"Seeing" Electric Network Frequency from Events

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*(* Equal contribution, † Corresponding author)*

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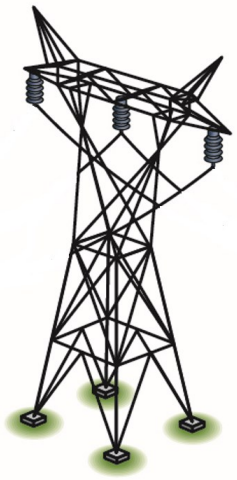
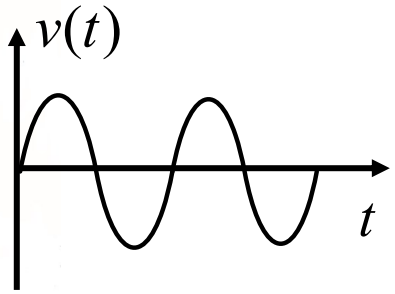
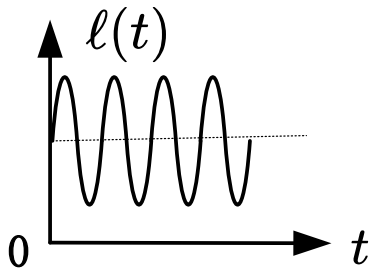
Quick Review





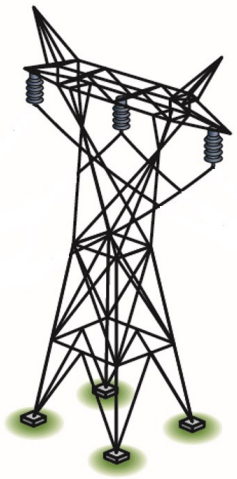
Power Supply

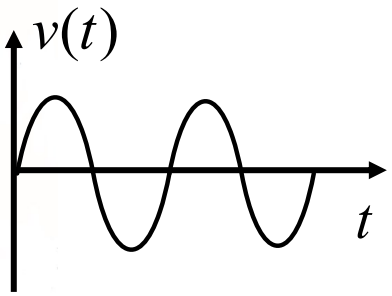
Power to Illumination



Light Flickering

Quick Review





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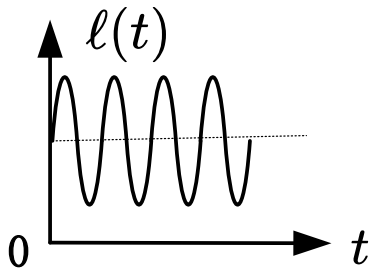

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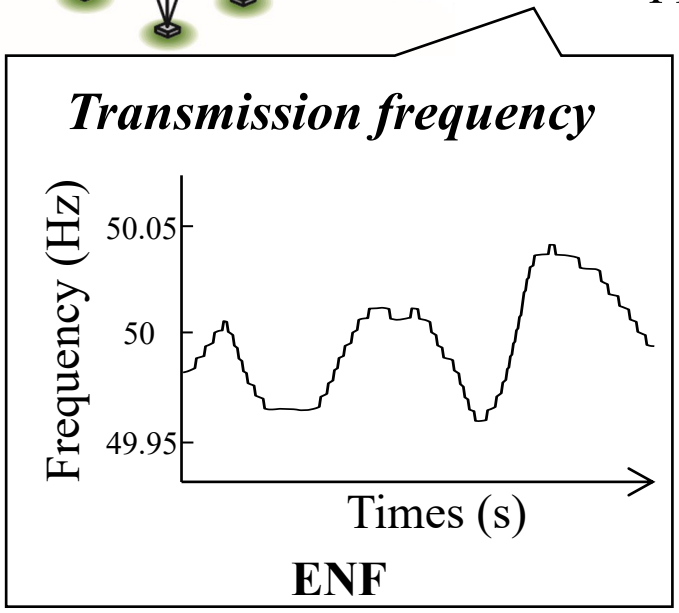
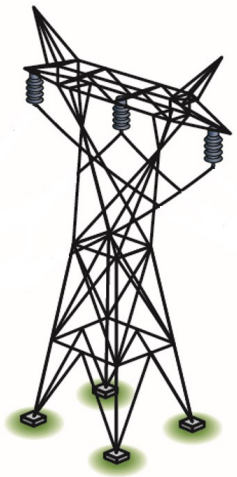
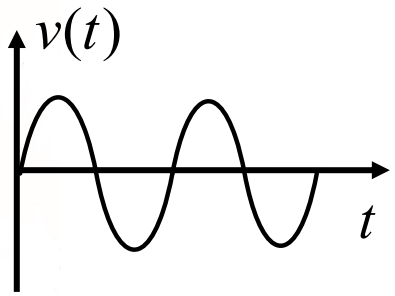


Electric Network Frequency (ENF):

- Transmission frequency
- Fluctuates slightly
- Regional/Temporal variations

Quick Review





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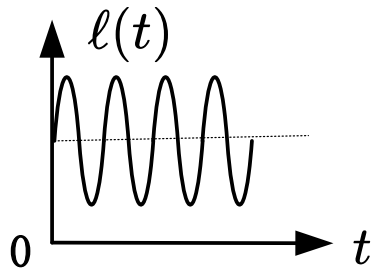

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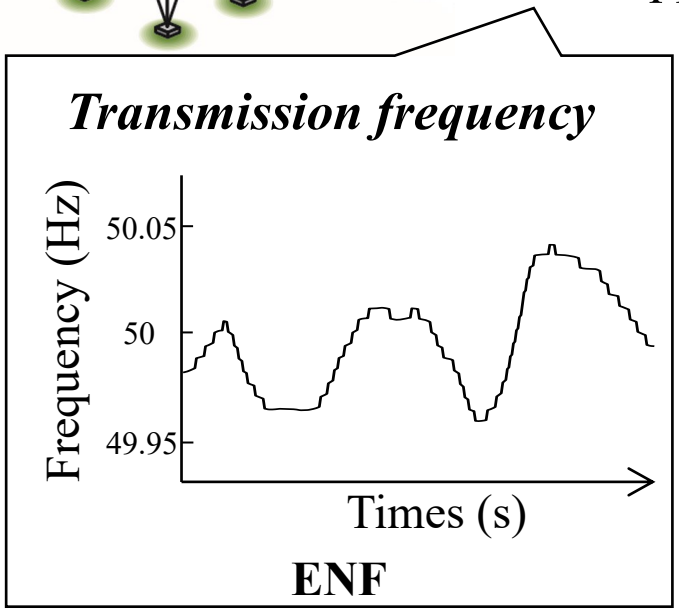

