


Asynchronous Perception and Control on Quadrotors

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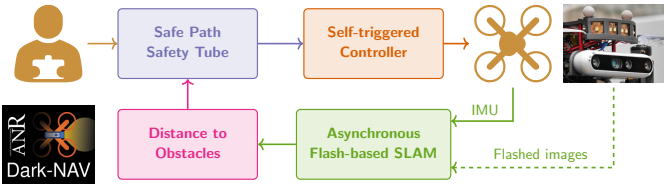
Quadrotor Challenges in Dark and Cluttered Environments

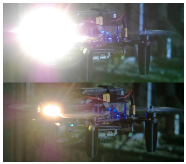
- Quadrotors widely used in **exploration and search-and-rescue** missions
- These missions are challenging in dark and cluttered environments
  - GNSS-denial $\mapsto$ visual inertial odometry for localization
  - Dark environments $\mapsto$ comptatible sensors (lightning system, . . . ?)
  - Fast exploration for search-and-rescue requires low-latency
- Traditional **synchronous** pipelines are **too slow** or **too resource-hungry**
- **Goal:** New frameworks for perception and control on quadrotors
- Two asynchronous paradigms: **flash-based** and **event-based**

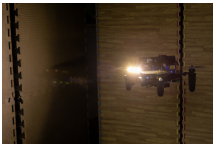
Inspection of tunnels with quadrotors

Flash-based Perception on Quadrotor

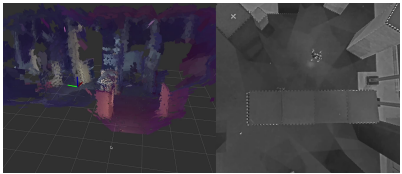
- **Dark-NAV:** from flashlight fish[1] to quadrotor strategies in the dark
- Design of a new sensor synchronizing **RGB-D images** with **light flashes**[2]
- **Visual-inertial SLAM:** map and pose from flashed images[3]







From flashlight fish to Dark-NAV quadrotor deployment



SLAM reconstruction in the dark based on flashes

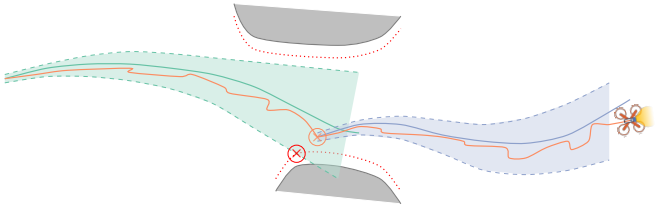
[1] Hellinger et al. *The Flashlight Fish Anomalops katoptron Uses Bioluminescent Light to Detect Prey in the Dark*, PLOS ONE, 2017.

[2] Castillo-Zamora,..., Pouthier et al. *Synchronization of a New Light-Flashing Shield With an External-Triggered Camera*, IEEE Sensors Letters, 2023.

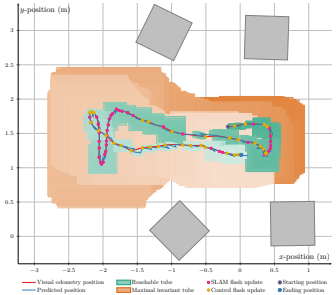
[3] Ndoye et al., *VIGS-Fusion: Fast Gaussian Splatting SLAM processed onboard a small quadrirotor*, International Conference on Advanced Robotics (ICAR), 2025.

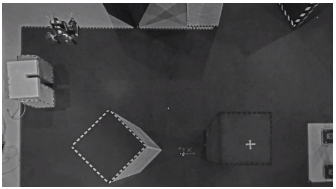
Flash-based and Self-Triggered Control on Quadrotor

- **Reachable tube** of system state → open-loop dynamics ⊕ uncertainties
- **Safety tube** → distance to obstacles and closed-loop dynamics
- **Self-triggered**[4] strategy ← trigs before reachability crosses safety limits



[4] Pouthier et al. *Guaranteed Self-Triggered Control of Disturbed Systems: A Set Invariance Approach*, Int. J. Robust Nonlinear Control (IJRNC), 2025.

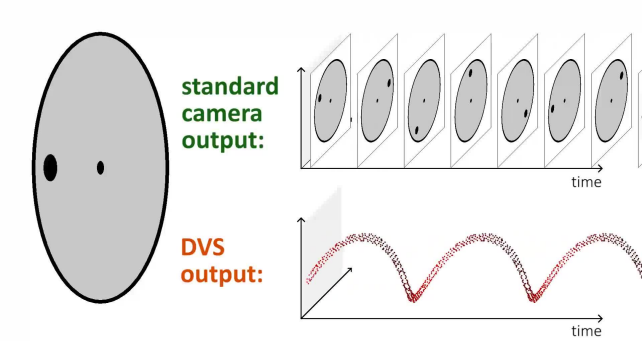




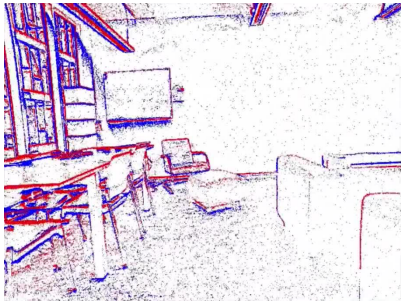
Flash-based navigation among obstacles with flashes

