A Comparison between Framed-based and Event-based Cameras for Flapping-Wing Robot Perception

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This work presents an **experimental comparison** between frame-based and event-based cameras. Both technologies are analyzed considering the particular **flapping-wing robot** specifications and experimentally analyzing the performance of well-known vision algorithms.

Motivation

GRIFFIN ornithopters aim at flying long distances and performing inspection & maintenance tasks.

For this reason, they need (i) **energy efficiency**, (ii) **perception capabilities**, and (iii) **autonomy**.

GRIFFIN

Event cameras have shown to be of benefit to GRIFFIN flapping-wing robots:

- Event-based visual **guidance** [1].
- Event-based dynamic **obstacle avoidance** [2].

However, are event-based cameras a more suitable solution for ornithopter perception than frame-based cameras?

Frame-based cameras	Event-based cameras
Small	High temporal resolution
Lightweight	Low latency
Cheap	High dynamic range
Mature technology	Low power consumption

Objectives

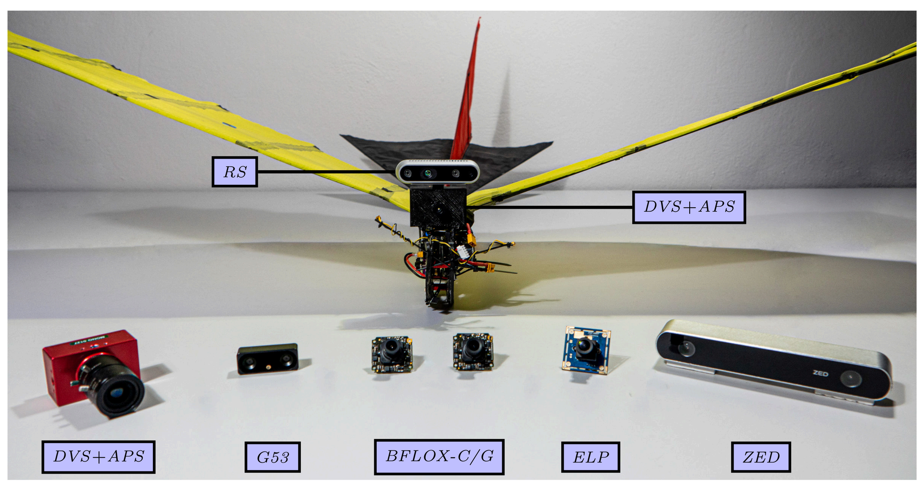
We intend to answer the following question:

Which vision sensor is more suitable for flapping-wing robots?

Methodology

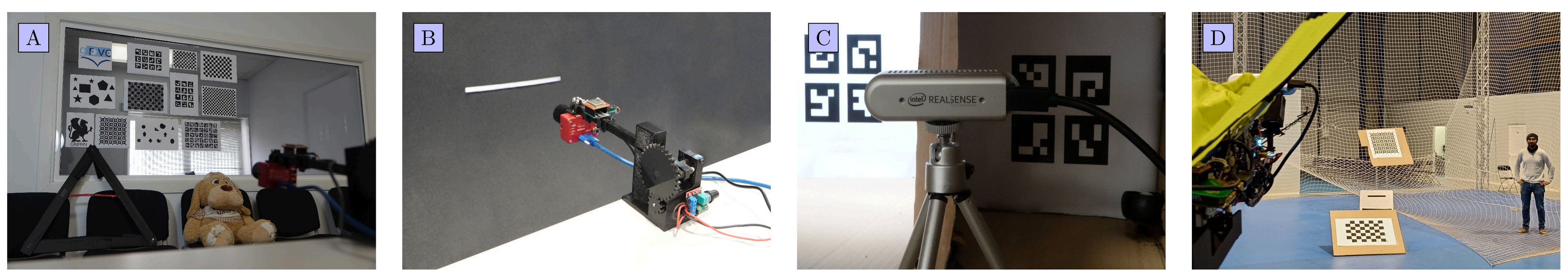
This work presents qualitative and quantitative comparisons between different vision sensors.

