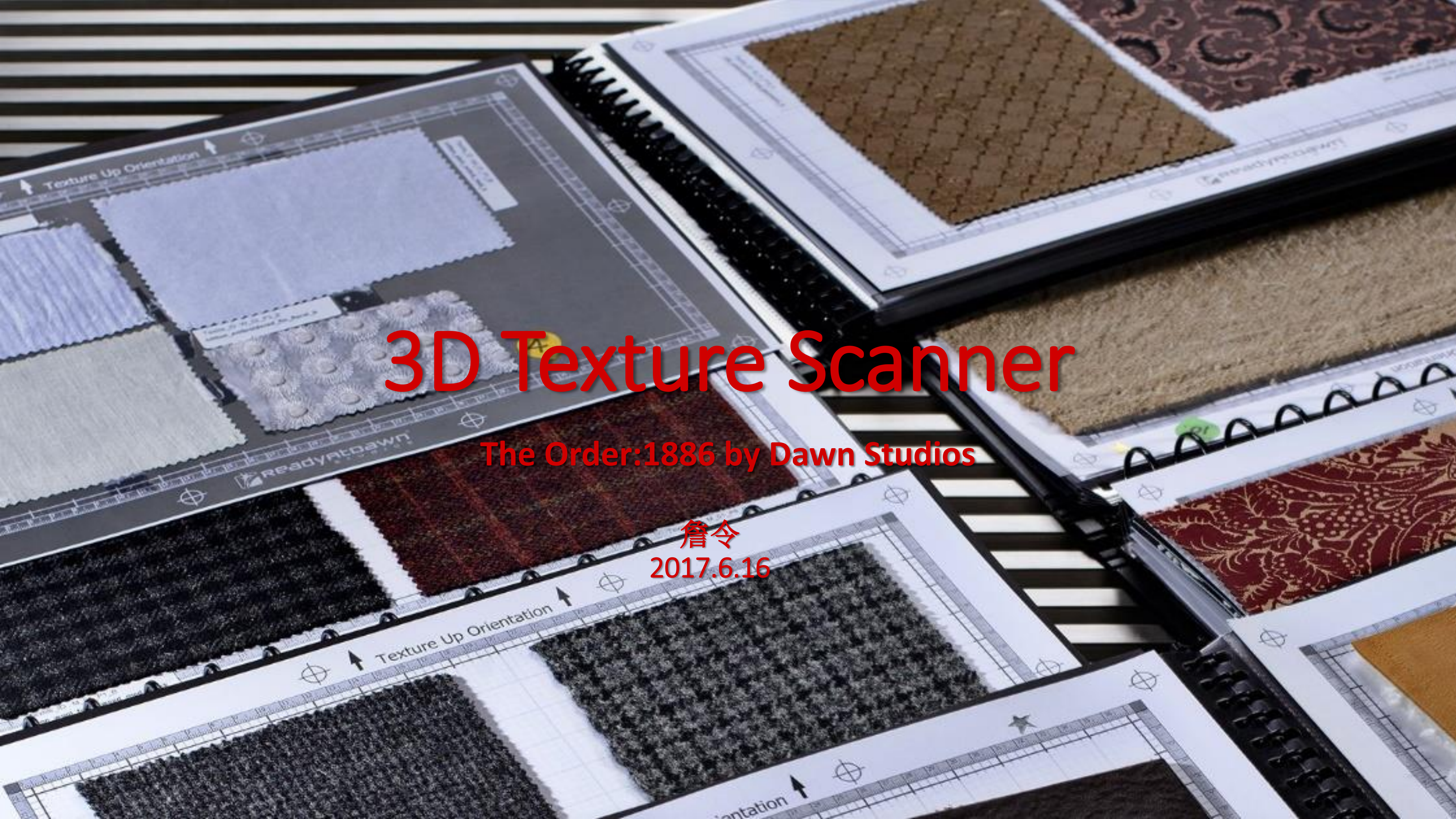
# 3D Texture Scanner

**The Order:1886 by Dawn Studios**

詹令

2017.6.16



# Background: Lambert Reflectance Model

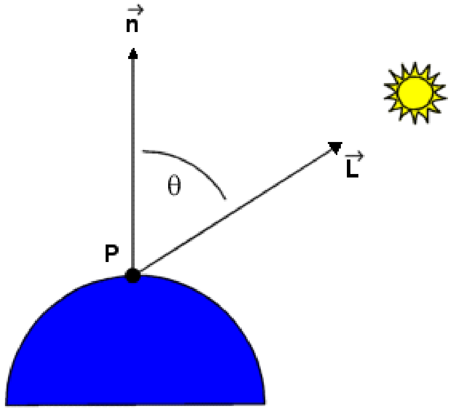
对于一个点光源

**Lambert reflectance model**

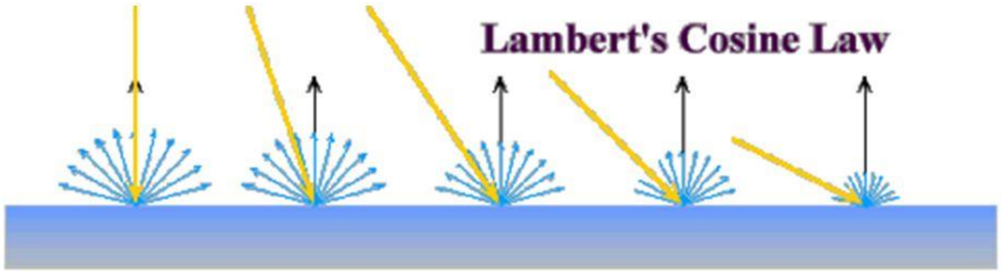
$$\boldsymbol{i k_d}(\boldsymbol{n} \cdot \boldsymbol{l}) = \boldsymbol{I}$$

$\boldsymbol{I}$: $pixel\ color\ (I_{red,}, I_{green,} I_{blue,})$
$\boldsymbol{l}$: light direction
$\boldsymbol{i}$: $light\ intensity\ (i_{red,}, i_{green,} i_{blue,})$
$\boldsymbol{k_d}$: $material\ albedo\ (k_{d_{red}}, k_{d_{green}}, k_{d_{blue}})$
$\boldsymbol{n}$: $normal$

本文假定布料是lambert的。。




Diffuse Reflection and Lambertian BRDF




Rendered Sphere with Lambertian BRDF

- Edges are dark (N.S = 0) when lit head-on
- See shading effects clearly.

