Texture and Shadow Insensitive Metric for Image-based Reconstruction

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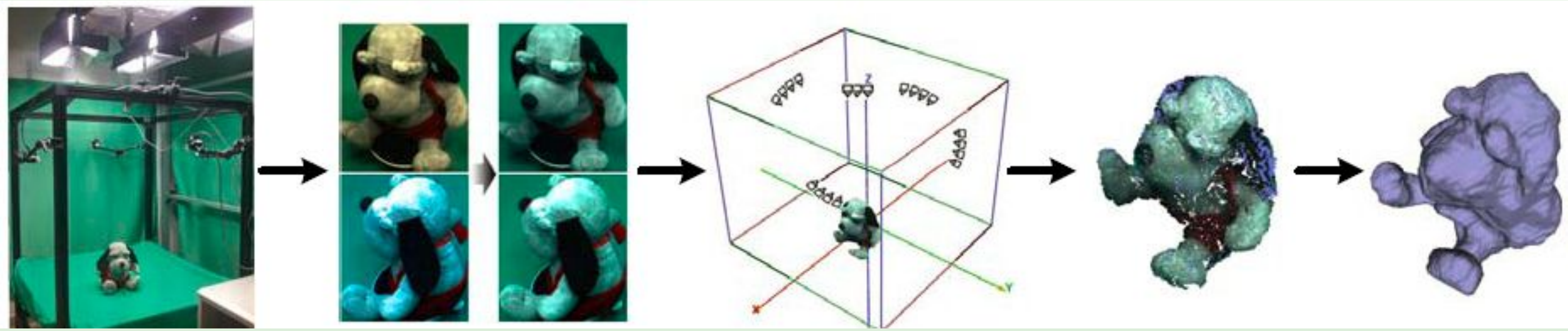
Outline

- Introduction
- Related Work
- Measuring 3D Reconstruction
- The Metric Computation
- Experimental Results
- Conclusion

Multi-View Stereo Reconstruction

- Key: Find the right feature points or patches with the same color distribution



Introduction

- Image-based 3D reconstruction has uncertainties.
- (Output) It's hard to evaluate the reconstruction results if we don't have the ground truth datasets
  - It's impractical for indoor/outdoor scene modeling
- (Input) It's hard to decide how many views are used together with their places
  - Not always true for more accurate reconstruction with more view images
  - Not all images contribute to the reconstruction result

Related Work

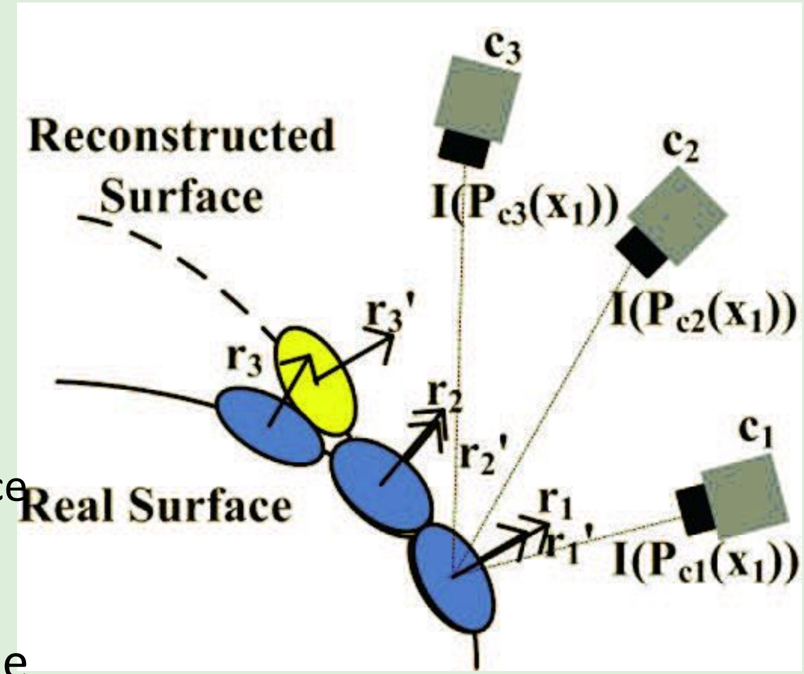
- MVS algorithm evaluation
  - [Seitz 2006 CVPR] [Strecha 2008 CVPR]
    - Compare with the ground truth from 3D scanner
- View planning
  - Next best view planning
    - [Wenhardt 2007 CVPR], [Dunn 2009 BMVC]
  - Image selection
    - [Hornung 2008 CVPR]
  - Key-frame extraction
    - [Ahmed 2010 VISAPP]
  - Internet image cluster
    - [Goesele 2007 ICCV], [Furukawa 2010 CVPR]

