This paper has been accepted for publication at the Workshop on Challenges of Flapping-wing aerial robots of the IEEE International Conference on Robotics and Automation (ICRA), Philadelphia, 2022. ©IEEE 2022

Stabilizing Event Data on Flapping-wing Robots for Simpler Perception

J.P. Rodríguez-Gómez, G. Gallego, J.R. Martínez-de Dios, A. Ollero

***Abstract*— We propose a stabilization method for event cameras mounted onboard flapping-wing robots. Differently from frame-based cameras, event cameras do not suffer for motion blur that typically occurs due to strong changes in the camera orientation. The method intends to offer an alternative to heavy gimbals mounted on ornithopters. It has been tested on event data acquired by a large-scale ornithopter (1.5m wingspan).**

I. INTRODUCTION

Ornithopters entail different challenges for robot perception. First, flapping strokes produce vibrations that hampers onboard perception. This particularly affects frame-based cameras, as the flapping motion may produce motion blur in the frames. Second, flapping-wing robots report strict payload limitations constraining the type and amount of onboard sensors. Besides, hardware installation is subject to specific weight distribution requirements to avoid compromising the robot's aerodynamics and flight performance. Third, ornithopters mount lightweight batteries setting power limitations for the onboard hardware.

Event cameras offer several advantages for robot perception: a very high dynamic range ($>$120 dB), µs resolution and a moderate weight. They also have minimal motion blur and power consumption, which are relevant for the above-mentioned challenges. However, since the data they produce is markedly different from that of frame-based cameras, new methods need to be developed to unlock their advantages [1].

We present a method to stabilize the visual data produced by an event camera onboard a large-scale ornithopter. It serves as an alternative to mechanical stabilizers (e.g., gimbals), whose installation is limited by the robot's payload and geometry. We assess the benefits of stabilization on event data acquired using the ornithopter in [2], for tasks such as linear velocity estimation.

II. MAIN IDEA

The proposed method aims at stabilizing events in terms of the camera's orientation R, which can be estimated using, e.g., an IMU [3] (most modern event cameras, such as the DAVIS346 or Prophesee Gen3, have an integrated IMU).

Each event $e_k = (\mathbf{x}_k, t_k, p_k)$ conveys the pixel coordinates $\mathbf{x}_k = (x_k, y_k)^\top$, timestamp t_k and sign $p_k \in \{+1, -1\}$ of an asynchronous brightness change, and it is stabilized as:

$$\mathbf{x}'_k \sim K R(t_k) K^{-1} \mathbf{x}_k, \qquad (1)$$

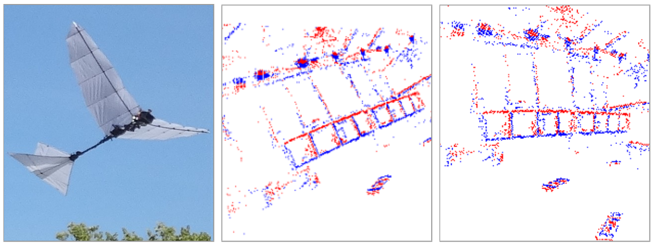

Fig. 1: Left) Ornithopter [2]; center) original events; right) stabilized events with respect to the initial camera orientation.

(in homogeneous coordinates) where K contains the camera's intrinsic parameters. Each event e_k is warped with a different orientation $R(t_k)$, computed by linear interpolation of two nearby orientations. This scheme compensates the local motion (due to angular velocity [4]) and stabilizes the events with respect to a reference (global) orientation.

III. RESULTS AND DISCUSSION

The proposed algorithm is tested on sequences from the flapping-wing perception dataset [2]. Fig. 1-center shows an example of a set of events, visualized as an image. Fig. 1-right shows the resulting events stabilized with respect to the initial camera orientation. The proposed algorithm reduces on average a 100 pix displacement of the events in the image with respect to the non-stabilized events. Besides, the method has an average latency of 70 ns per event, 14× smaller than the event's temporal resolution (µs). Our research assesses the benefits of event stabilization on the estimation of the camera's linear velocity using an adaptation of the Expected Residual Likelihood (ERL) method [5]. The results show that stabilized events provide more robust linear velocity estimates than those obtained by non-stabilized events, or by using grayscale frames, which suffer from motion blur.

REFERENCES

[1] G. Gallego, T. Delbruck, G. M. Orchard, C. Bartolozzi, B. Taba, A. Censi, S. Leutenegger, A. Davison, J. Conradt, K. Daniilidis, and D. Scaramuzza, "Event-based vision: A survey," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 44, no. 1, pp. 154–180, 2022.

[2] J. Rodríguez Gómez, R. Tapia, J. Paneque, A. Gómez Eguíluz, P. Grau, J. Martínez de Dios, and A. Ollero, "The GRIFFIN perception dataset: Bridging the gap between flapping-wing flight and robotic perception," *IEEE Robot. Autom. Lett.*, vol. 6, no. 2, pp. 1066–1073, 2021.

[3] R. G. Valenti, I. Dryanovski, and J. Xiao, "Keeping a good attitude: A quaternion-based orientation filter for imus and margs," *Sensors*, vol. 15, no. 8, pp. 19 302–19 330, 2015.

[4] G. Gallego and D. Scaramuzza, "Accurate angular velocity estimation with an event camera," *IEEE Robot. Autom. Lett.*, vol. 2, no. 2, pp. 632–639, 2017.

[5] A. Jaegle, S. Phillips, and K. Daniilidis, "Fast, robust, continuous monocular egomotion computation," in *IEEE Int. Conf. Robot. Autom. (ICRA)*, 2016, pp. 773–780.

This work was funded within GRIFFIN ERC Advanced Grant (Action 788247) from the European Research Council.

J.P. Rodríguez-Gómez, J.R. Martínez-de Dios and A. Ollero are with the GRVC Robotics Laboratory of the University of Seville, Seville, Spain.

G. Gallego is with the Technische Universitat Berlin, the Einstein Center Digital Future, and the SCIoI Excellence Cluster, Berlin, Germany.