Asynchronous Perception and Control on Quadrotors

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Quadrotors play a crucial role in difficult tasks such as exploration, inspection and search-and-rescue in dark and cluttered environments. These are usually GPS-denied environments, and the positioning required for autonomous navigation of quadrotors must therefore be based on onboard visual inertial odometry. This embedded localization can quickly become computationally and energy intensive, and even prove ineffective if the complete perception and control loop is designed in a conventional, periodic manner. As an alternative, we propose rethinking the way quadrotors perceive and navigate their environment based on asynchronous strategies, which can be observed in many animals in nature.

Consider, for example, visual inertial odometry-based navigation of a quadrotor in the dark. Such a strategy should typically be based on periodic image capture and therefore constant illumination of the scene by the lighting system on board the quadrotor. Such a strategy is ineffective because (i) it consumes a lot of energy to keep the lighting system on throughout the navigation and (ii) it can lead to the destruction of the lighting system due to overheating. In contrast, observation of the flashlight fish (*Anomalops katoptron*) shows its ability to navigate the dark waters of the Pacific Ocean by relying on light flashes (as studied by Hellinger 2017). This flashing behavior has been transposed to a quadrotor by proposing an asynchronous perception and navigation strategy (Figure 1). Such strategy relies on a new flashed-images sensor proposed by Castillo-Zamora 2023, whose capture is triggered asynchronously by a self-triggered SLAM and a self-triggered controller as the one proposed by Pouthier 2025.

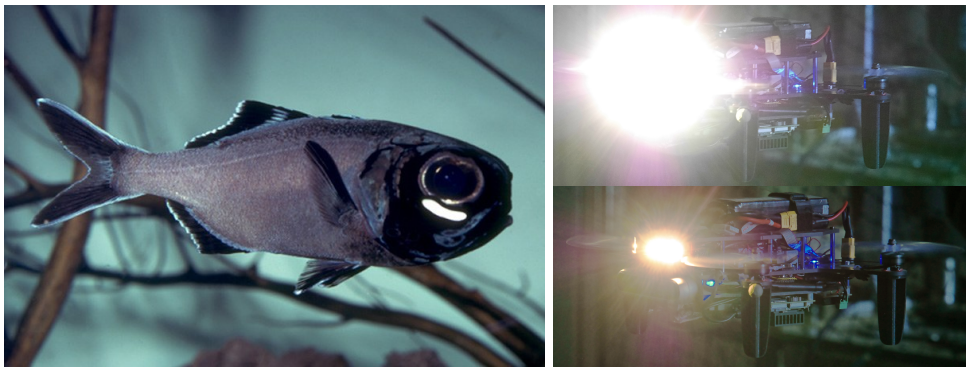

Figure 1: Bioluminescence of the flashlight fish inspires the deployment of a flash-based strategy on a quadrotor. Credits: Kenneth Lucas (left), Marchand Nicolas (right).

Visual inertial odometry for a fast quadrotor in cluttered environments can also rely on an event camera (as done by Niu 2025 for instance). This type of camera monitors changes in brightness in the scene, inspired by the vision of certain types of fast flying insects such as Drosophila (Figure 2). Event sensors encode logarithmic changes in brightness on each pixel asynchronously with a polarity describing the increase or decrease in brightness. These cameras are particularly useful for navigation in dark or sunny environments due to their very high dynamic range. They also allow for faster navigation because they eliminate the motion blur effect commonly seen with standard cameras. Event-based vision has been surveyed by Gallego 2020. However, the events collected from the camera require a rethinking of perception and control algorithms to ensure stability and estimation accuracy. In particular, it seems inefficient to process events on fixed-duration accumulation windows when the speed of the quadrotor is likely to change during navigation. Ongoing and future work explores the possibilities of processing asynchronous event packets with flush triggers based on stability or the presence of obstacles.

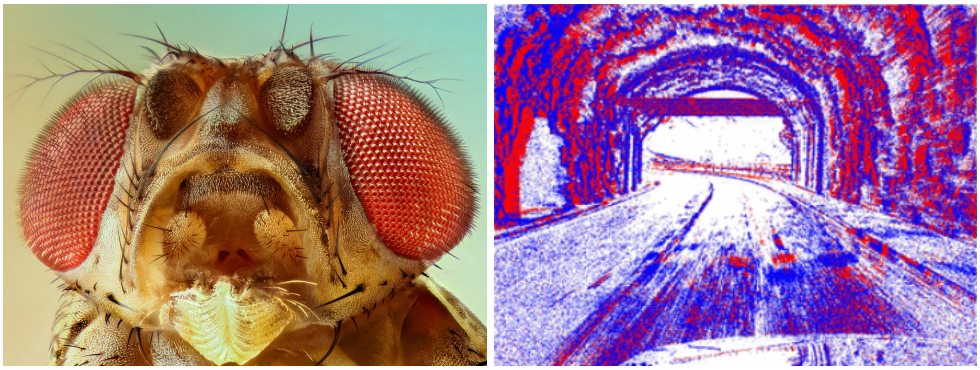

Figure 2: Output of the event camera mimics the vision of Drosophila based on changes in ambient light. Credits: Getty Images/iStockphoto (left), Gehrig *et al.*, DSEC dataset, IEEE RA-L, 2021 (right).

The work presented here leads us to rethink how perception and control are achieved on board quadrotors. Biomimetic inspiration makes it possible to improve navigation by considering the asynchronous paradigm. This involves integrating new types of sensors and inventively designing state estimators and controllers.

References

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