Related Work

- Instead of using traditional metrics, we propose a novel metric combined with shading to measure image-based reconstruction
  - Key idea
    - estimating irradiance using the rendering equation
  - Image formation model [Kajiya 1986 SIGGRAPH]
  - Spherical Harmonic coefficients for incident radiance [Ramamoorthi 2001 JOSA]
  - Precomputation Based Rendering[Sloan 2002 SIGGRAPH]

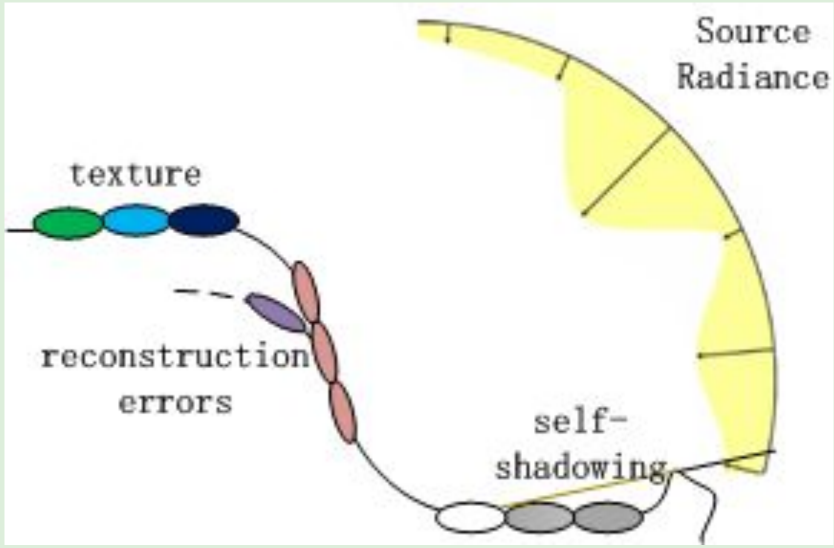
Measuring 3D Reconstruction

- Why the irradiance gradient can be the 3D reconstruction metric? [Zhao 2012 ICPR]
  - Assume the irradiance on the real surface changes continuously
  - The irradiance (i.e. light field on 3D model surface) corresponds to the reflected light intensity
    - Depend on the surface topology, reflectance properties, visibility and consistent color
  - If the estimated irradiance differs from the real irradiance, the differences between the two become significant
    - It means the irradiance gradient can indicate the regions where image-based 3D reconstruction error occurs