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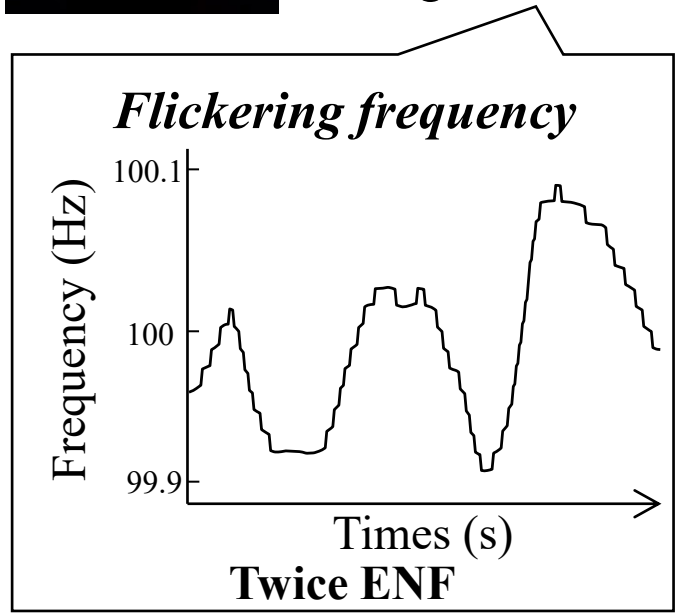
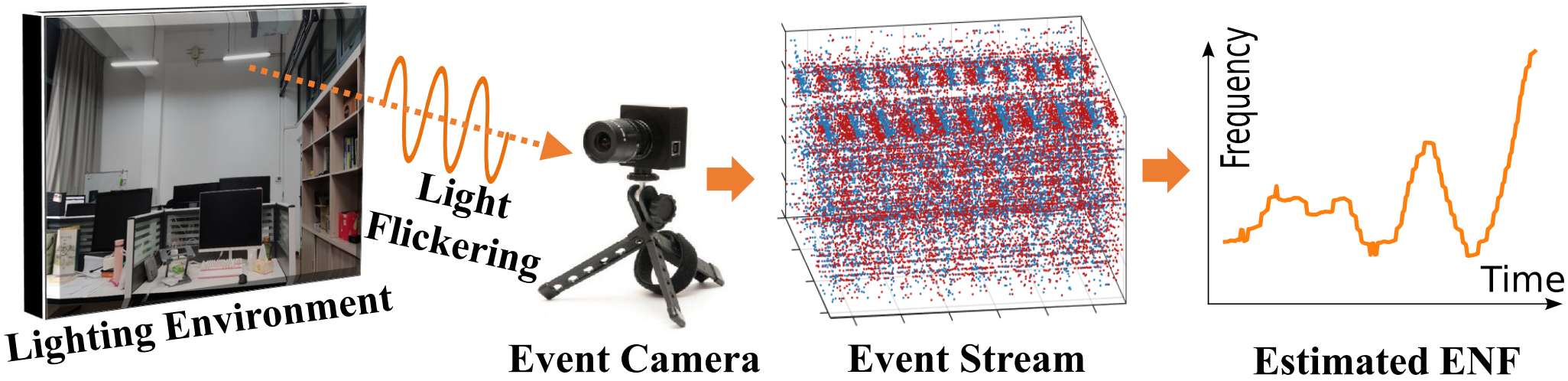


Light Flickering:

- *Twice ENF*

Quick Review

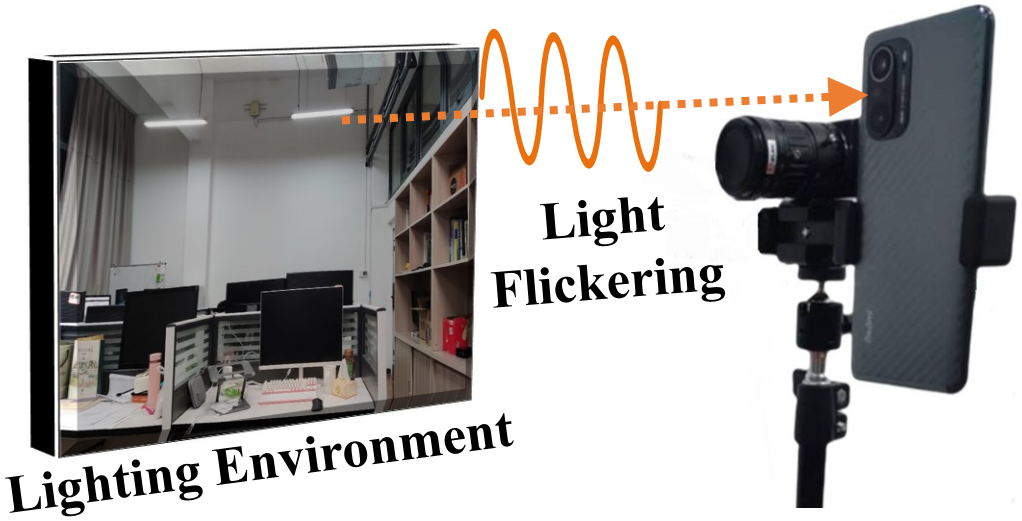


Contributions

- Validation of **ENF capture** in events.
- Introduction of pioneering event-based ENF extraction method (**E-ENF**).
- Construction of the first Event-Video hybrid ENF Dataset (**EV-ENFD**).

Motivation

- Video-based ENF (V-ENF) extraction methods



$$I(t) = G\{\ell_{\mathrm{ENF}}(t) + \ell_{\mathrm{M}}(t) + \ell_{\mathrm{S}} + \ell_{\mathrm{N}}(t)\}$$

Signal

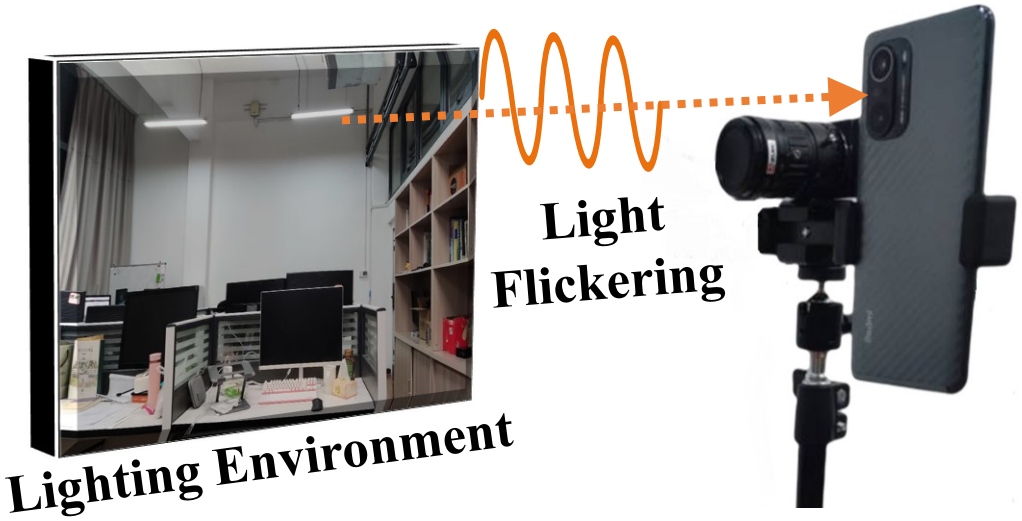
Noise

Averaging pixel intensity ➡ Light flickering

Brightness of the lighting

Motivation

- Video-based ENF (V-ENF) extraction methods



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Challenges:

- Non-ideal sampling.
- Motion.
- Extreme lighting conditions.

