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Light Source Separation and Intrinsic Image Decomposition under AC Illumination

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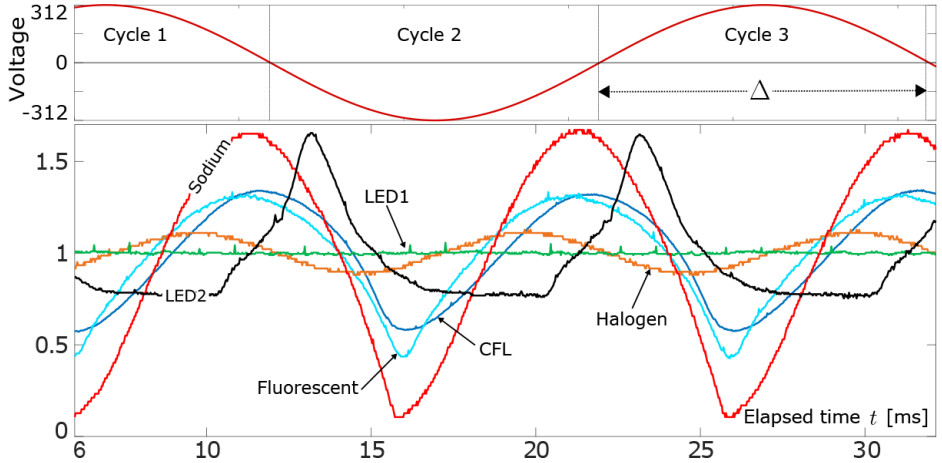
Backgrounds

- Artificial light sources
  - often powered by **alternating current (AC)**
  - cause **flickers** in the radiance values of a scene

captured at 2,500fps & replayed at 25fps

- Temporal intensity profiles
  - depend not only on the phase of electric grid but also on light sources themselves



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Our Goal

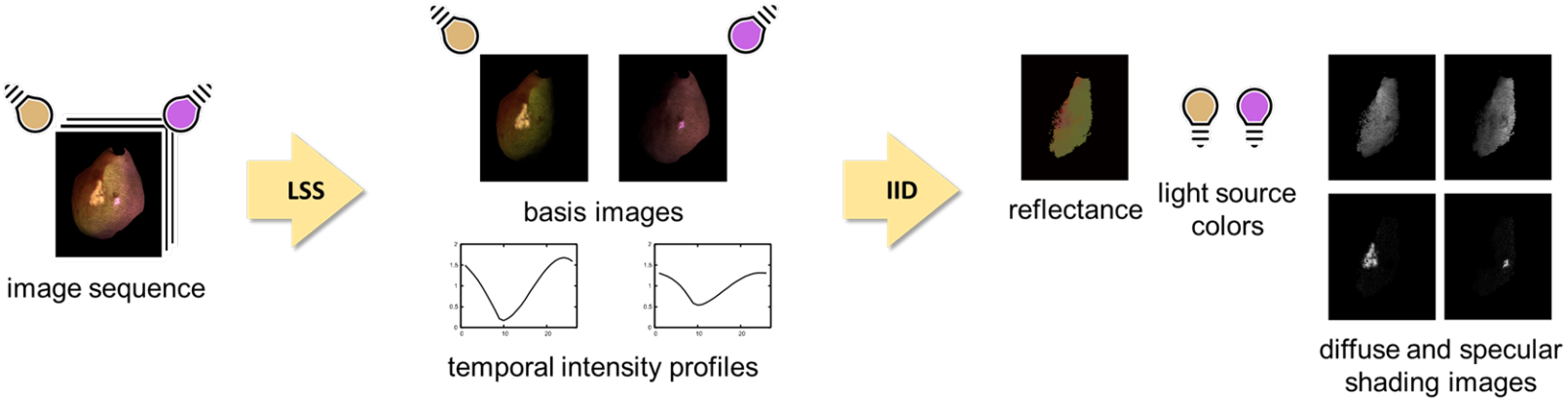
Flickers are useful for extracting rich information on a scene