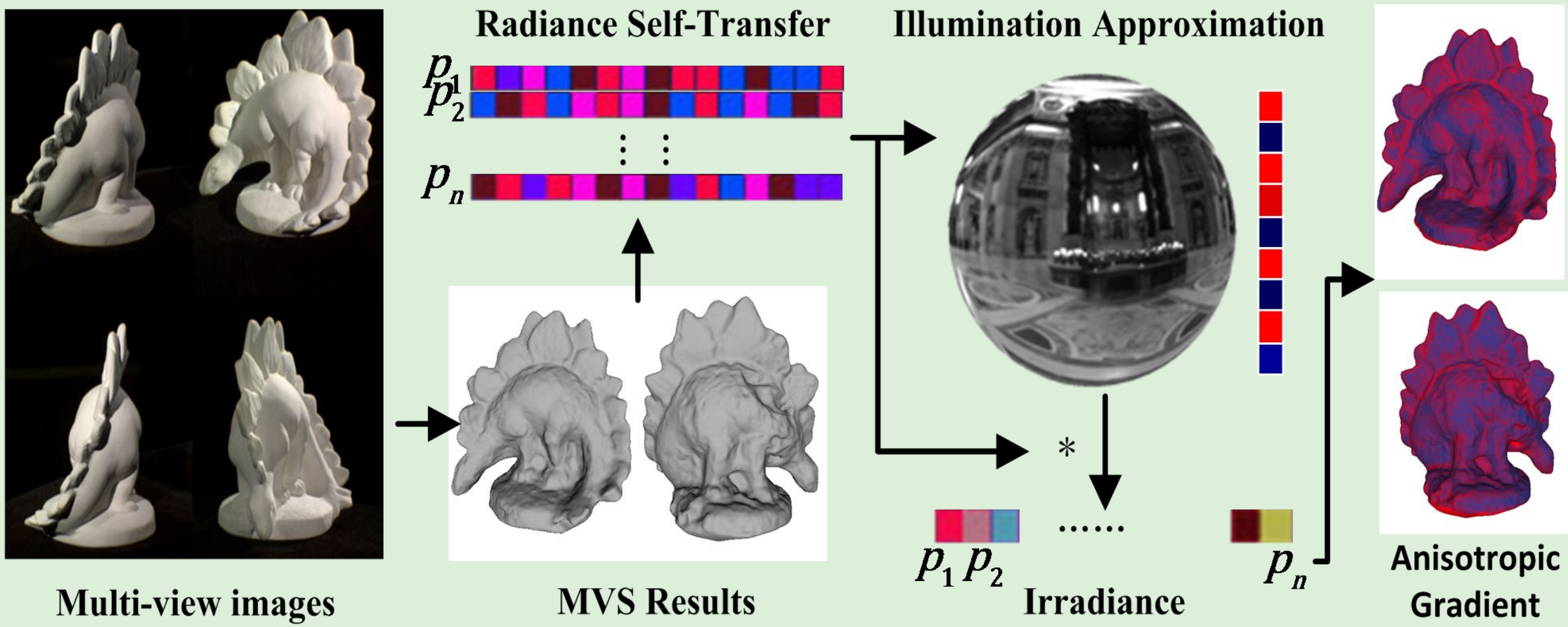
Measuring 3D Reconstruction

- Issues
  - Except the surface topology, the texture and shadow may also affect the continuity of irradiance changes
  - We estimate the reflectance of each vertex to gain an irradiance field compatible with the input images.
  - We combine triangulation-based approaches with shading techniques, and calculate the gradient of the difference between estimated and observed irradiance.



The Metric Computation

- Outline of the computation pipeline



how the model shadows and scatter lights onto itself

estimate the incident illumination

The Metric Computation: irradiance

- Assuming all objects in the scene are non-emitters, the image rendering equation can be defined as

$$B(x, \omega_o) = B_{DS}(x, \omega_o) + B_{DI}(x, \omega_o)\ ;$$

$$B_{DS}(x, \omega_o) = \int_\Omega \rho(x, \omega_i, \omega_o) L(x, \omega_i) V(x, \omega_i) H(x, \omega_i) d\omega_i;$$

$$B_{DI}(x, \omega_o) = \int_\Omega \rho(x, \omega_i, \omega_o)\, \bar{L}(x, \omega_i)\, (1 - V(x, \omega_i))\, H(x, \omega_i) d\omega_i$$

  - Irradiance: refection, inter-reflected light
  - For diffuse object under distant illumination

$$B(x) = (\rho(x) / \pi) \int_\Omega L(\omega_i) V(x, \omega_i) H(x, \omega_i) d\omega_i$$

$$+ (\rho(x) / \pi) \int_\Omega \bar{L}(x, \omega_i)\, (1 - V(x, \omega_i))\, H(x, \omega_i) d\omega_i$$

The Metric Computation

- Based on the mesh model from MVS, for each vertex
- Calculate the Radiance Self-Transfer
  - The object's response to its environment can be viewed as transfer function, mapping incoming to outgoing radiance.
  - In the SphereHarmonic domain, we have