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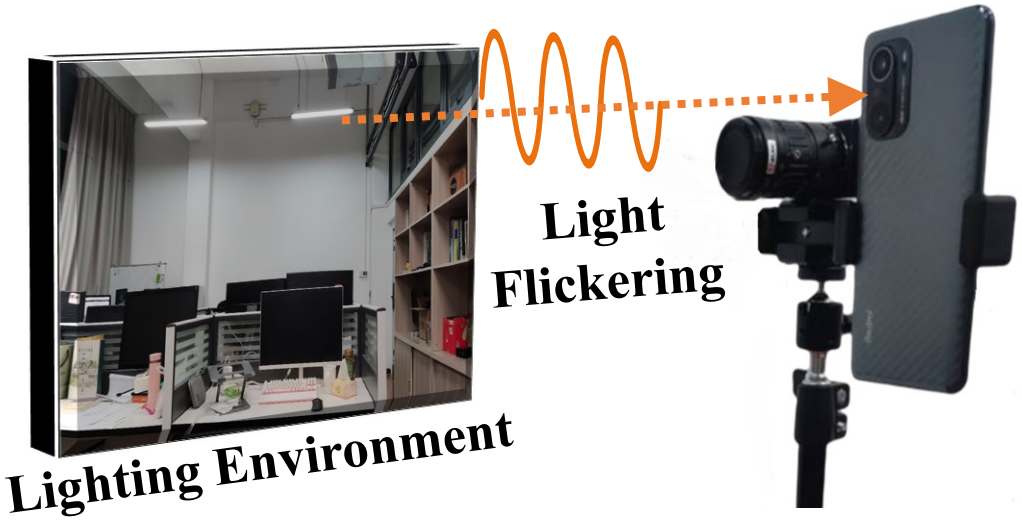

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Challenges:

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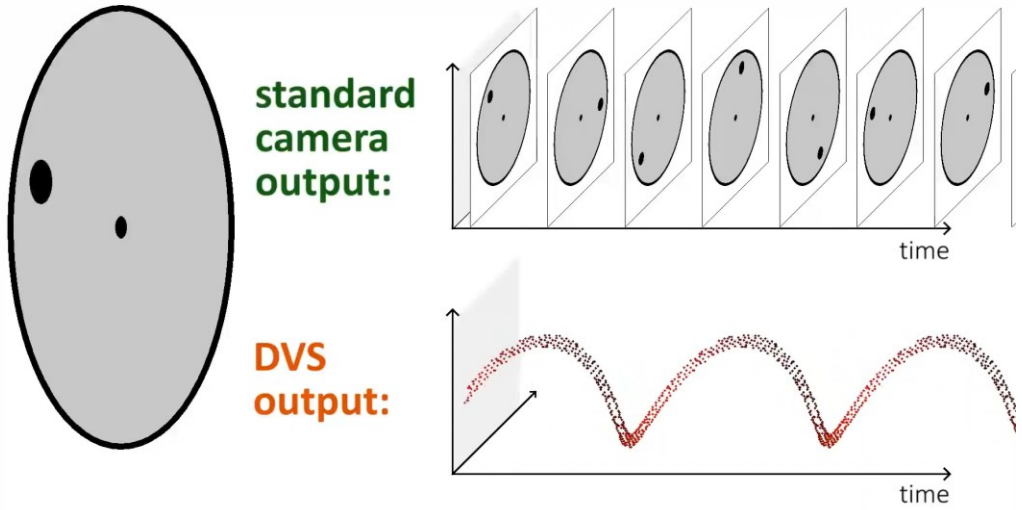
Solved by
"Event Camera"

Preliminary

➢ Event Camera

– record pixel intensity changes asynchronously per-pixel



– Standard camera output and event camera output
(Video from here: https://www.youtube.com/watch?v=LauQ6LWTkxM)

- Event generation model:

$$\log\left(I\left(\mathbf{x}_k, t_k\right)\right) - \log\left(I\left(\mathbf{x}_k, t_k - \Delta t_k\right)\right) = p_k C$$

➢ Event Camera

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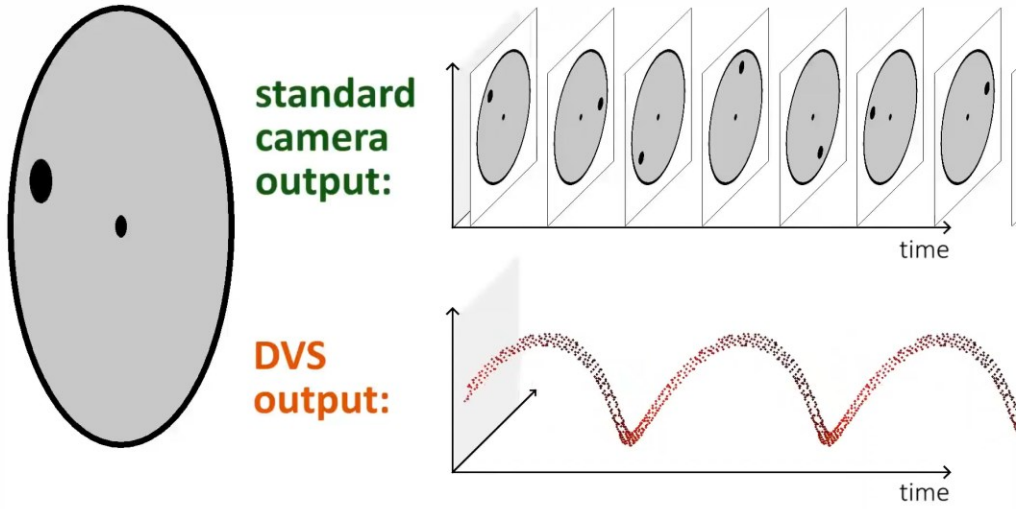

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Advantages:

- High temporal resolution
- High dynamic range
- Low latency

ENF Capture

- Pixel intensity under ideal flickering:

$$I_{\mathbf{x}}(t) = A(t)\cos\left(4\pi f_e(t) + \phi\right) + B(t)$$

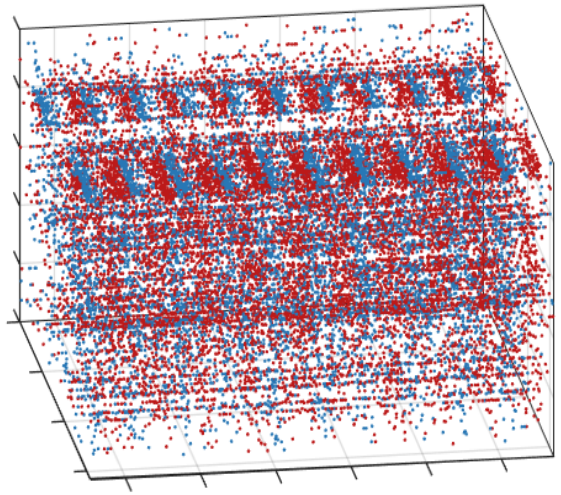
- Event generation model:

Let $p \triangleq (B(t) + \sqrt{B(t)^2 - A(t)^2}) / 2$, $q \triangleq (B(t) - \sqrt{B(t)^2 - A(t)^2}) / A(t)$

ENF Capture $\log\left(I_{\mathbf{x}}(t)\right) = \log p + 2\sum_m (-1)^{m-1} \frac{q^m}{m} \cos m\omega$

Illumination Events $\log\left(I_{\mathbf{x}}(t_k)\right) - \log\left(I_{\mathbf{x}}(t_k - \Delta t_k)\right) = pC$