- **Light source separation (LSS)** and **intrinsic image decomposition (IID)** from an image sequence taken under multiple AC light sources
- LSS

  image sequence
  => basis images & intensity profiles

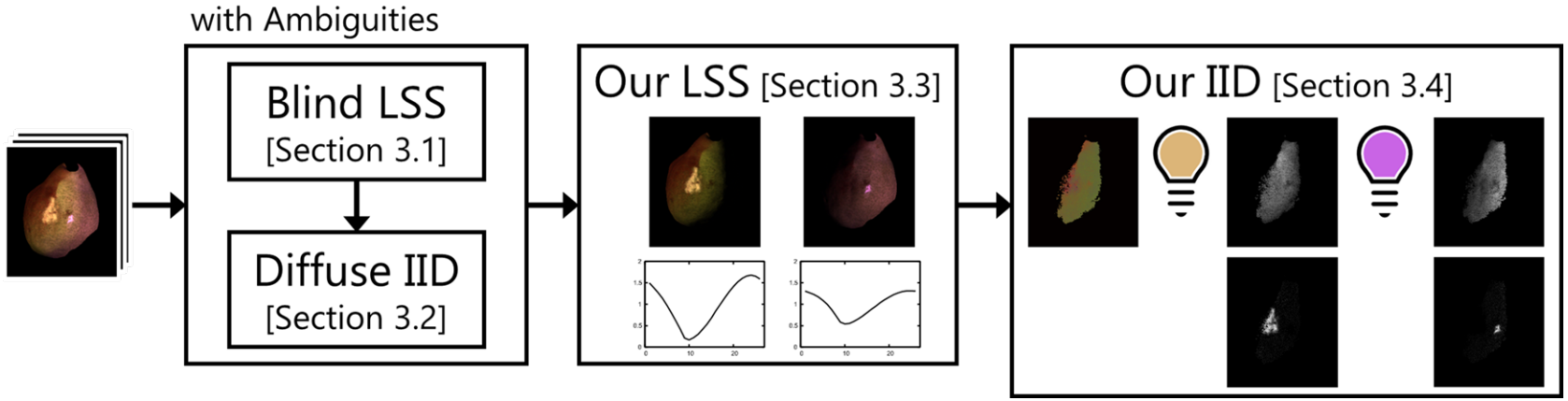
- IID

  basis images
  => properties of scene & light sources



Outline of Our Proposed Method

- **LSS followed by IID**



- Our LLS
  - input: image sequence, output: basis images and intensity profiles
- Our IID
  - input: basis images
  - output: light source colors, diffuse reflectance, diffuse and specular shadings

Difficulties: Ambiguities in LSS and IID

- LSS
  - superposition principle: linear combination of basis images
  - blind LSS via matrix factorization

$$\boldsymbol{I} = \boldsymbol{B}\boldsymbol{A}$$

$\boldsymbol{I}$: input image sequence

$\boldsymbol{B}$: basis images

$\boldsymbol{A}$: temporal intensity profiles

  - ambiguity between **basis images and intensity profiles**
  - invariant to **unknown matrix $\boldsymbol{X}$**

$$\boldsymbol{I} = \boldsymbol{B}\boldsymbol{X}\boldsymbol{X}^{-1}\boldsymbol{A}$$

- IID
  - IID assuming diffuse reflection model

$$\begin{aligned} \boldsymbol{b}_{pn} &= d_{pn} \begin{pmatrix} r_{p1} & 0 & 0 \\ 0 & r_{p2} & 0 \\ 0 & 0 & r_{p3} \end{pmatrix} \begin{pmatrix} l_{n1} \\ l_{n2} \\ l_{n3} \end{pmatrix} \\ &= d_{pn}\boldsymbol{R}_p\boldsymbol{l}_n. \end{aligned}$$

$\boldsymbol{b}_{pn}$: pixel values of basis image

d_{pn}: diffuse intensity

$\boldsymbol{r}_p$: diffuse reflectance

$\boldsymbol{l}_n$: light source color

  - ambiguity between **diffuse reflectance and light source colors**
  - invariant to **unknown matrix $\boldsymbol{Y}$**

$$\boldsymbol{b}_{pn} = d_{pn}\boldsymbol{R}_p\boldsymbol{Y}\boldsymbol{Y}^{-1}\boldsymbol{l}_n$$