$$B(x) = \sum_{k=1}^{n^2} M_k(x) L_k$$

  - Two pass calculation process:
    - Shadow transfer

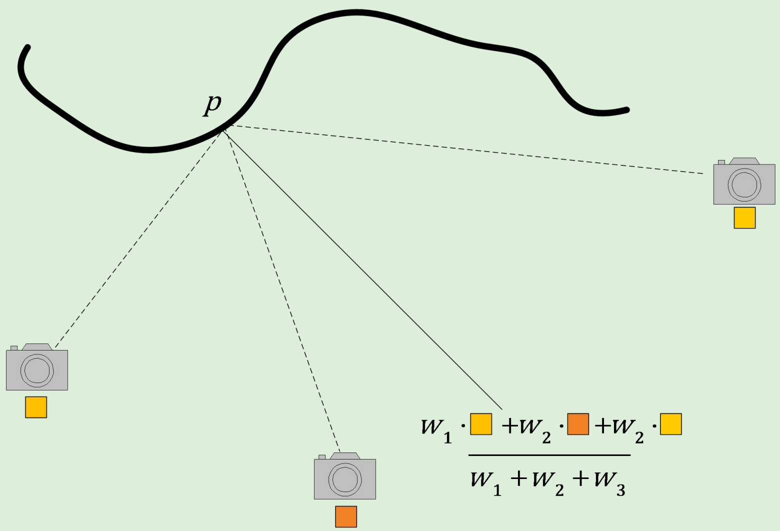
$$M(x) = V(x, \omega_i) H(x, \omega_i)$$

    - Inter-reflection transfer

$$\bar{M}(x) = (1 - V(x, \omega_i)) H(x, \omega_i)$$

The Metric Computation

- Reflectance Estimation
  - Given the radiance transfer coefficients, to estimate the incident illumination coefficients, we first need to approximate the albedos, $\rho(x)$, of the surface.



$$\rho(x_i) = \frac{\sum_{c \in Q(x_i)} w_c I_c(P_c(x_i))}{\sum_{c \in Q(x_i)} w_c}$$

$$w_c = \frac{vec(x_i, cam_c) \cdot \mathbf{n}(x_i)}{\|vec(x_i, cam_c)\| \cdot \|\mathbf{n}(x_i)\|}$$

The Metric Computation

- Lighting Estimation
  - Based on the transfer coefficients and albedo of each vertex, we estimate the lighting coefficients by minimizing

$$\hat{l} = \arg\min_{l} \sum_{i} \sum_{c \in Q(i)} \left| \sum_{k=1}^{n^2} l_k t_k - I(P_c(x_i)) \right|$$

  - We try to minimize the difference between estimated and observed irradiance with the help of Levenberg-Marquardt method.

The Metric Computation

- Anisotropic Gradient Field Calculation
  - Given the estimated irradiance which is compatible with the observed one, we focus on the different between the real and the approximated.