Event Stream



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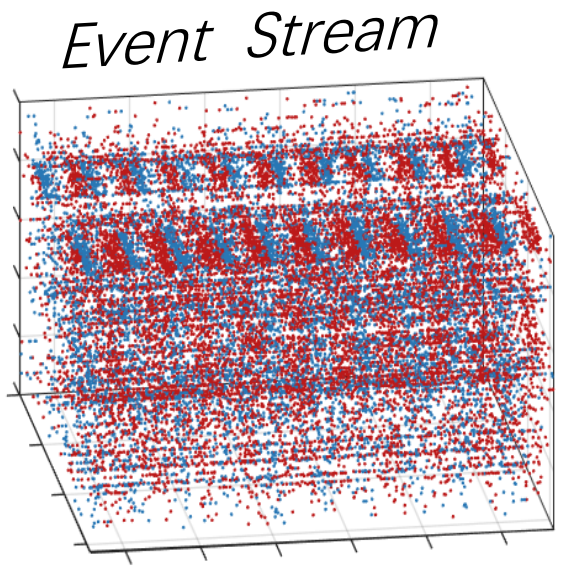

Conclusions:

- In addition to twice the ENF, its **harmonic content** was also recorded in the event stream.
- Light flickering generates numerous events exhibiting a unified polarity simultaneously, unlike those from noise and motion.

Event-based ENF (E-ENF)

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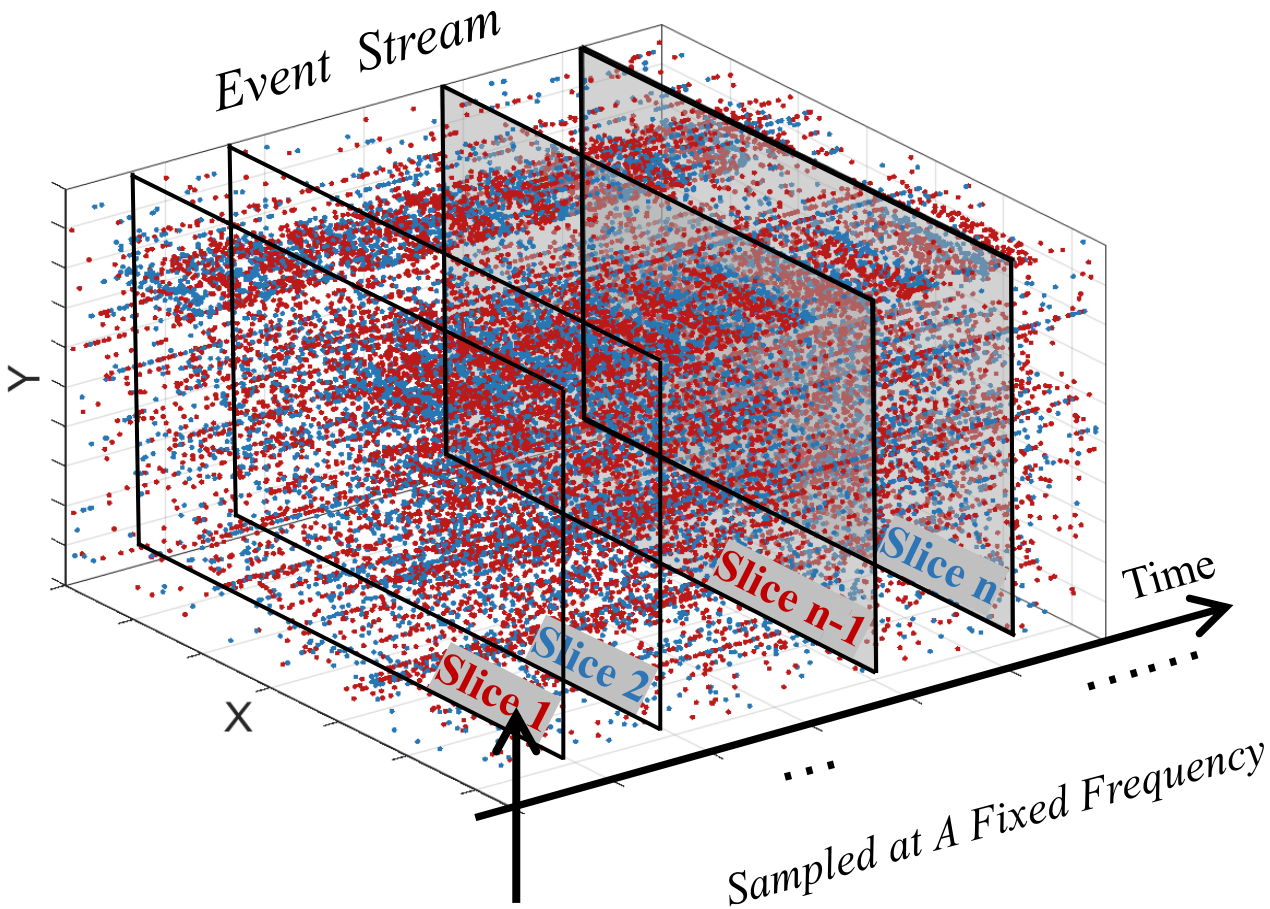
➢ Temporal Sampling

● Event Stream ⇨ Event Slices



- Frame the asynchronous events into uniform time intervals

Event-based ENF (E-ENF)

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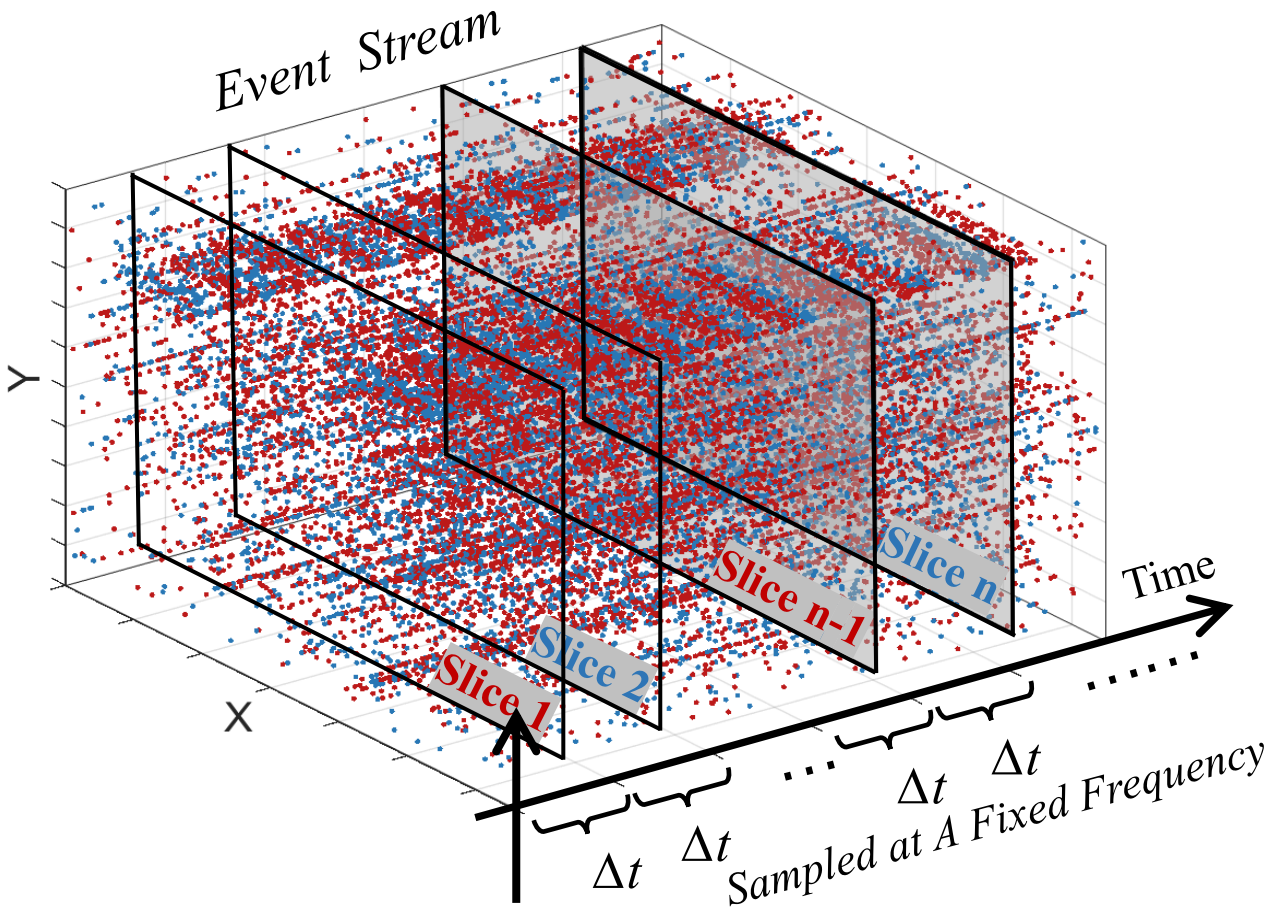