## Hardware configuration

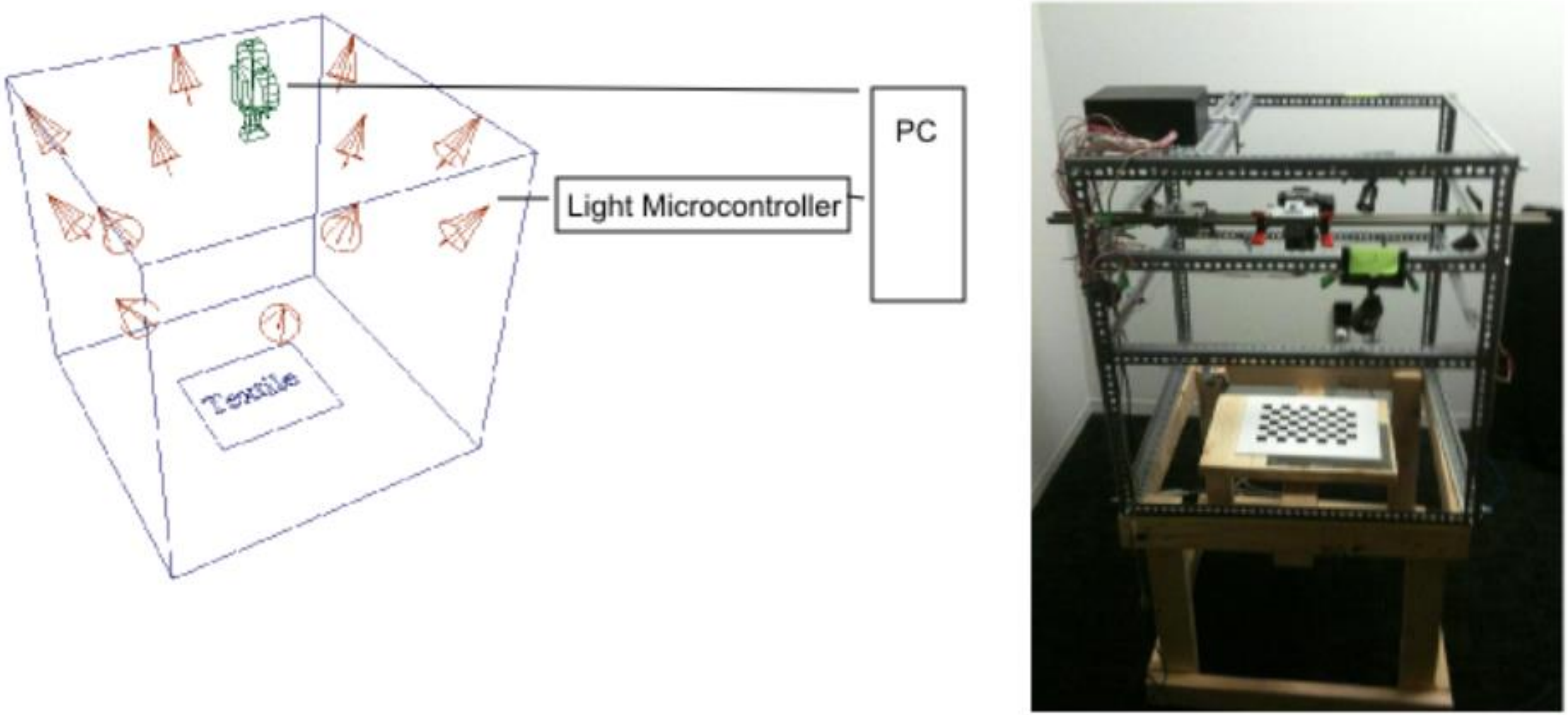



**Figure 8:** Hardware diagram and actual picture of the hardware

# Camera Calibration

- Camera's **position**, **orientation**, **lens distortion**.
  - OpenCV
  - a series of pictures of a checkboard pattern in different positions and orientations
- non-linear tone-mapping
  - Matte neutral gray values
- White Balance
  - Matte neutral gray values

# Light Calibration

1. 大致测量每个灯的中心到原点的位置
2. 利用相机标定得到的**相机矩阵**，可以求出照片的每个像素在真实世界中的位置。 这样可以大致得出每个像素的灯光方向 $\boldsymbol{l}$。
3. 计算每个点光源在每个像素上的light intensity $\boldsymbol{i}$ ：把Munsell Neutral Value Scale表放平在灯箱中：

$$\boldsymbol{i}k_d(\boldsymbol{n}\cdot\boldsymbol{l}) = \boldsymbol{I} \longrightarrow \boldsymbol{i} = \frac{\boldsymbol{I}}{l_y}$$

求Light intensity

$\boldsymbol{n} = (0,1,0)$

$\boldsymbol{I}$ *is photo pixel color*

$\boldsymbol{k_d} \approx \boldsymbol{1}$

$\boldsymbol{l}$ : *light direction is estimated from step* 2

灯光位置估计不准确
点光源衰减

?

照片中心精度高，照片边缘精度低

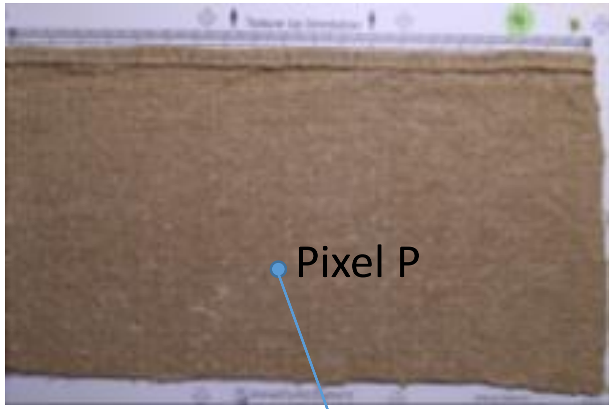
解决

4. 99% white diffuse sheet of paper ?