Event Camera: an Innovative Asynchronous Sensor

- An event camera (DVS)[5] only measures **motion in the scene**
- Stream of **events**[6] $e_k \triangleq (x_k, t_k, p_k)$ occuring on brightness changes



What the fly sees when you try to swat it



Event camera stream when moving in a room

[5] Lichtsteiner et al., *A 128× 128 120 dB 15μs Latency Asynchronous Temporal Contrast Vision Sensor,* IEEE J. Solid-State Circuits, 2008.

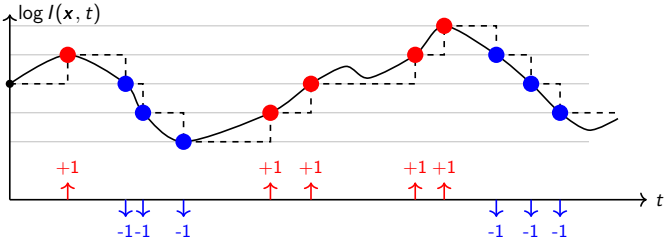
[6] Gallego et al., *Event-Based Vision: A Survey,* IEEE T-PAMI, 2022.

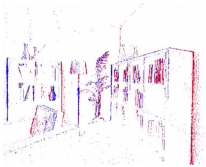
Event Camera: Event Generation Model and Opportunities

- **Events**[5,6] ← log-intensity thresholds crossing on pixel $\boldsymbol{x}_k$ at time t_k:

$$\Delta L(\boldsymbol{x}_k, t_k) \triangleq \log I(\boldsymbol{x}_k, t_k) - \log I(\boldsymbol{x}_k, t_k - \Delta t_k) = p_k C.$$

- $C \triangleq$ contrast threshold, $p_k \triangleq$ polarity (brightness increase / decrease)
- Advantages: No motion blur, **High Dynamic Range** (> 120dB vs 60dB)
- ▶ **Frame-based vision algorithms cannot be directly applied!**





Motion blur avoidance with event camera[7]

HDR capabilities of event camera driving out a tunnel[8]

[5] Lichtsteiner et al., *A 128×128 120 dB 15μs Latency Asynchronous Temporal Contrast Vision Sensor,* IEEE J. Solid-State Circuits, 2008.

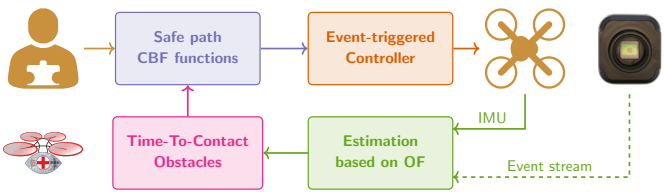
[6] Gallego et al., *Event-Based Vision: A Survey,* IEEE T-PAMI, 2022.

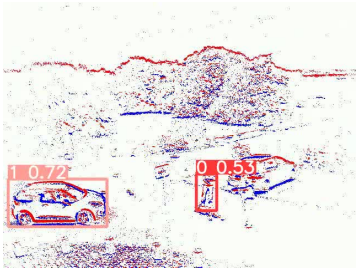
[7] Rebecq et al., *ESIM: an Open Event Camera Simulator,* PMLR Conference on Robot Learning, 2018.

[8] Gehrig et al., *DSEC: A Stereo Event Camera Dataset for Driving Scenarios,* IEEE RA-L, 2021.

Event-based Perception and Control on Quadrotor

- **Detection** of **cars** and **persons** with low-latency YOLO[9]
- State estimation based on **Optical Flow (OF)** ← directly from events
- Safe path computed on **Time-to-Contact obstacles** (no global map)





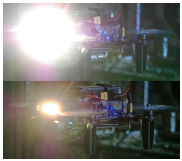
Low-latency YOLO detection onboard quadrotor[9]

[9] Amessegher, ..., Pouthier et al. *Towards Low-Latency Object Detection on Board Reactive Search-and-Rescue Drones*, Int. Symp. Saf. Secur. Rescue Robot., 2025.

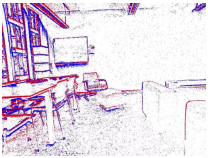
Asynchronous Strategies for Efficient and Bio-inspired Quadrotors

- **Asynchronous strategies** efficient in dark and clutter

- **Flash-based paradigm** inspired by the flashlight fish:
  - ↘ light power consumption ▶ ↗ quadrotor autonomy
  - ↘ light dissipated power ▶ ↗ light cooling



- **Event-based paradigm** inspired by the flies (*drosophila*, *etc.*...):
  - ↘ detection latency ▶ ↗ diagnosis speed
  - Optical flow pipeline ▶ fast estimation and safe navigation



Doing **less things**, *at the* **right instant**, *to* **explore further**

Thank You! - Questions

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