Key Ideas: Resolving Ambiguities in LSS and IID

- LSS
  - unknown $\boldsymbol{X}$ causes **non-uniform light source color** in basis image

$$\boldsymbol{b}_{pn}^{(e)} = \begin{pmatrix} r_{p1} & 0 & 0 \\ 0 & r_{p2} & 0 \\ 0 & 0 & r_{p3} \end{pmatrix} \underbrace{\left(\sum_{m=1}^{N} d_{pm} \boldsymbol{l}_m x_{mn} \right)}_{\text{light source color}}$$

  - **uniform light source color** in each basis image resolves the ambiguity

  => combination with diffuse IID

- IID
  - diffuse colors are invariant but **specular colors depend on** unknown Y

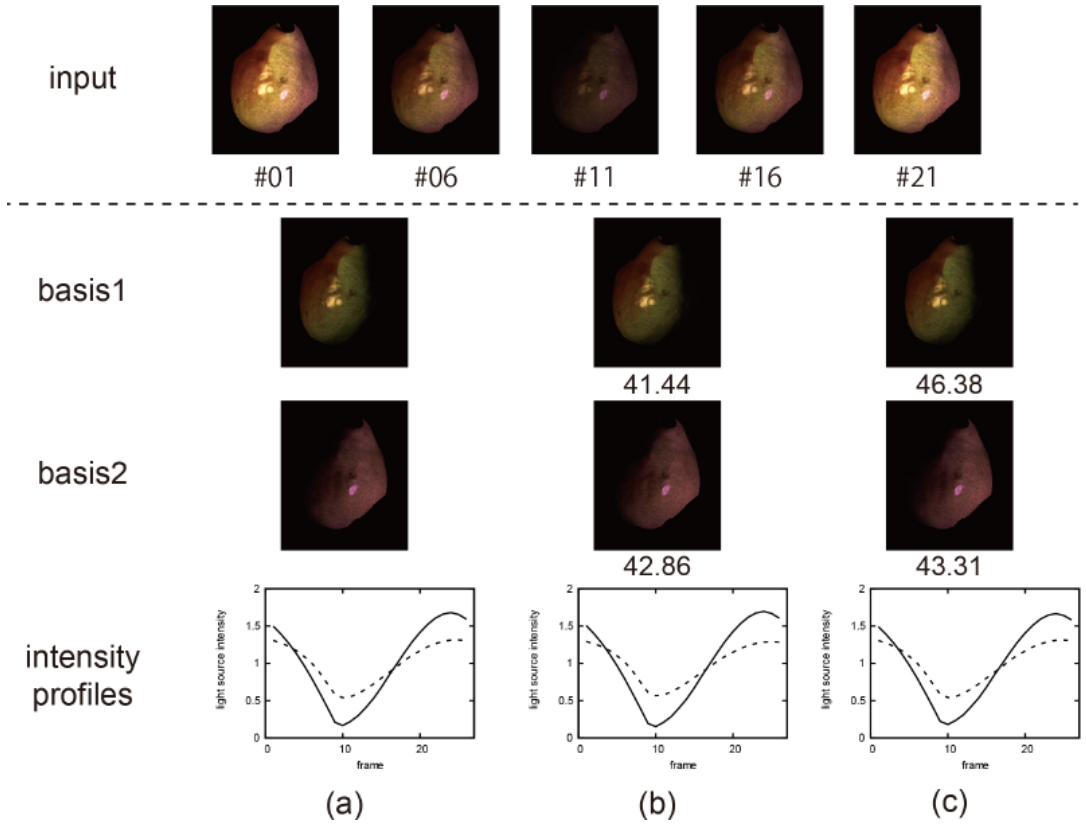
$$\boldsymbol{b}_{pn} = d_{pn} \boldsymbol{R}_p \boldsymbol{Y} \boldsymbol{Y}^{-1} \boldsymbol{l}_n + \underbrace{s_{pn} \boldsymbol{Y}^{-1} \boldsymbol{l}_n}_{\text{specular reflection component}}.$$

  - **specular reflection components** resolve the ambiguity: specular color = light source color