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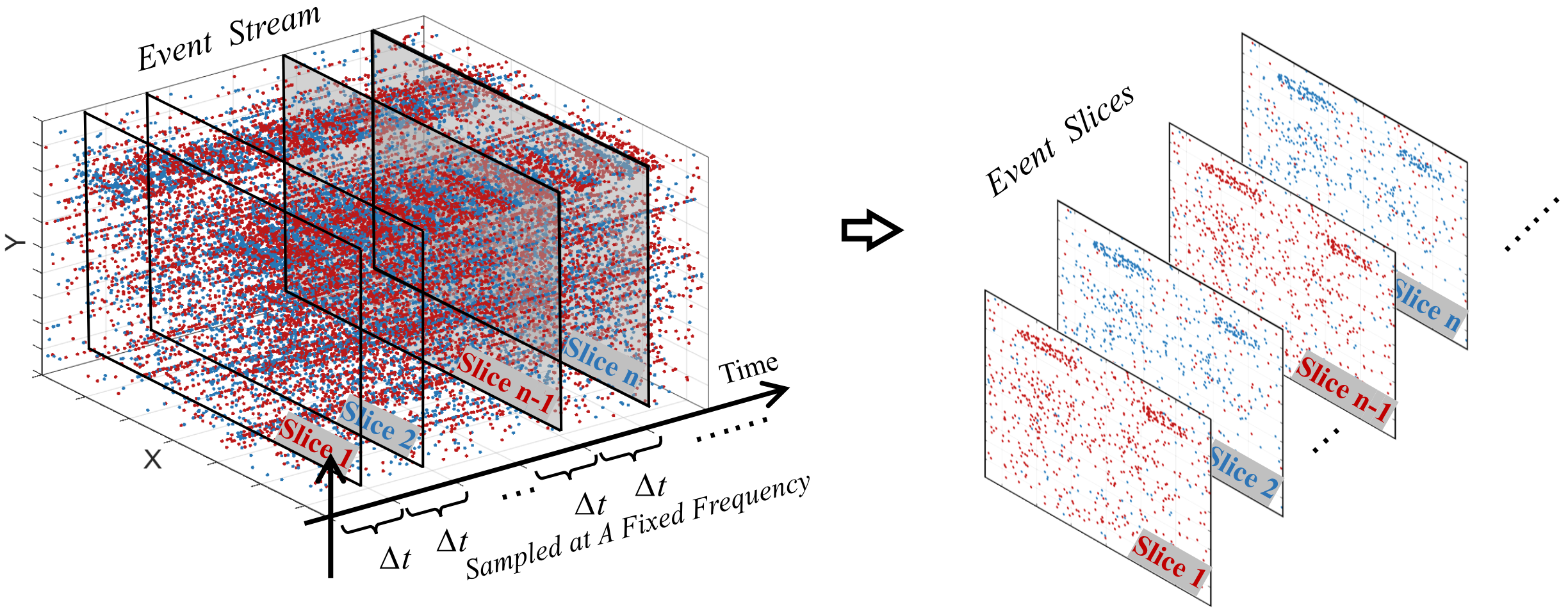

- Frame the asynchronous events into uniform time intervals

Event-based ENF (E-ENF)

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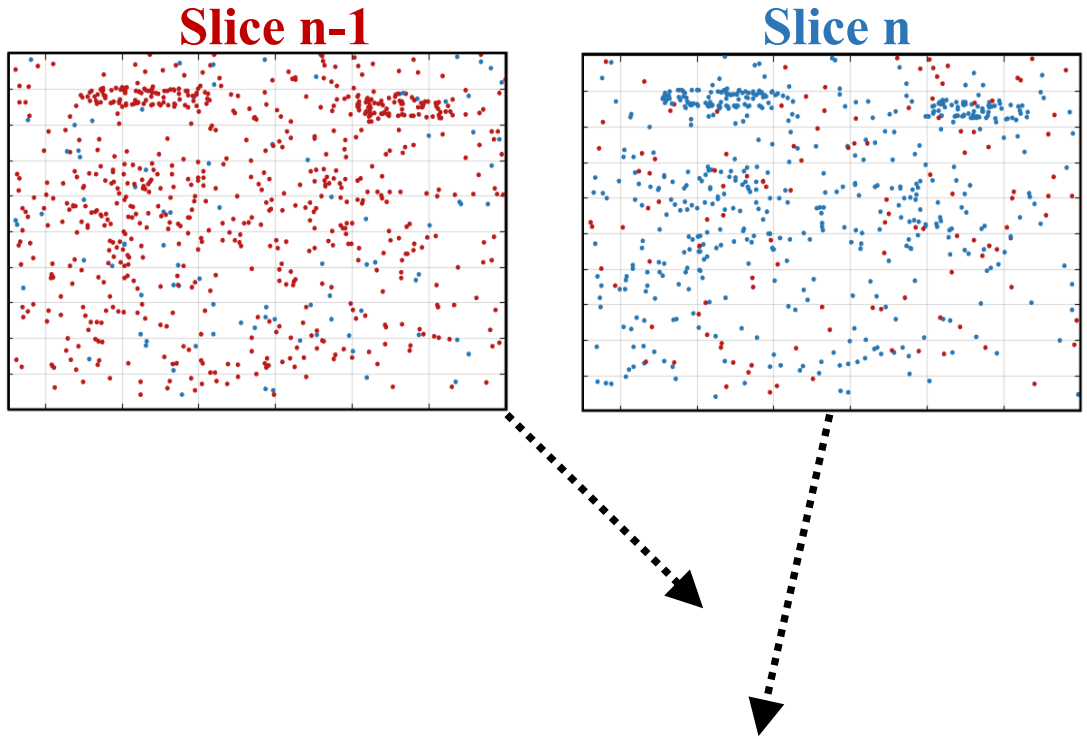
➢ Spatial Sampling