$$\bar{G}(x_i) = \sum_{x_j \in N(x_i)} \sum_{c \in Q(x_i, x_j)} d(x_i, x_j)^2$$

$$g(x_i, x_j) = d(x_i) - d(x_j)$$

$$d(x_i) = B(x_i) - I(P_c(x_i))$$

  - Anisotropic weight

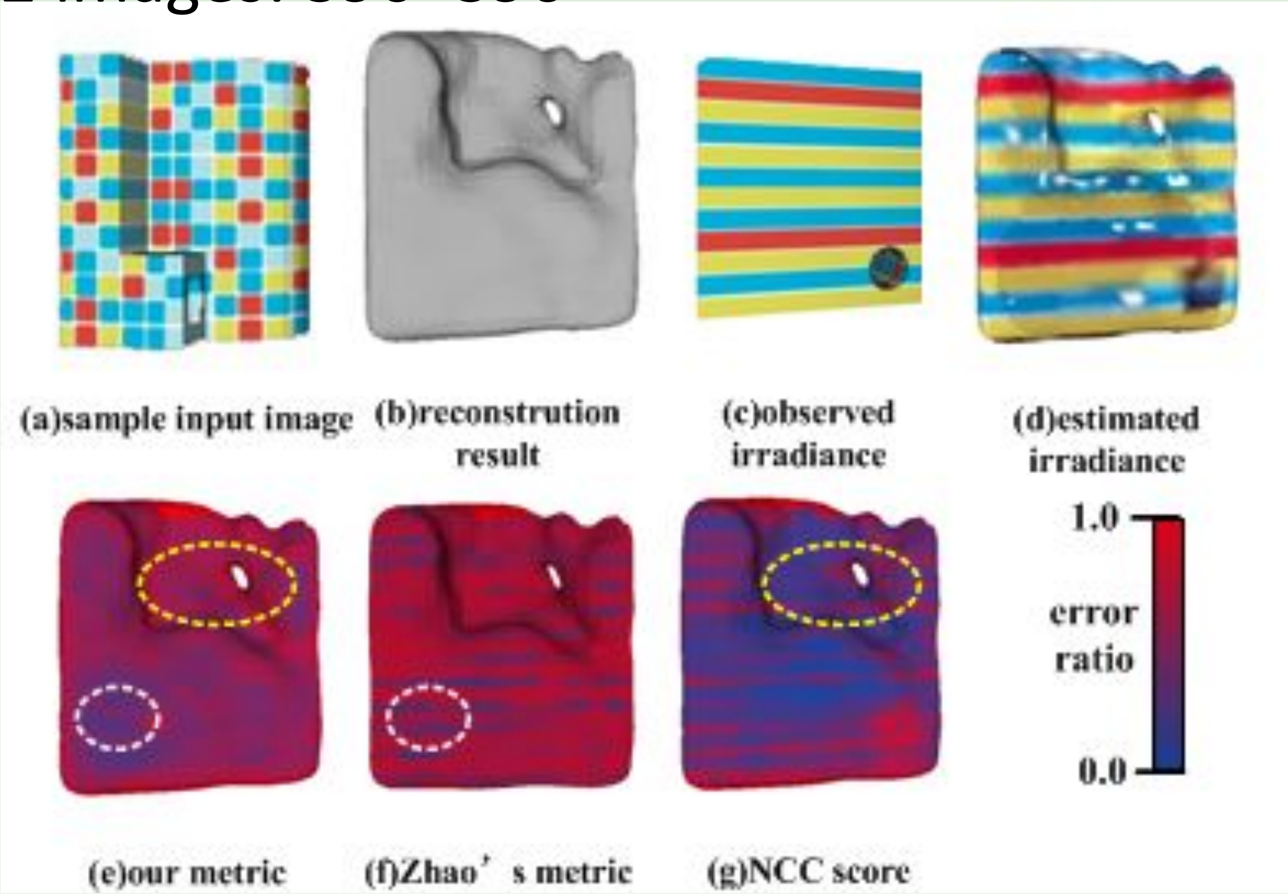
$$w(x_i, x_j) = radius / dis(x_i, x_j)$$

$$G(x_i) = \sum_{x_j \in N(x_i)} \sum_{c \in Q(x_i, x_j)} w(x_i, x_j) * g(x_i, x_j)^2$$