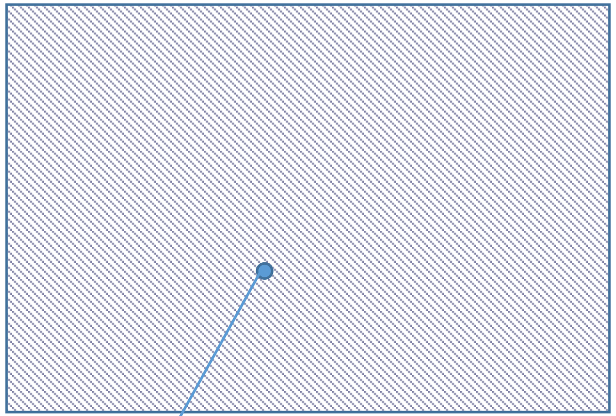
$$\boldsymbol{i} = \frac{\boldsymbol{I}}{l_y} \longrightarrow l_y = \frac{\boldsymbol{I}}{\boldsymbol{i}}$$

# 对于某一个点光源

某一个点光源下的布料照片




某一个点光源下的light intensity



Light calibration 得到每个光源的一张light intensity图

**Lambert reflectance model**

$$\boldsymbol{i}\boldsymbol{k_d}(\boldsymbol{n}\cdot\boldsymbol{l}) = \boldsymbol{I}$$

$\boldsymbol{I}$: *pixel color* $(I_{red,}, I_{green,} I_{blue,})$

$\boldsymbol{l}$: light direction

$\boldsymbol{i}$: *light intensity* $(i_{red,}, i_{green,} i_{blue,})$

已知

$\boldsymbol{k_d}$: *material albedo* $\left(k_{d_{red}}, k_{d_{green}}, k_{d_{blue}}\right)$

$\boldsymbol{n}$: *normal*

待求

# Normal and Albedo Solver (Photometric Stereo/光度立体法)

一个点光源

**Lambert reflectance model**

$$\boldsymbol{i}\boldsymbol{k_d}(\boldsymbol{n}\cdot\boldsymbol{l}) = \boldsymbol{I}$$

$\boldsymbol{l}$: light direction

$\boldsymbol{I}$: *pixel color* $(I_{red,}, I_{green,} I_{blue,})$

$\boldsymbol{i}$: *light intensity* $(i_{red,}, i_{green,} i_{blue,})$

$\boldsymbol{k_d}$: *material albedo* $\left(k_{d_{red}}, k_{d_{green}}, k_{d_{blue}}\right)$

$$let\ \boldsymbol{I}' = \frac{\boldsymbol{I}}{\boldsymbol{i}}$$

$$\boldsymbol{k_d}(\boldsymbol{n}\cdot\boldsymbol{l}) = \boldsymbol{I}'$$

$$\boxed{k_{d\_red}(\boldsymbol{n}\cdot\boldsymbol{l}) = I'_{red}}$$

$$k_{d\_green}(\boldsymbol{n}\cdot\boldsymbol{l}) = I'_{green}$$

$$k_{d\_blue}(\boldsymbol{n}\cdot\boldsymbol{l}) = I'_{blue}$$

$$let\ \boldsymbol{N_{red}} = k_{d\_red}\,\boldsymbol{n}$$

$$\boldsymbol{N_{red}}\cdot\boldsymbol{l} = I'_{red}$$

已知

求 $k_{d\_green}$

$k_{d\_blue}$

$$N_{red\_x} * l_x + N_{red\_y} * l_y + N_{red\_z} * l_z = I'_{red}$$

3个点光源就可以？

10个点光源

$$N_{red\_x} * l_{x0} + N_{red\_y} * l_{y0} + N_{red\_z} * l_{z0} = I'_{red0}$$

…

$$N_{red\_x} * l_{x9} + N_{red\_y} * l_{y9} + N_{red\_z} * l_{z9} = I'_{red9}$$

$$\begin{bmatrix} l_{x0} & l_{y0} & l_{z0} \\ \vdots & \vdots & \vdots \\ l_{x9} & l_{y9} & l_{z9} \end{bmatrix}_{10\times3} \begin{bmatrix} N_{red\_x} \\ N_{red\_y} \\ N_{red\_z} \end{bmatrix}_{3\times1} = \begin{bmatrix} I'_{red0} \\ \vdots \\ I'_{red9} \end{bmatrix}_{10\times1}$$