Name	Type	Ch.	Resolution	Dimensions (mm)	FPS	Weight (g)
DAVIS346	EVENT	1	346×260	40×60×25	APS:30	100
eCapture G53	STEREO	3	640×400	50×14.9×20	30	100
Realsense D435	STEREO	3	1280×720	90×25×25	30	340
ELP Mini720p	MONO	3	1280×720	39×39×20	30	17
StereoLabs ZED	STEREO	3	1280×720	175×30×33	60	170
mvBlueFOX MLC200wC	MONO	3	752×480	35×33×25	90	10
mvBlueFOX MLC200wG	MONO	1	752×480	35×33×25	90	10



The sensors are compared considering the **ornithopter requirements**, which can be classified into:

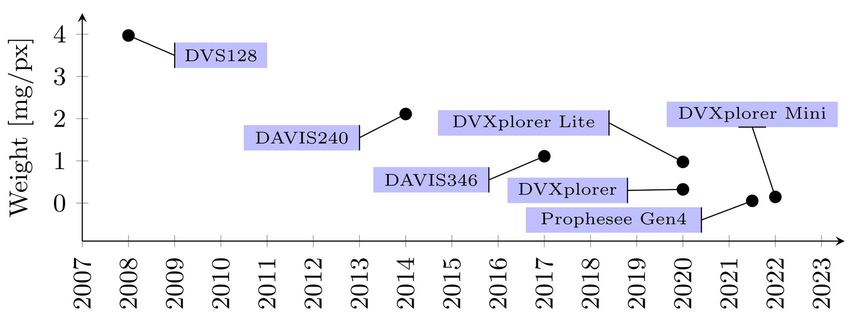
- **Platform** requirements → Payload, size, weight distribution, and power consumption.
- **Flight** requirements → Motion blur and dynamic range.
- **Application** requirements.



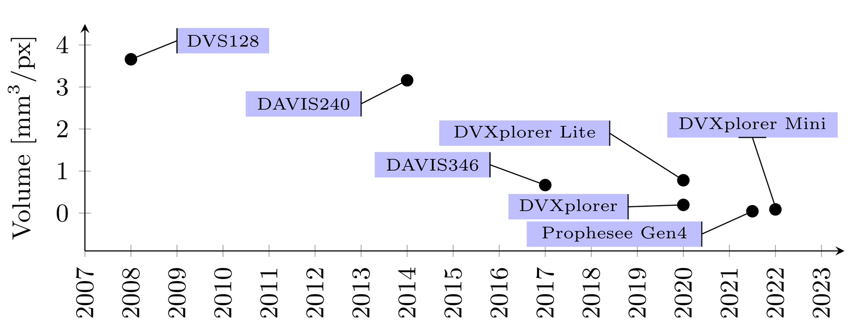
Setups used for power consumption (A), motion blur (B), and dynamic range (C) experiments. Scenario D was used to evaluate different event- and frame-based algorithms.

Platform Requirements

Weight

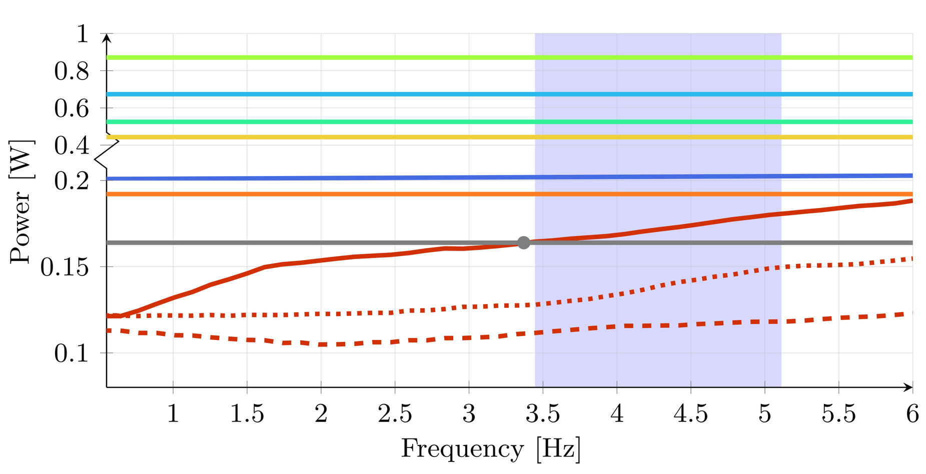


Size



- Frame cameras are still smaller and lighter than event cameras.
- The evolution of event cameras technology **tends to smaller and more lightweight devices**.

