Time-Resolved Image Demixing

A Phase-Retrieval Approach for Reflection Canceling Cameras

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Summary

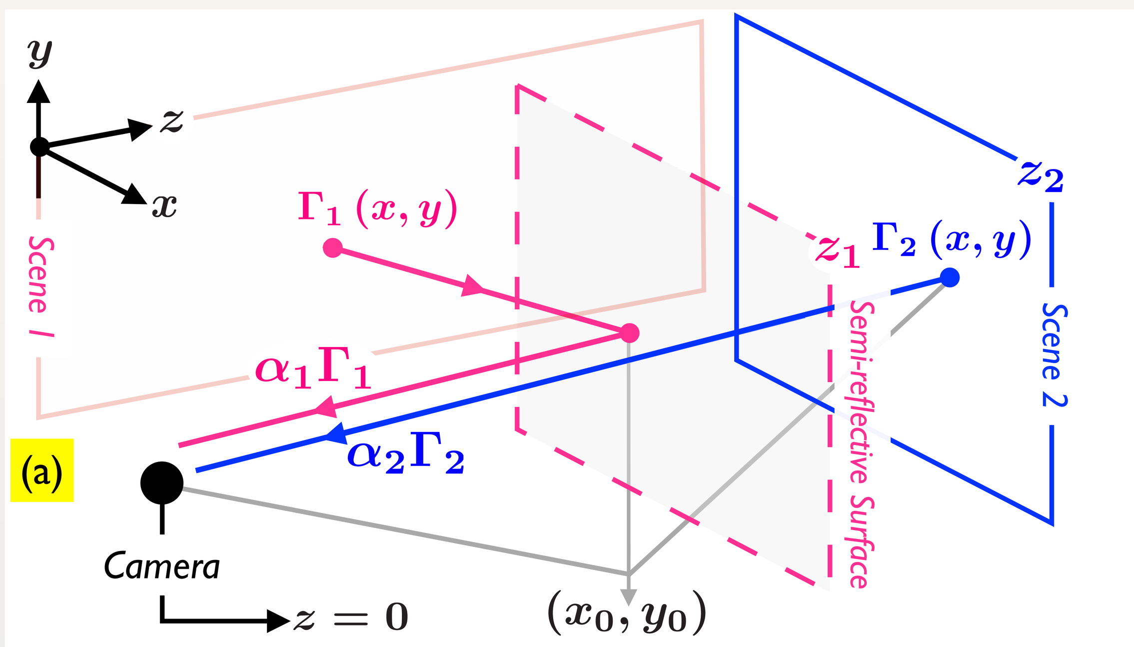
Key Takeaways

1. Demixing constituent components of an image mixture is a highly ill–posed problem.
2. We approach the image-mixing problem from a time-resolved perspective by exploring the question: What if each photon is time-stamped?
3. We propose a demixing algorithm based on phase-retrieval and our results are corroborated with experiments conducted using Microsoft Kinect ToF sensor.

Motivation

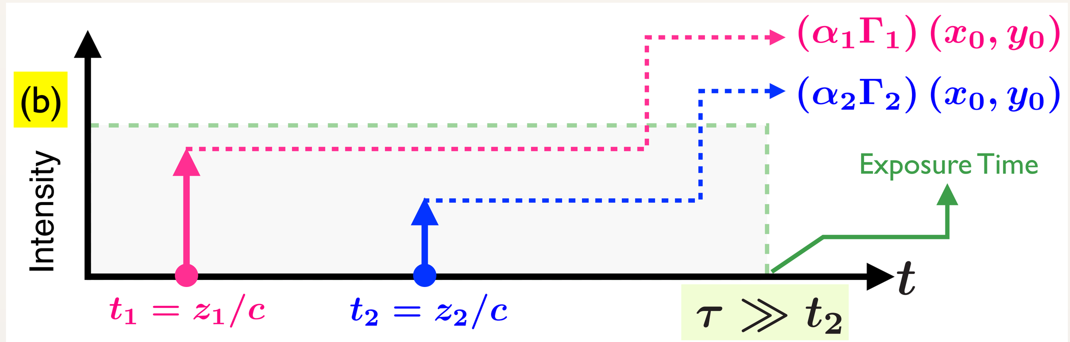
Can we recover images when multiple optical paths mix at the sensor or when there exists a many--to--one mapping between the scene and the pixel?