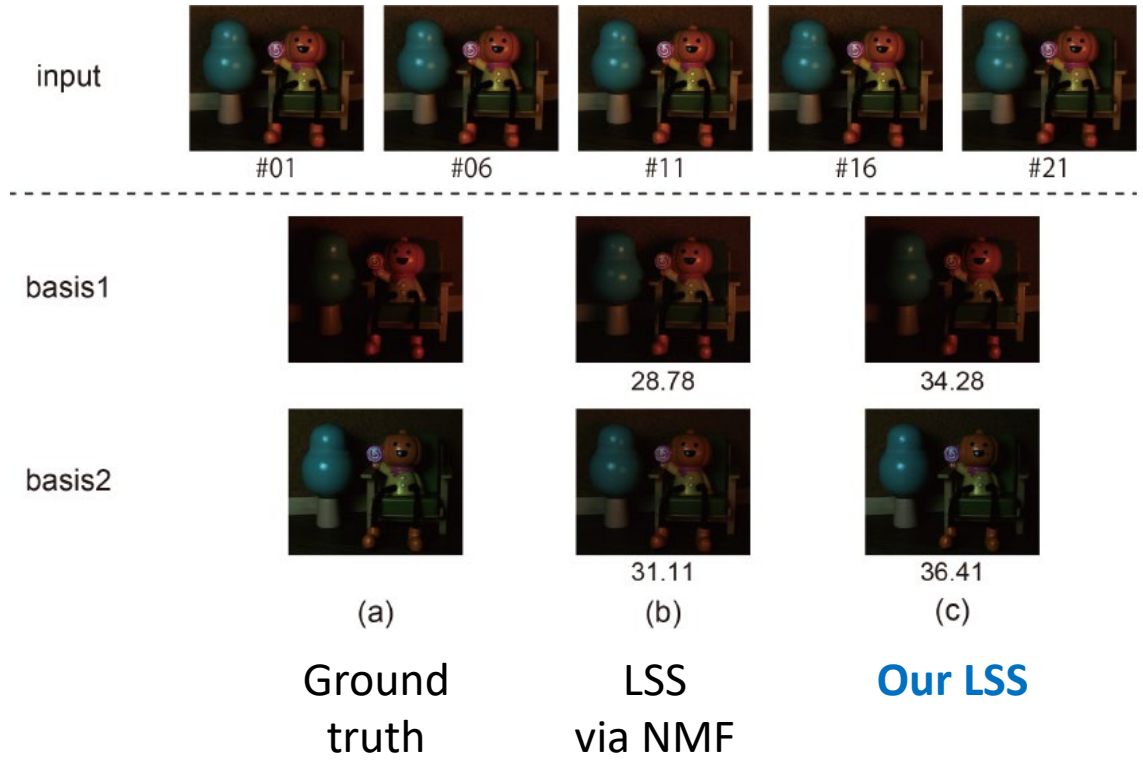
  => IID assuming the dichromatic reflection model