  - Find the gradient discontunuties

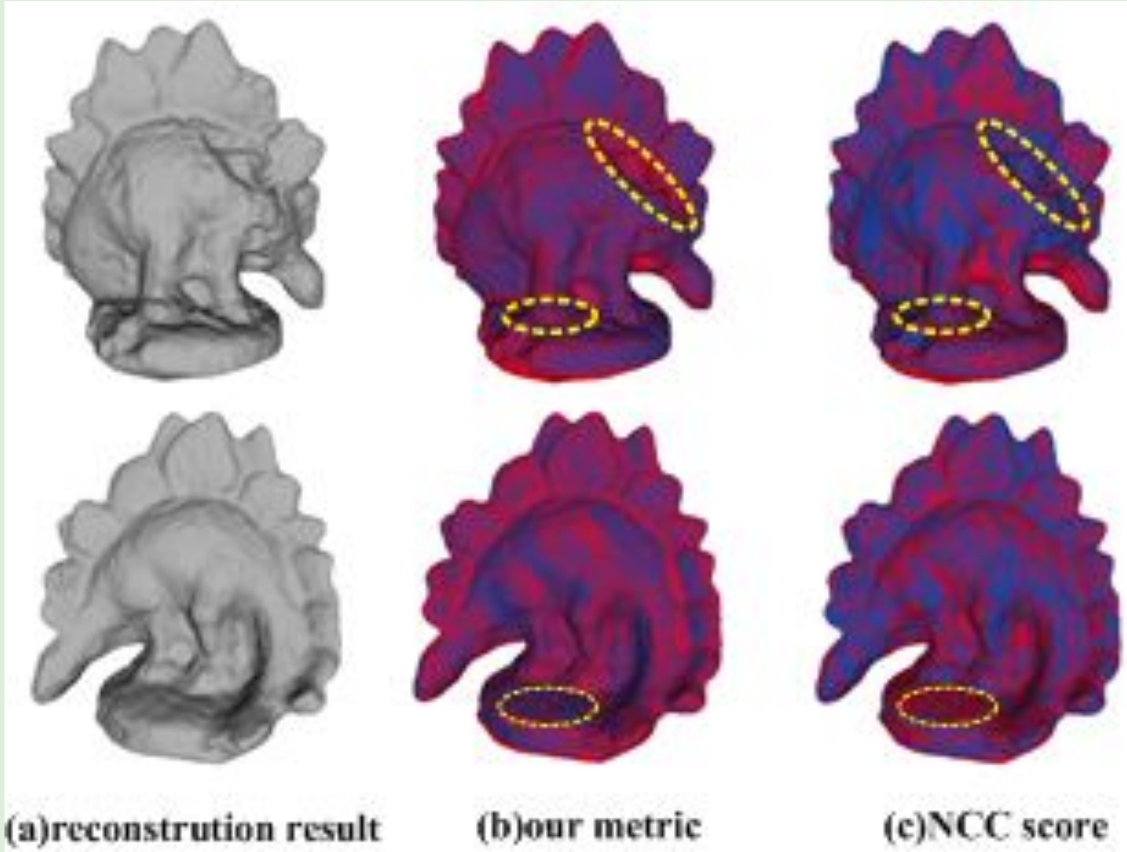
Experimental Results

- Results
  - Synthetic scene: a mechanical component
  - 12 images: 390*390



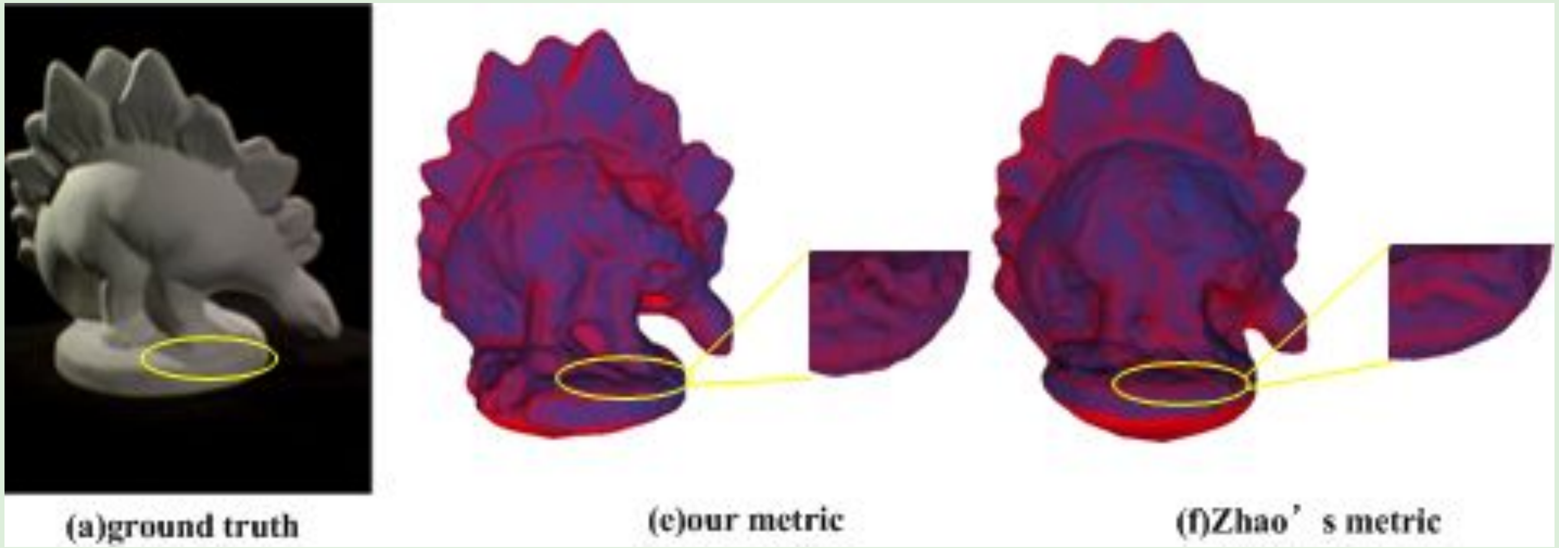
Experimental Results

- Results
  - indoor scene: the Middlebury dinosaur



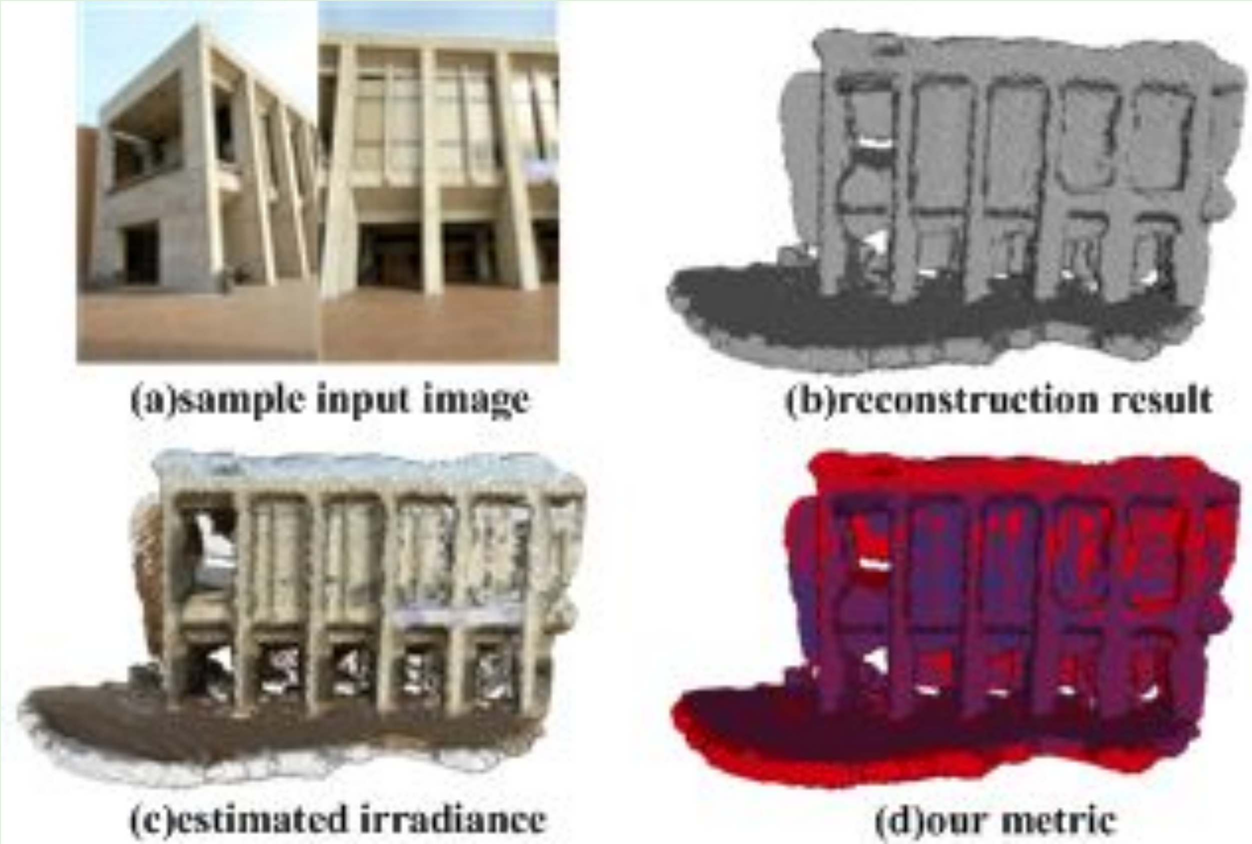
Experimental Results

- Results
  - indoor scene: the Middlebury dinosaur



Experimental Results

- Results
  - Outdoor scene: a hall



Conclusion

- We present a new metric based on the anisotropic irradiance gradient to measure the 3D reconstruction automatically
  - It has been successfully applied to view planning
- Main limitation
  - The metric only can be applied to diffuse objects

Thanks you for listening!

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