Rethinking Image Formation



Conventional vs Transient Imaging.

Image Formation Model

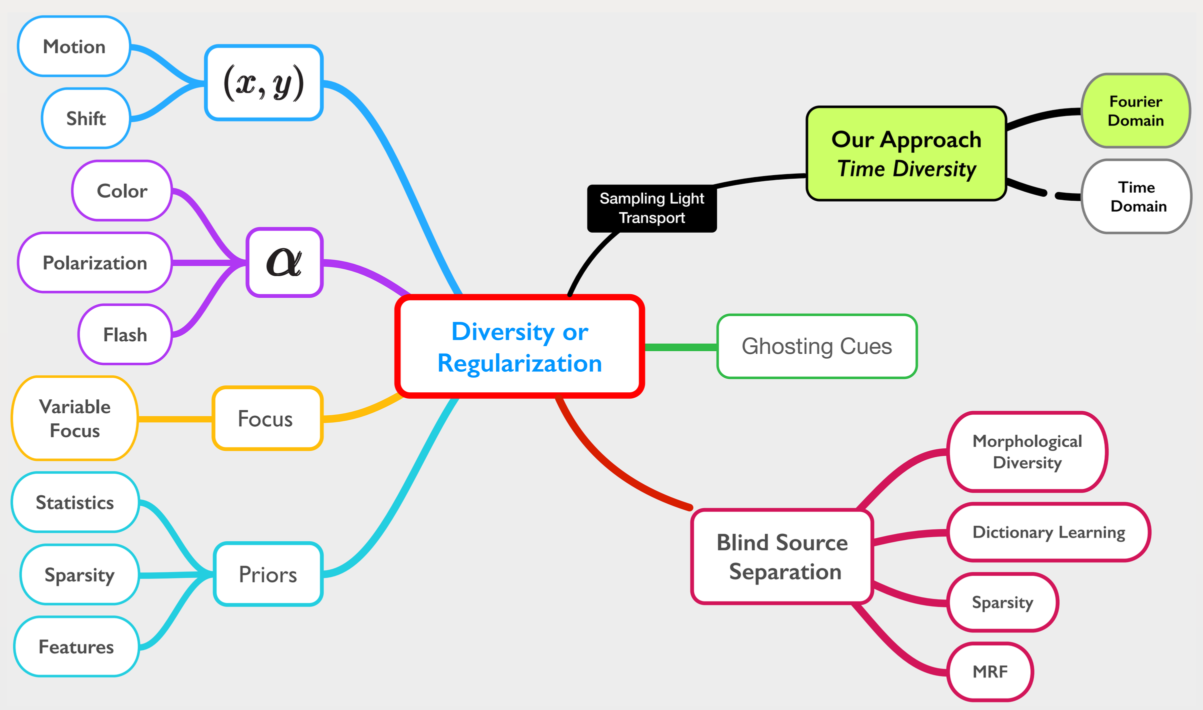


Transient $\quad m(x,y,t)=\sum_{k=0}^{K-1}(\alpha_k\Gamma_k)(x,y)\,\delta(t-t_k)$

