta,\rho,l) + \mu g(z) + \nu h(\theta) + \lambda p(\rho)$$
$$\text{s.t. } \theta = (z, \nabla z)$$

$$\mathcal{L}_\kappa(z,\rho,l,\theta,u) = f(\theta,\rho,l) + \mu g(z) + \nu h(\theta) + \lambda p(\rho) + u^{\mathrm{T}}\big(\theta - (z,\nabla z)\big) + \frac{\kappa}{2}\|\theta - (z,\nabla z)\|_2^2$$

z : *Depth Map (high res)*
∇z : *Gradient of Depth Map*
ρ : *Surface Reflectance*
l : *Lighting*
μ, ν, λ : *Weights*
u : *Langrange Multiplier*
κ : *Step Size*

Numerical Solution of the Variational Approach

$$\mathcal{L}_\kappa(z,\rho,l,\theta,u) = f\big(\theta,\rho,l\big) + \mu g\big(z\big) + \nu h\big(\theta\big) + \lambda p\big(\rho\big)$$
$$+ u^{\mathrm{T}}\big(\theta - (z,\nabla z)\big) + \frac{\kappa}{2}\|\theta - (z,\nabla z)\|_2^2$$

$$\rho^{(k+1)} = \operatorname*{argmin}_{\rho} f\big(\theta^{(k)},\rho,l^{(k)}\big) + \lambda p\big(\rho\big)$$
$$l^{(k+1)} = \operatorname*{argmin}_{l} f\big(\theta^{(k)},\rho^{(k+1)},l\big)$$
$$\theta^{(k+1)} = \operatorname*{argmin}_{\theta} f\big(\theta,\rho^{(k+1)},l^{(k+1)}\big) + \nu h\big(\theta\big) + \frac{\kappa}{2}\|\theta - (z^{(k)},\nabla z^{(k)}) + u^{(k)}\|_2^2$$
$$z^{(k+1)} = \operatorname*{argmin}_{z} \mu g\big(z\big) + \frac{\kappa}{2}\|\theta^{(k+1)} - (z,\nabla z) + u^{(k)}\|_2^2$$
$$u^{(k+1)} = u^{(k)} + \theta^{(k+1)} - \big(z^{(k+1)},\nabla z^{(k+1)}\big)$$

z : *Depth Map (high res)*
∇z : *Gradient of Depth Map*
ρ : *Surface Reflectance*
l : *Lighting*
μ,ν,λ : *Weights*
u : *Langrange Multiplier*
κ : *Step Size*

Numerical Solution of the Variational Approach

$$\min_{z,\rho,l,\theta} f(\theta,\rho,l) + \mu g(z) + \nu h(\theta) + \lambda p(\rho)$$

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

$$\rho^{(k+1)} = \underset{\rho}{\operatorname{argmin}}\ f(\theta^{(k)}, \rho, l^{(k)}) + \lambda p(\rho)$$

$$l^{(k+1)} = \underset{l}{\operatorname{argmin}}\ f(\theta^{(k)}, \rho^{(k+1)}, l)$$

$$\theta^{(k+1)} = \underset{\theta}{\operatorname{argmin}}\ f(\theta, \rho^{(k+1)}, l^{(k+1)}) + \nu h(\theta) + \frac{\kappa}{2}\|\theta - (z^{(k)}, \nabla z^{(k)}) + u^{(k)}\|_2^2$$

$$z^{(k+1)} = \underset{z}{\operatorname{argmin}}\ \mu g(z) + \frac{\kappa}{2}\|\theta^{(k+1)} - (z, \nabla z) + u^{(k)}\|_2^2$$

$$u^{(k+1)} = u^{(k)} + \theta^{(k+1)} - (z^{(k+1)}, \nabla z^{(k+1)})$$

z : *Depth Map (high res)*
∇z : *Gradient of Depth Map*
ρ : *Surface Reflectance*
l : *Lighting*
μ, ν, λ : *Weights*
u : *Langrange Multiplier*
κ : *Step Size*