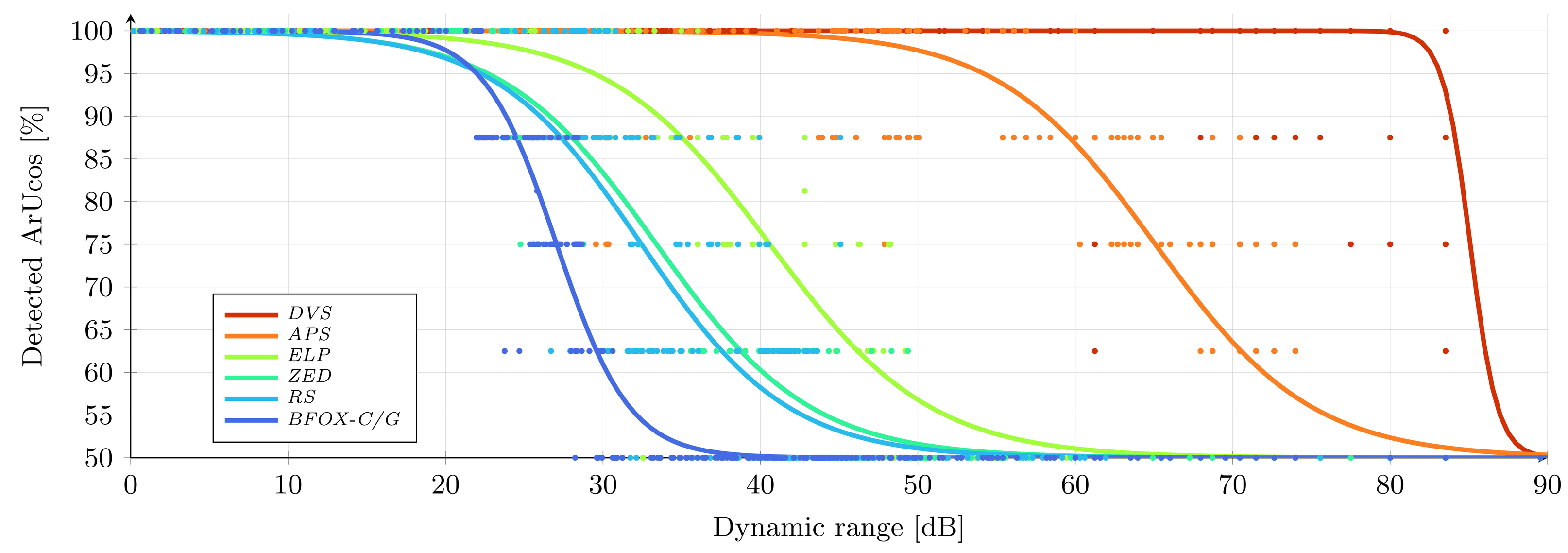
Power Consumption



- The power consumption depends on the number of events generated.
- DVS reported one of the lowest consumptions when flapping at ∼[3.5, 5] Hz (typical range of our ornithopters).