Experimental Results: LSS

- Synthetic images: Figure 2



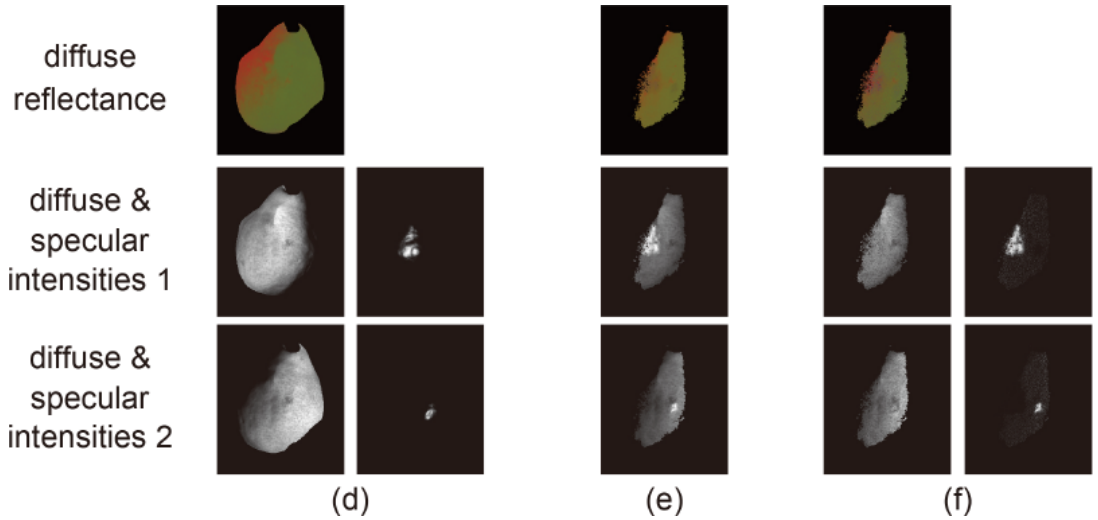
- Real images: Figure 4



* input images were captured by using a high-speed camera (exposure time: 0.4ms, fps: 2,500)