Convergence

$$\min_{z,\rho,l,\theta} f\big(\theta,\rho,l\big) + \mu g\big(z\big) + \nu h\big(\theta\big) + \lambda p\big(\rho\big)$$

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

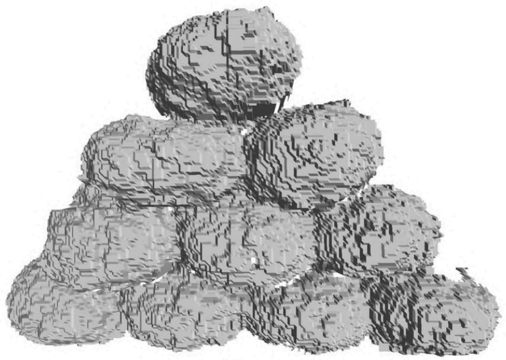
- Non-convex optimization problem
- No convergence can be imposed
- In “Fight Ill-Posedness with Ill-Posedness”:
  Always Convergence after 10-20 iterations
- Computation time: ~ 2 minutes

Numerical Examples

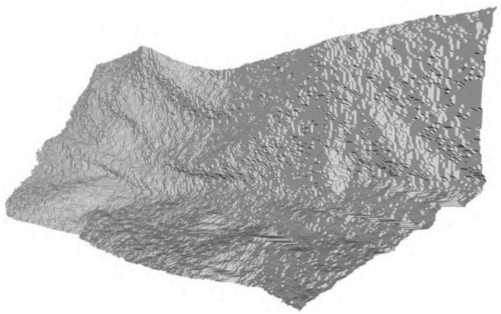
Real World Examples

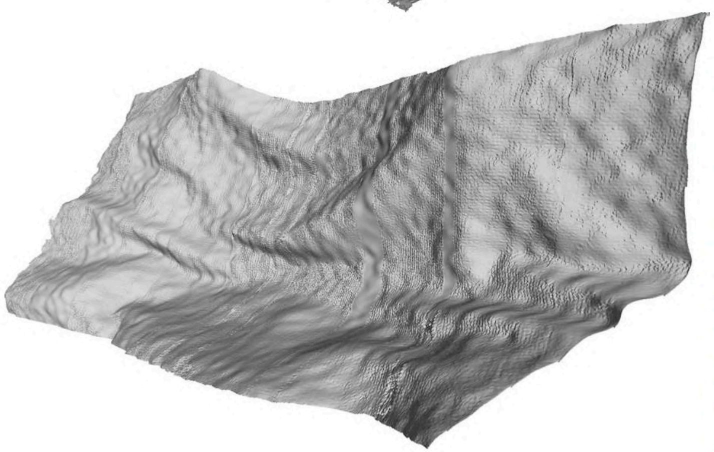
Real World Examples

Real World Examples: Saturated Colors

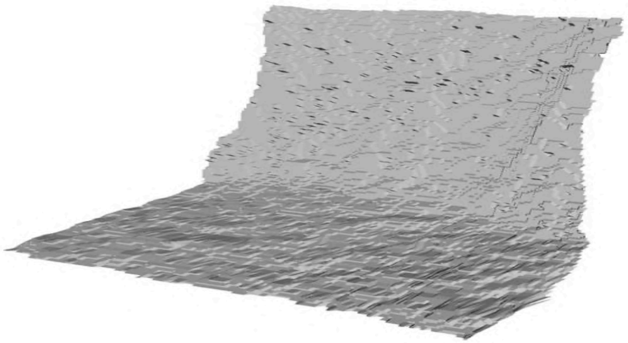


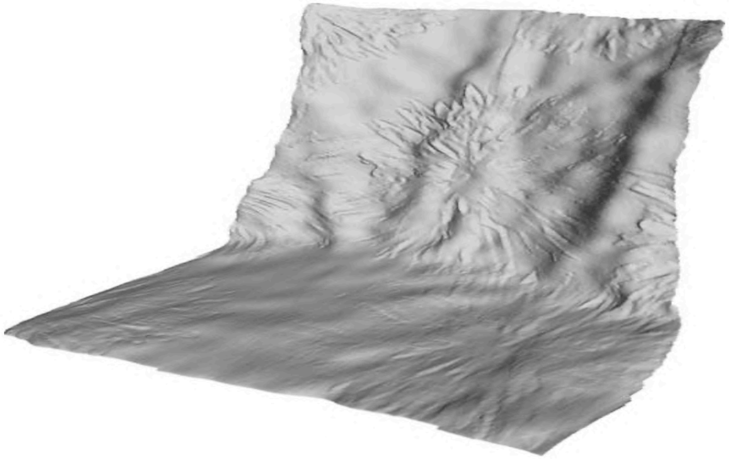
Real World Examples: Black Areas





Real World Examples:
Not Piecewise Constant Reflectance





Conclusion

Conclusion

- Ill-posedness in shape from shading and single depth map super-resolution
- Variational model to construct high resolution depth map from a single RGB-D image
- Corresponding numerical solution
- Numerical examples with this approach were discussed

- Relatively Fast Approach
- Requires little data (one image + one low resolution depth map)
- Extension: non-piecewise constant reflectance assumption
- Extension: Application to single-class problems (e.g. reconstructing faces)

Sources

Sources

- Bjoern Haefner, Yvain Queau, Thomas Mollenhoff, and Daniel Cremers. Fight Ill-Posedness with Ill-Posedness: Single-shot Variational Depth Super- Resolution from Shading. In 2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition, pages 164–174, Salt Lake City, UT, June 2018. IEEE.
- Stephen Boyd. Distributed Optimization and Statistical Learning via the Alternating Direction Method of Multipliers. Foundations and Trends® in Machine Learning, 3(1):1–122, 2010.