Conventional $\quad m(x,y)=\sum_k(\alpha_k\Gamma_k)(x,y)$

Problem Statement

Problem: Given $m(x,y)$, identify $\{\Gamma_k(x,y)\}_{k=0}^{k=1}$

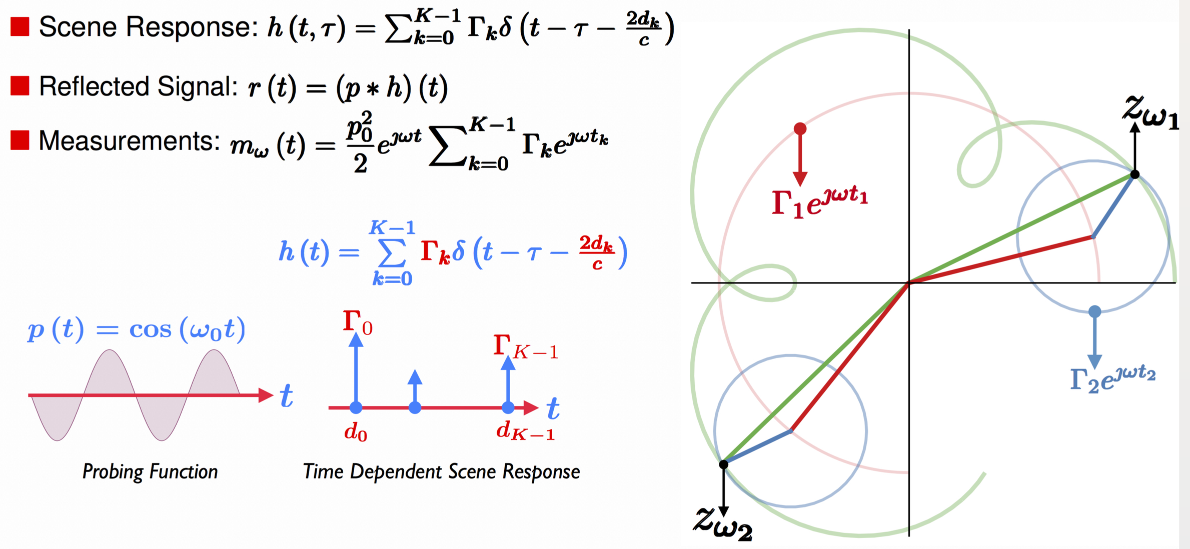


Time-Resolved Imaging

$$p \to \boxed{h} \to r \to \otimes_p \to m \xrightarrow{\text{Sampling}} m_k = m(k\Delta)$$

Frequency Domain ToF Imaging

- Probing Function: $p(t)=\cos(\omega t)$
- Scene Response: $h(t,\tau)=\sum_{k=0}^{K-1}\Gamma_k\delta\left(t-\tau-\frac{2d_k}{c}\right)$
- Reflected Signal: $r(t)=(p*h)(t)$
- Measurements: $m_\omega(t)=\frac{p_0^2}{2}e^{\jmath\omega t}\sum_{k=0}^{K-1}\Gamma_k e^{\jmath\omega t_k}$