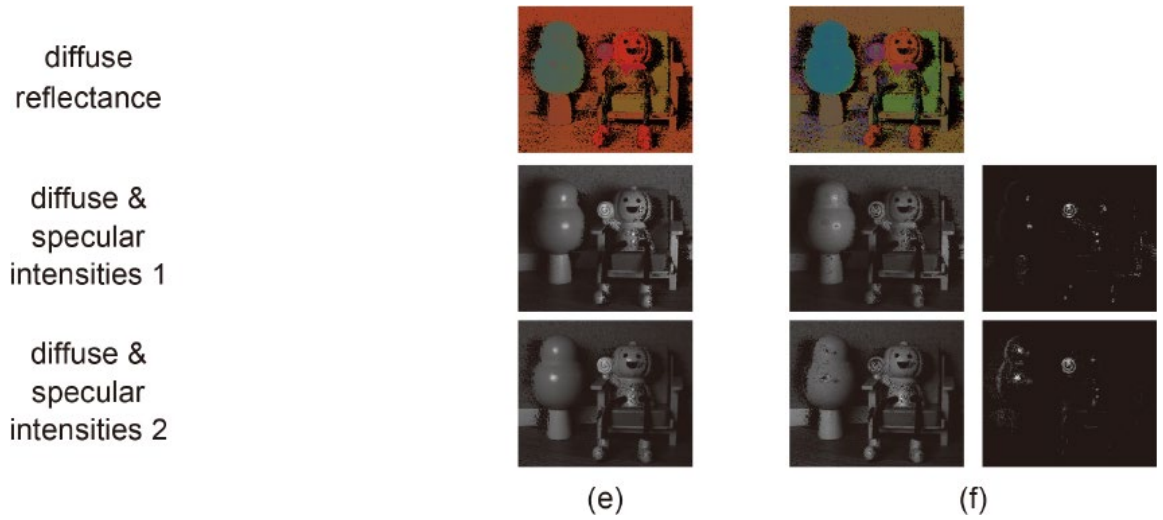
Experimental Results: IID

- Synthetic images: Figure 2 & Table 2



G. T. Diffuse IID **Our IID**

- Real images: Figure 4 & Table 3



Diffuse IID **Our IID**

– light source colors

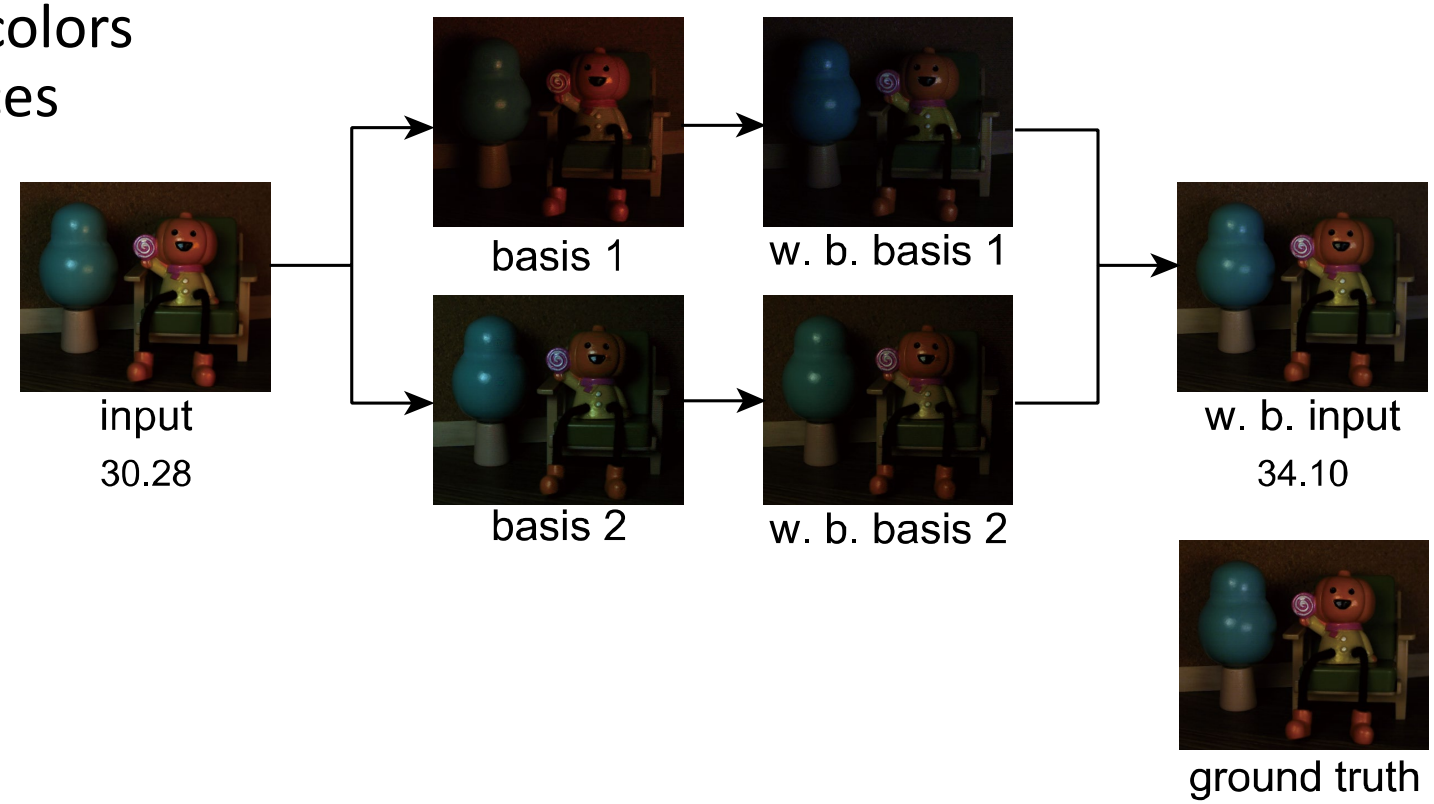
light	ground truth	diffuse IID	our IID
(i) 1	(0.42, 0.35, 0.23)	(0.33, 0.33, 0.33)	(0.42, 0.37, 0.21)
2	(0.38, 0.19, 0.43)	(0.28, 0.16, 0.56)	(0.39, 0.20, 0.41)

– light source colors

light	ground truth	diffuse IID	our IID
(A) 1	(0.56, 0.30, 0.14)	(0.33, 0.33, 0.33)	(0.58, 0.29, 0.13)
2	(0.24, 0.36, 0.40)	(0.16, 0.39, 0.45)	(0.24, 0.33, 0.44)

Applications: Auto White Balancing

- Difficulties
  - non-uniform light source colors due to multiple light sources
- Key ideas
  - **combining white balanced basis images**



Main Contributions

- Tackle a novel problem
  - we tackle a novel problem of the IID under AC illumination, and show that **flickers due to AC illumination are useful for IID** as well as LSS
- Reveal and resolve the ambiguities in LSS and IID
  - we **reveal the ambiguities in the blind LSS and diffuse IID** under AC illumination, and **show why and how those ambiguities can be resolved** via physics-based approach
- Easy-to-implement but effective method
  - our method **does not require a self-built camera and the dataset of various light sources**, and is **effective for application to auto white balancing**