- Yudeog Han, Joon-Young Lee, and In So Kweon. High Quality Shape from a Single RGB-D Image under Uncalibrated Natural Illumination. In 2013 IEEE International Conference on Computer Vision, pages 1617–1624, Sydney, Aus- tralia, December 2013. IEEE
- Zheng Lu, Yu-Wing Tai, Fanbo Deng, Moshe Ben-Ezra, and Michael S. Brown. A 3D Imaging Framework Based on High-Resolution Photometric-Stereo and Low-Resolution Depth. International Journal of Computer Vision, 102(1-3):18– 32, March 2013.
- Bastian Goldlücke, Mathieu Aubry, Kalin Kolev, and Daniel Cremers. A Super- Resolution Framework for High-Accuracy Multiview Reconstruction. Interna- tional Journal of Computer Vision, 106(2):172–191, January 2014.
- https://azure.microsoft.com/en-us/services/kinect-dk/#industries

- E.H. Adelson and A.P. Pentland, “The Perception of Shading and Reflectance,” in *Perception as Bayesian Inference*, ed. David C. Knill and Whitman Richards, 1st ed. (Cambridge University Press, 1996), 409–24

Thanks for your Attention! ☺

Homoscedasticity

In statistics, a sequence (or a vector) of random variables is **homoscedastic** /ˌhoʊmoʊskəˈdæstɪk/ if all its random variables have the same finite variance. This is also known as **homogeneity of variance.**

https://en.wikipedia.org/wiki/Homoscedasticity

Azure Kinect Resolution Modes and Framerate

Color camera supported operating modes

Azure Kinect DK includes an OV12A10 12MP CMOS sensor rolling shutter sensor. The native operating modes are listed below:

RGB Camera Resolution (HxV)	Aspect Ratio	Format Options	Frame Rates (FPS)	Nominal FOV (HxV)(post-processed)
3840x2160	16:9	MJPEG	0, 5, 15, 30	90°x59°
2560x1440	16:9	MJPEG	0, 5, 15, 30	90°x59°
1920x1080	16:9	MJPEG	0, 5, 15, 30	90°x59°
1280x720	16:9	MJPEG/YUY2/NV12	0, 5, 15, 30	90°x59°
4096x3072	4:3	MJPEG	0, 5, 15	90°x74.3°
2048x1536	4:3	MJPEG	0, 5, 15, 30	90°x74.3°

https://docs.microsoft.com/de-de/azure/kinect-dk/hardware-specification