● Event Slices ⇨ Polar Sequence



Event Slices

- Inconsistent polarity
- Inconsistent location

⇩

- Judge flickering from inconsistent polarity and location

Event-based ENF (E-ENF)

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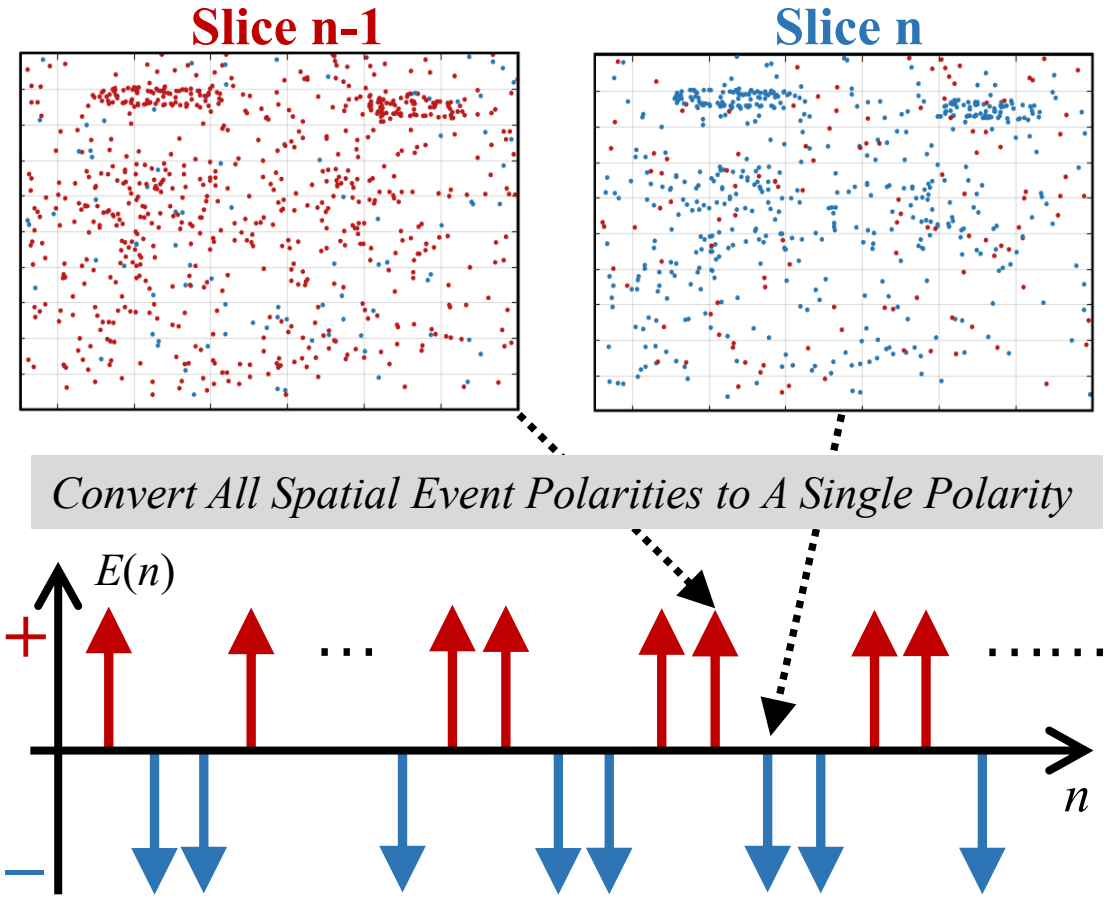
➢ Spatial Sampling

● Event Slices ⇨ Polar Sequence



Event Slices

- Inconsistent polarity
- Inconsistent location

⇩

Polar Sequence $E(n)$

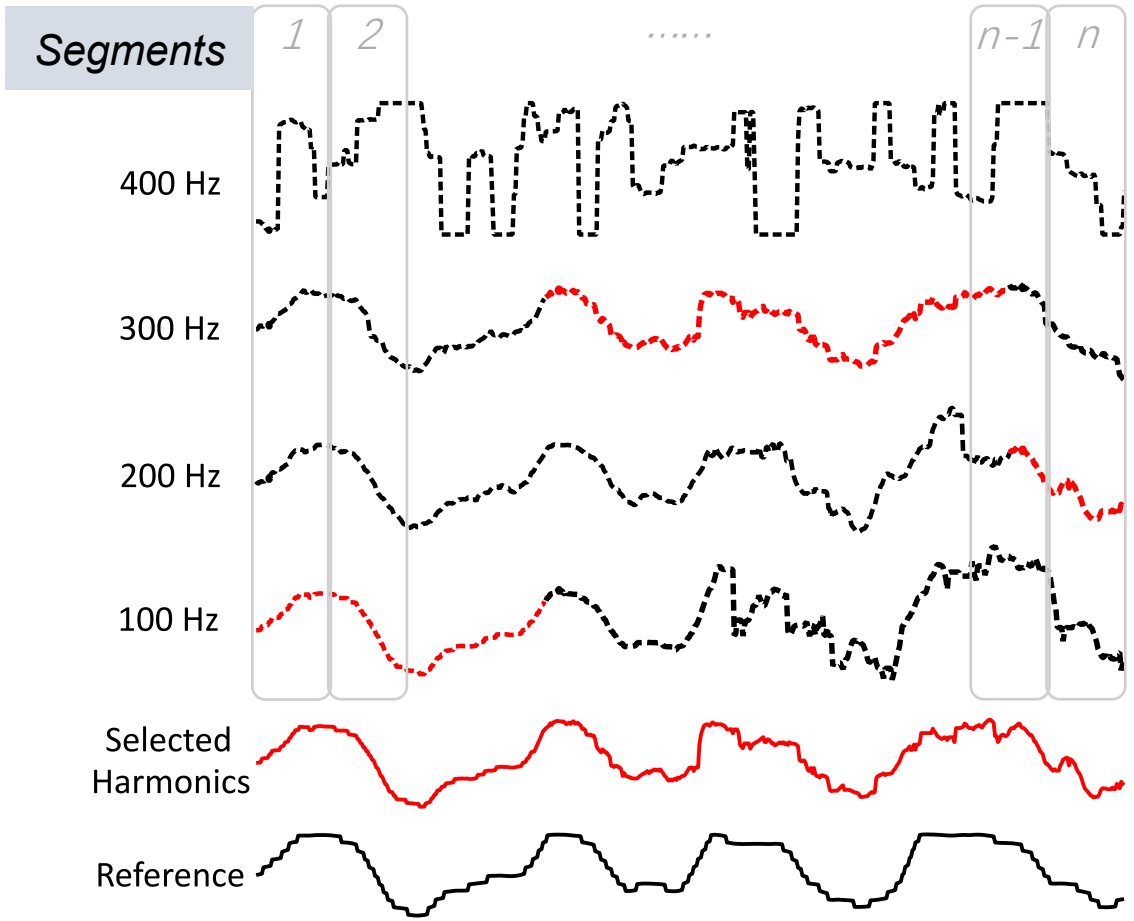
- One-dimensional
- Contains only ± 1
- Encodes illumination changes