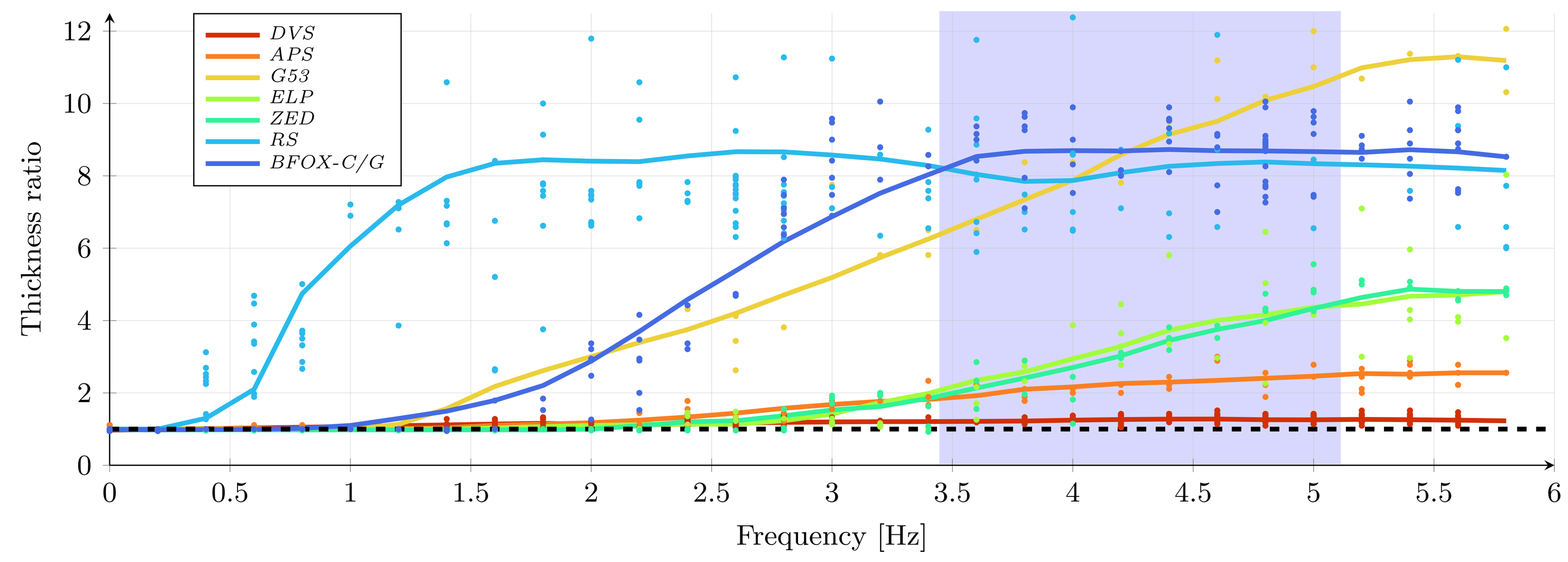
Flight Requirements

Dynamic Range



- We assess dynamic range by evaluating the capacity of detecting **ArUco markers**.
- ArUco boards were separated by a plate. One board was illuminated with **constant lighting**, while the second one with **increasing lighting**.
- Events were accumulated at 30 Hz to **reconstruct frames** using E2VID.

Motion Blur



- We evaluated the **blur** produced by a line as a function of the **camera pitch rate**.
- The events from DVS were accumulated in **event images** of 1000 events.
- The amount of **blur** was evaluated as the relative increase in its **thickness**.

Application Dependent Requirements

We evaluate the performance of commonly used **computer vision algorithms** using **events** and **images** collected on board the **E-Flap GRIFFIN ornithopter**.

The ornithopter flew over: a 7×8 **checkerboard**, a pattern with two **horizontal lines**, and two **people**. Pose ground truth was obtained using the **GRVC Robotics Lab OptiTrack MCS**.

	Representation	Algorithms
Corner detection	Single events	Harris, eHarris*
VIO	Event images	VINS-MONO, USLAM
Line detection	Event images	Hough transform
Human detection	Reconstructed frames	YOLO

	Corner detection			VIO			Line detection			Human detection			
	Pr.	Rec.	Freq.	E_{RMS}	E_σ	ε_{goal}	E_ρ	N	Freq.	Acc.	Pr.	Rec.	Freq.
APS	0.972	0.806	39.92	**0.828**	**0.439**	**0.231**	0.529	1.886	39.92	**0.960**	0.960	**1.000**	39.92
DVS	0.891	**0.909**	**0.97M**	0.879	0.607	0.277	0.377	**1.893**	**119.903**	0.909	**0.985**	0.921	**57.69**
RS	**1.000**	0.014	29.96	1.178	0.698	0.304	**0.255**	0.659	29.96	0.759	0.869	0.857	29.96

- The results using single events and e.img. tend to **outperform** those obtained with intensity frames.
- Event-based methods provided the **fastest input rates** (i.e., potentially**faster responses**).

Conclusions

- Our results suggest **event cameras** as the most suitable sensors for **ornithopters**.
- It also evidences some **open challenges** for event-based vision on board flapping-wing robots.
- Frame-based methods are in a considerably **mature stage** w.r.t. event algorithms.
- The growth of the event vision community suggests **novel**, **faster**, and more **robust** algorithms.

References

[1] A. Gómez Eguíluz *et al.*, "Why fly blind? event-based visual guidance for ornithopter robot flight," in *IEEE/RSJ IROS*, 2021.

[2] J. P. Rodríguez-Gómez *et al.*, "Free as a bird: Event-based dynamic sense-and-avoid for ornithopter robot flight," *IEEE RA-L*, 2022.

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