Physic-based Vision at High-speed

Surface Normal and Reflectance Estimation Using an Event Camera

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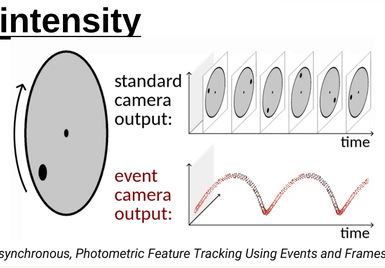
Event Camera

is a neuromorphic vision sensor designed for detecting **changes in pixel intensity**



Asynchronous, Photometric Feature Tracking Using Events and Frames, ECCV2018

High Speed
Theoretically up to million FPS

High Dynamic Range
Can simultaneously handle both direct reflection and scattering

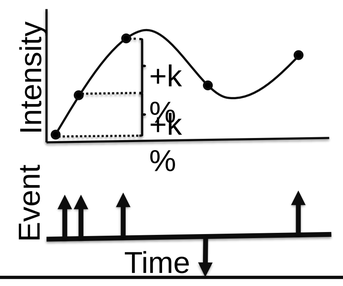
Bandwidth Efficient
Only changes are recorded

Advantage

Key Formation

Relative Intensity between two consecutive events defined as:

$$I(\tau_k) = e^{C\sigma_k} I(\tau_{k-1})$$
$$\log(I(\tau_k)) = \log(I(\tau_{k-1})) + C\sigma_k$$



Challenge

Goal

- **High-speed active light systems**, surpassing traditional cameras.
- However, events provide only **relative information based on prior states**.
- The key factors for success are as follows:

Simple Modulator | **Fast Device** | **Reconstruct Algorithm**

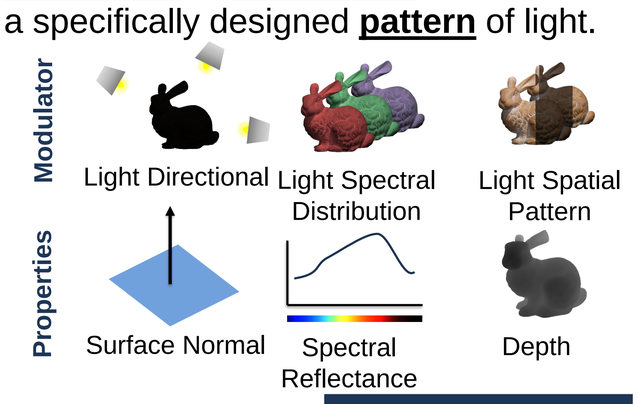
Overcome

Slow & Bandwith Inefficient

- Large amount of modulated pattern
- Requires multi-bracket HDR capturing

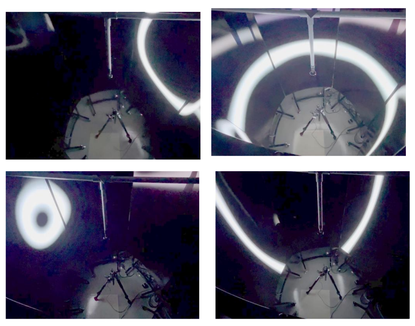
Active Lighting

is widely used to extract **physical properties** by **modulating** the scene with a specifically designed **pattern** of light.