- Judge flickering from inconsistent polarity and location

Event-based ENF (E-ENF)

➢ Harmonic Selection

- Polar Sequence ⇨ ENF Estimation



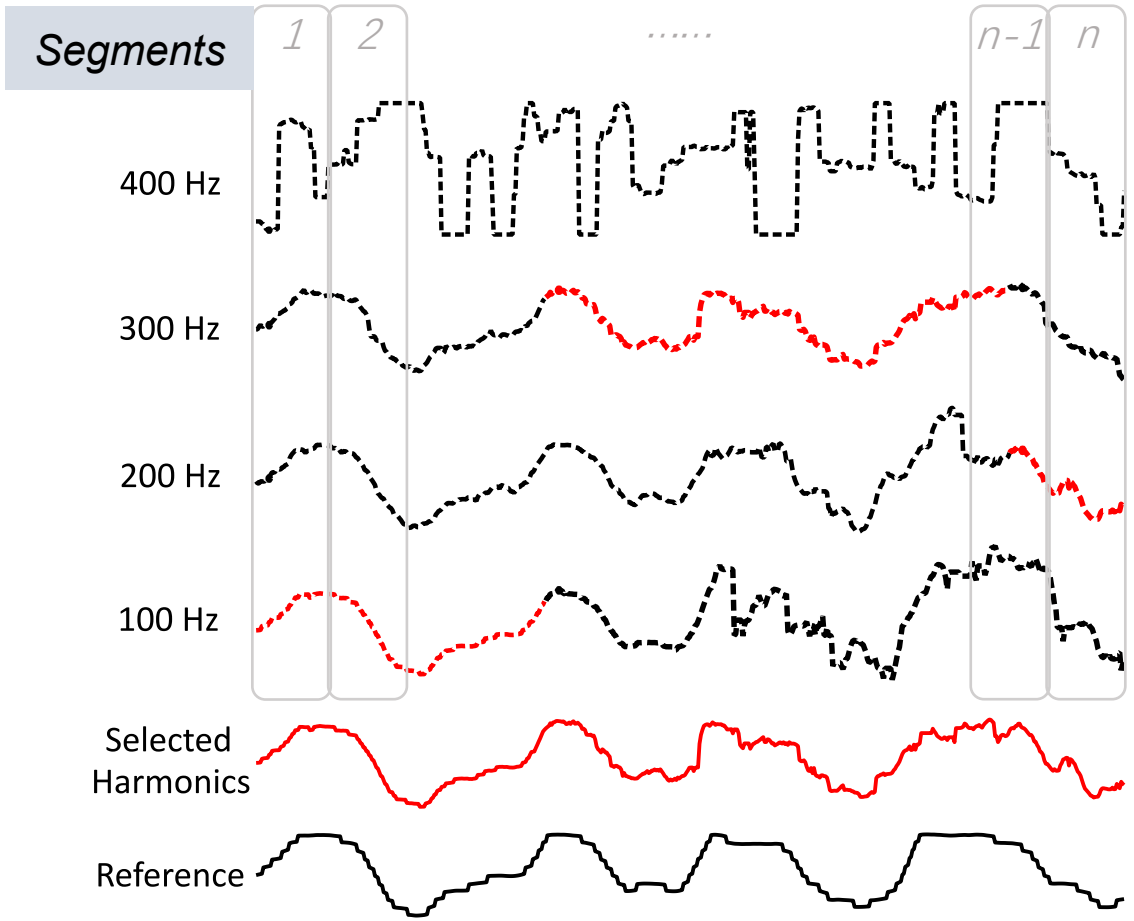
- Polar Sequence $E(n)$

- Combine the time-frequency variation into ENF estimation

Event-based ENF (E-ENF)

➢ Harmonic Selection

● Polar Sequence ⇨ ENF Estimation



● Polar Sequence $E(n)$

⇩

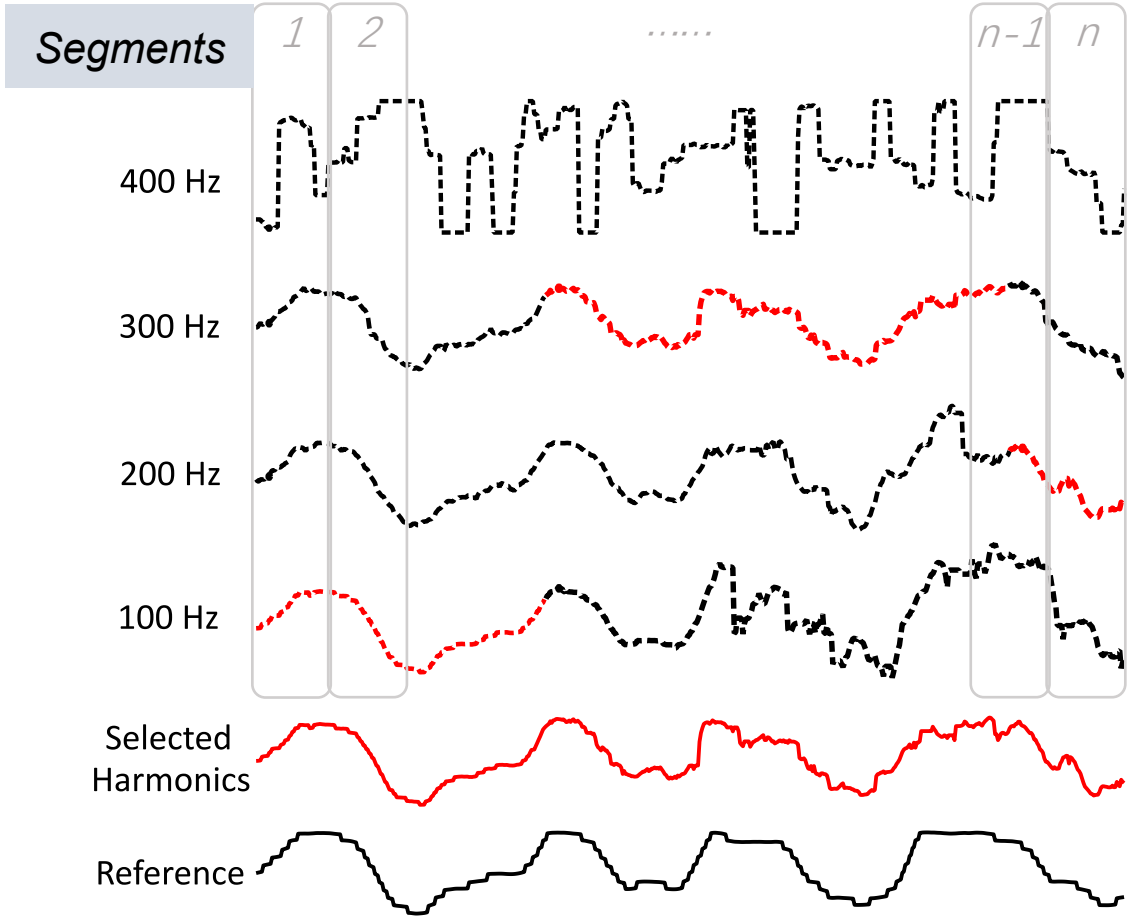
● STFT and peak search

- Combine the time-frequency variation into ENF estimation

Event-based ENF (E-ENF)