Frequency Domain Time-Resolved Imaging

Phase-Retrieval Approach for Image Demixing

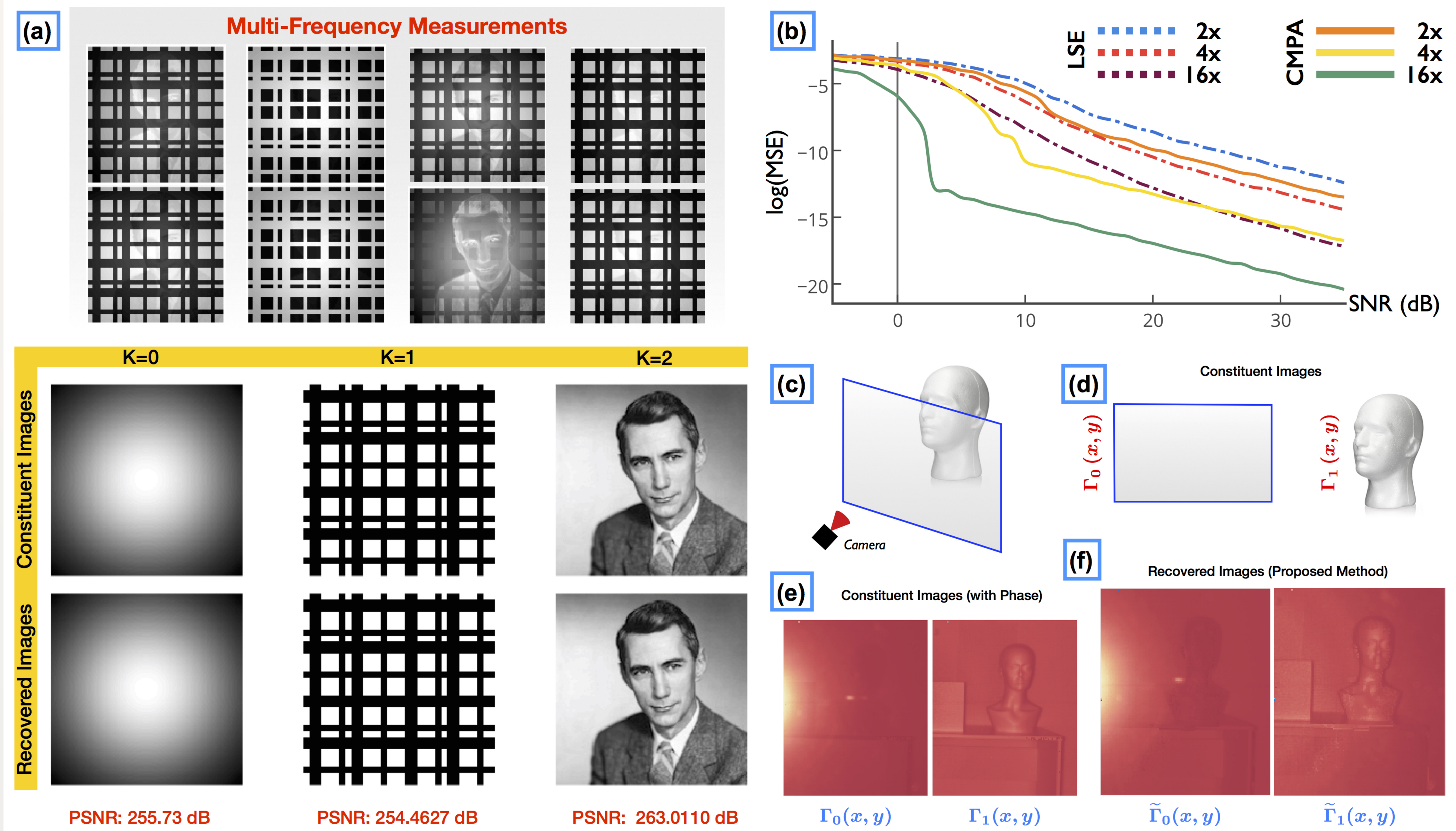
- Conventional ToF sensor for single ToF, $h(t,\tau)=\Gamma_0\delta(t-\tau-t_0),\ t_0=2d_0/c$,

$$\underbrace{\Gamma_0\left(1+\frac{p_0^2}{2}\cos(\omega(t+t_0))\right)}_{\text{Measurement } m_\omega(t)} \xrightarrow{\{m_\omega(\frac{k\pi}{2\omega})\}_{k=0}^{3}} \underbrace{z_\omega=\tilde{\Gamma}_0 e^{\jmath\omega\tilde{t}_0}}_{\text{ToF Estimate}} \xrightarrow{|(\cdot)|^2} |\tilde{\Gamma}_0|^2$$

- Our approach: Multiple image mixture. The SRF is $h(t,\tau)=\sum_{k=0}^{K-1}\Gamma_k\delta(t-\tau-t_k)$,

$$|z_\omega|^2=\underbrace{\left|\sum_{k=0}^{K-1}\Gamma_k e^{-\jmath\omega t_k}\right|^2}_{\text{Phase-free Measurements}}\equiv\sum_{k=-K_0}^{k=+K_0}\underbrace{\gamma_k}_{\text{Unknown}}e^{\jmath n\omega_0\nu_k},\quad K_0=\left(K^2-K\right)/2$$

Results and Discussion



References

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