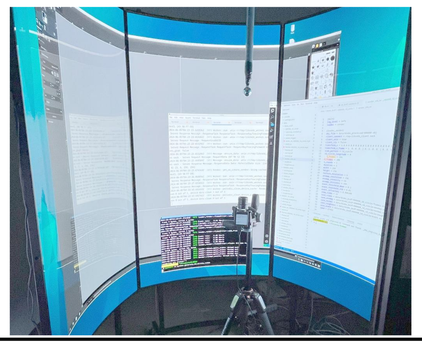


Normal & Roughness

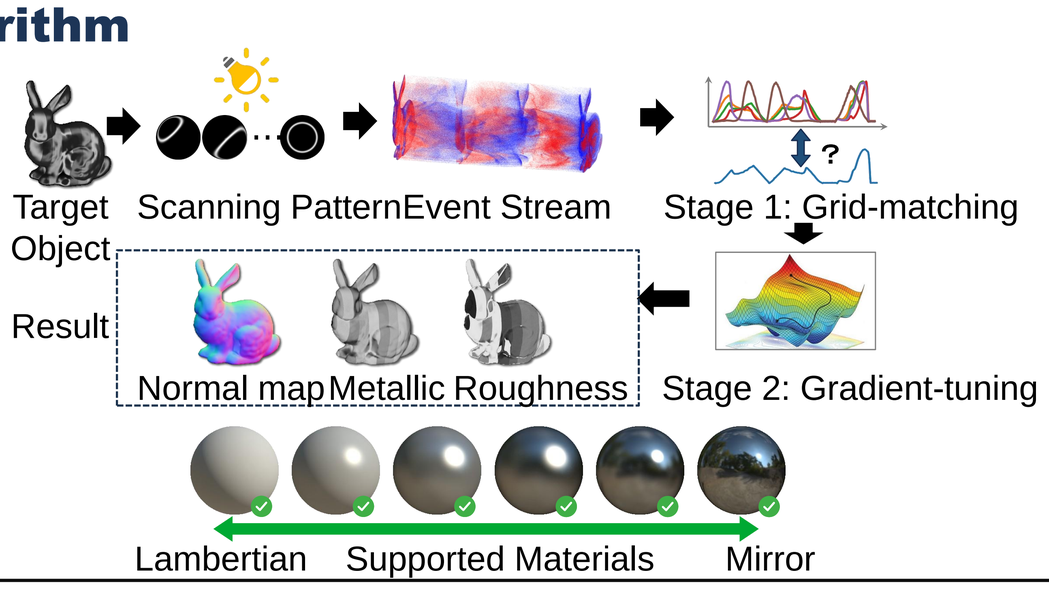
Modulator



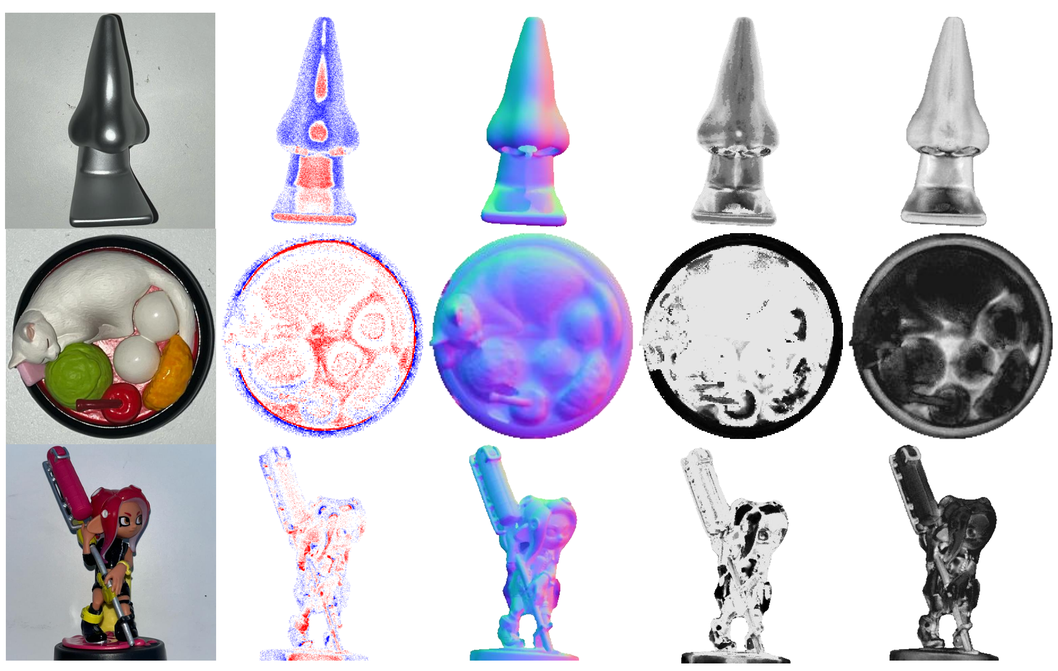
Device



Algorithm



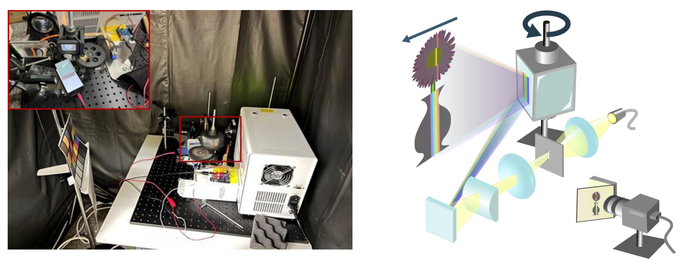
Results



Spectral Reflectance

Modulator

Device



Algorithm

Continuous form **Discrete form** **Vector form**

Hyperspectral Intensity · Light source spectral · Calibrated constant $A_m(\tau)$

$$I(\tau) = \int_\lambda \underbrace{S(\lambda)D(\lambda)}_{\text{Camera Response}} \frac{L(\lambda,\tau)}{E(\lambda)} d\lambda = \sum_m S_m \int_{\lambda_m+\delta/2}^{\lambda_m-\delta/2} D(\lambda)\frac{L(\lambda,\tau)}{E(\lambda)} d\lambda = a_\tau \cdot x$$

Augmented null spectrum vector

By providing a direct light c into the censor, null spectrum vector can be augmented.

$$\hat{I}(\tau) = a_T \cdot x + c = \begin{bmatrix} x \\ 1 \end{bmatrix} \cdot \begin{bmatrix} a_\tau \\ c \end{bmatrix}$$
$$\begin{bmatrix} x \\ 1 \end{bmatrix} \cdot \hat{n}_k = 0$$

Solve by constrained optimization problem

$$\min_x (\|Nx\|_2^2 + \alpha_{int} R_{int}(x) + \alpha_{spec} R_{spec}(x)) \;\; s.t. \; x \geq 0, \|x\|_2 = 1$$

Anti-drift constraint · Smoothness constraint

Results