➢ Harmonic Selection

● Polar Sequence ⇨ ENF Estimation



- ● Polar Sequence $E(n)$
- ⇩
- ● STFT and peak search
- ⇩
- ● Harmonic Selection

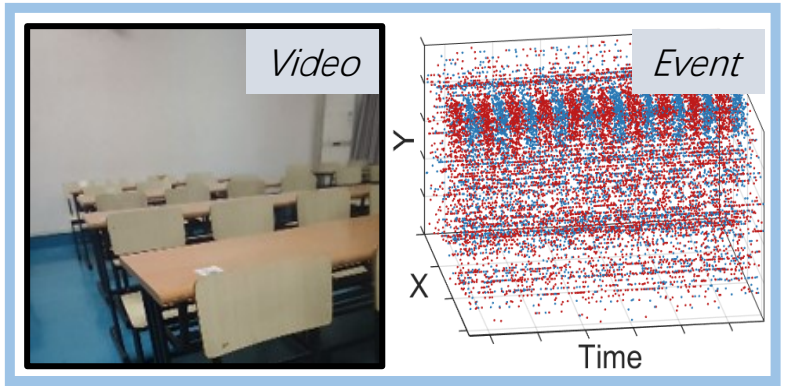
✓ Selection Criteria : $S_m = \sum_{n=1}^{N_f} |f_m[n] - f_m[n-1]|$

- Combine the time-frequency variation into ENF estimation

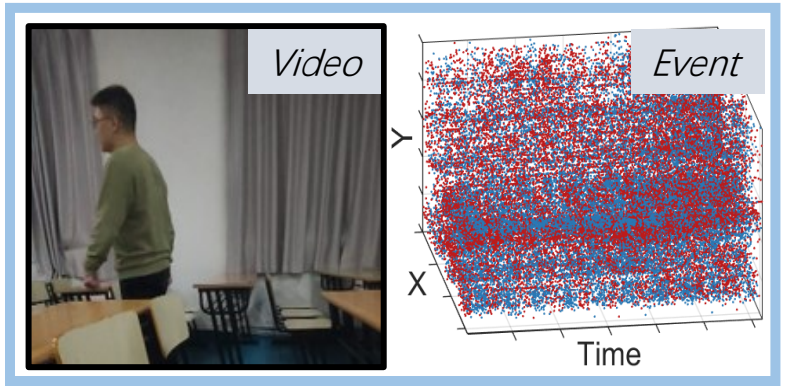
Event-Video hybrid ENF Dataset :

➢ EV-ENFD

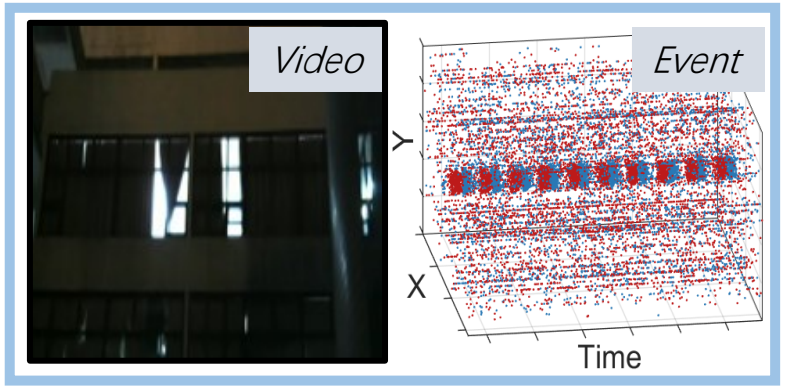
—51 sets of data, each set of data contains two video sequences and one event sequence.



Static Scenes
(16 sets)



Dynamic Scenes
(25 sets)



Extreme Lighting
(10 sets)

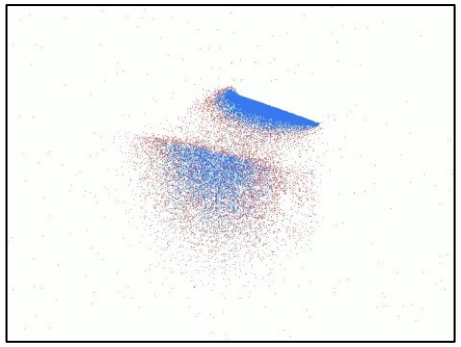
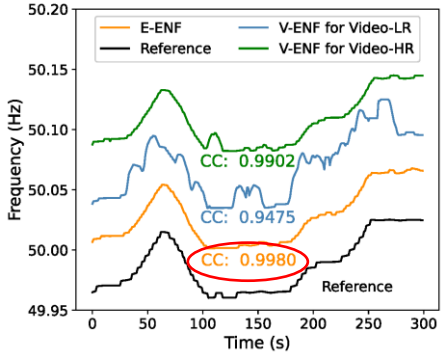
- A hybrid dataset containing both events and videos recorded in real-world lighting environments.

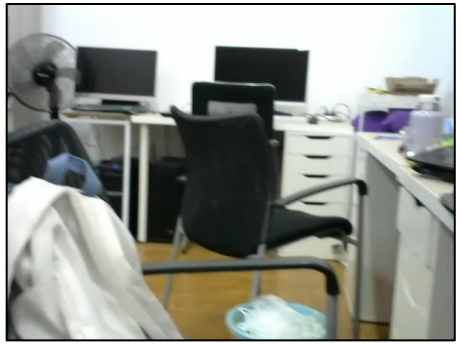
Results

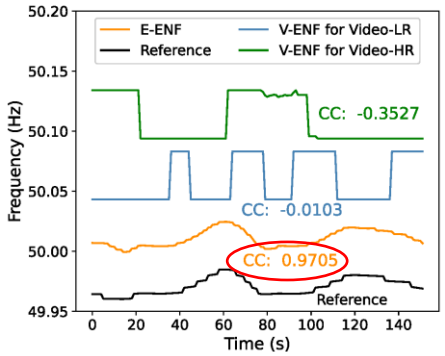
Static Scene

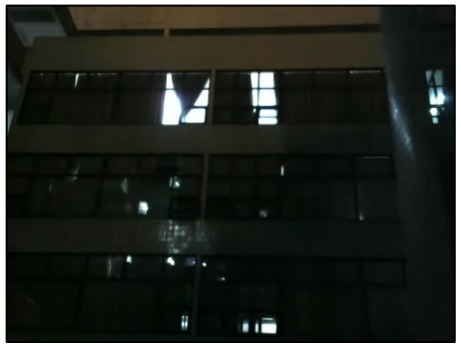
Dynamic Scene

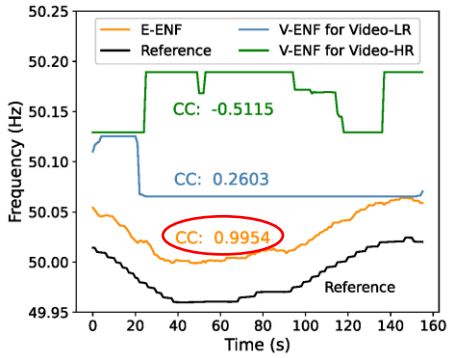
Extreme Lighting









Video

Event

Estimation

- **V-ENF** struggles with dynamic and extreme lighting scenes.
- **E-ENF** exhibits optimal performance across three distinct typical scenes.

THANKS

Project Page: https://xlx-creater.github.io/E-ENF/