$$\boldsymbol{L}\boldsymbol{N_{red}} = \boldsymbol{I_{red}}$$

$$\boldsymbol{L}^T\boldsymbol{L}\boldsymbol{N_{red}} = \boldsymbol{L}^T\boldsymbol{I_{red}}$$

$$\boldsymbol{N_{red}} = (\boldsymbol{L}^T\boldsymbol{L})^{-1}\boldsymbol{L}^T\boldsymbol{I_{red}}$$

$$\because \|\boldsymbol{n}\| = \boldsymbol{1}$$

$$\therefore\ \boldsymbol{n} = \frac{\boldsymbol{N_{red}}}{\|\boldsymbol{N_{red}}\|} \qquad k_{d\_red} = \|\boldsymbol{N_{red}}\|$$

**Figure 11:** Textile lit from the 10 different lighting directions that is used for solving the normal and albedo. The last two images in the sequence, in the red box, are the solved albedo and normal map. Notice all the detail is captured in the normal map and the albedo is void of any lighting cues.

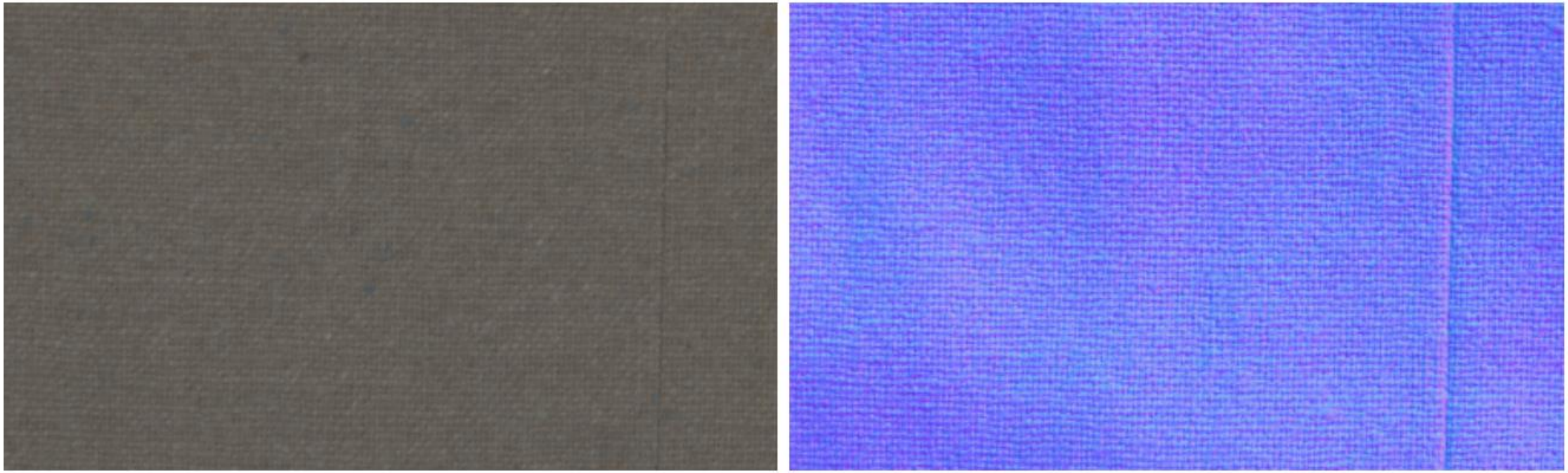


**Figure 7:** Zoomed in pictures of a scanned fabric sample (albedo and normal). Almost all the lighting information is removed from the albedo map. The normal map retains both the high-freqeuncy micro detail of the fabric and the larger wavey details from folds in the fabric.

# Limitations

- Big problems
  - Doesn’t work for shiny things, semi-translucent things
  - Shadows, inter-reflections

- Smaller problems
  - Calibration requirements
    - measure light source directions, intensities
    - camera response function

# Reference


- Crafting a Next-Gen Material Pipeline for The Order: 1886 [LINK]
- Photometric Stereo - Lecture Slide [LINK]

谢谢