Event-based imaging for visualization and measurement of turbulent flows

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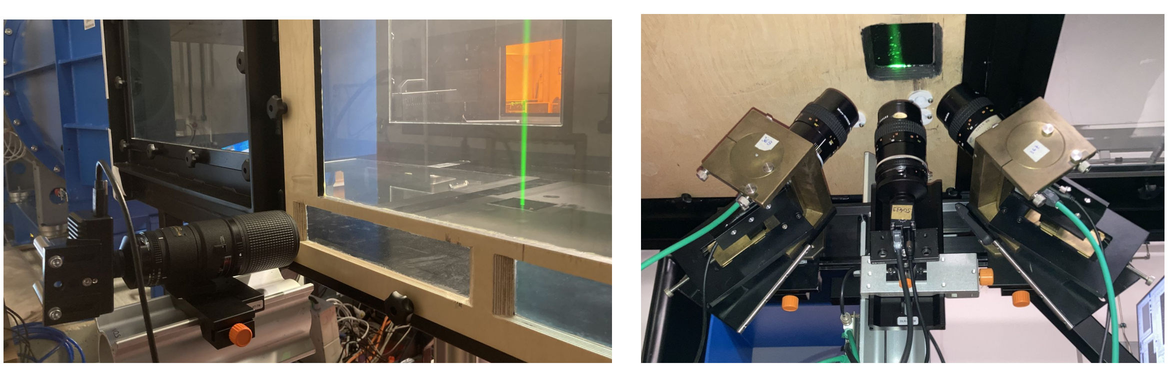
Key-words: experiment, turbulent boundary layer, event-based imaging, particle tracking velocimetry, PIV

Abstract:
Event-based vision (EBV), dynamic vision sensing (DVS) or neuromorphic imaging describe a rather new sub-field within computer vision, differing considerably from classical frame-based imaging (Gallego et al., 2022). Event cameras only record contrast changes (“events”) within the scene, either going from dark to bright (positive event) or bright-to-dark (negative event). As the pixels “fire” independently an asynchronous stream of *events* results that consist of pixel coordinates, a time stamp and a binary contrast change signal. Static areas in the imaged scene provide no information; intensity data is essentially not available. At the same time, event cameras feature a very high dynamic range (>110 dB) and are considerably more sensitive than conventional CCD/CMOS cameras.

In the context of particle imaging, narrow event streaks are produced in the space-time domain and can be processed to provide 3D-3C particle tracking velocimetry (PTV) data.The recently introduced event-based imaging velocimetry (EBIV) technique combines EBV and light sheet illumination to provide time-resolved, planar (2D-2C) velocity fields (Willert and Klinner, 2022; Willert, 2023)). In this work we apply EBIV to obtain time-resolved velocity profiles of a turbulent boundary layer (TBL) in analogy to the profile-PIV technique (Willert, 2015). The latter has been used to simultaneously provide detailed velocity statistics and time-resolved data of turbulent flows (see eg. Willert et al., 2017). The field of view is generally illuminated by a high-speed pulsed laser that is collimated into a narrow light sheet.

Fig. 2 presents exemplary velocity statistics obtained with EBIV at the 1m wind tunnel of the DLR Institute of Aerodynamics and Flow Technology (Göttingen) with $U_\infty = 5.2$ m/s, $\mathrm{Re}_\tau = 520$ using the setup shown in Fig. 1(a). A viscous scale of $\nu/u_\tau = 67\,\mu$m and an image magnification of 84 pixel/mm results in a resolution of 5.7 pixel per viscous unit. The data was processed using a multiple-frame, cross-correlation based PIV algorithm but can also be handled by 2D particle tracking algorithms. The described system is capable of providing data quality on par with currently used, considerably more expensive, high-speed PIV hardware and is currently suitable for measurements up to 10 m/s on a field of view of 50 mm.

A second EBIV configuration (c.f. Fig. 1(b)) captured the flow in the viscous sublayer of the TBL using a thin wall-parallel light sheet of <1 mm thickness and a set of three synchronized event-cameras. The ultimate aim of this setup is to estimate the unsteady wall shear stress field through triangulation of the recorded particle tracks which will be addressed in the proposed contribution. The dynamics of the near wall flow can already be visualized in the raw event data for which two examples are shown in Fig. 3, although the static imagery can only partially reveal the true particle motion.



(a) (b)

Figure 1: *(a): velocity profile measurement setup using an event-camera; (b): triple-event camera setup for particle tracking in the viscous and buffer layers of a TBL.*

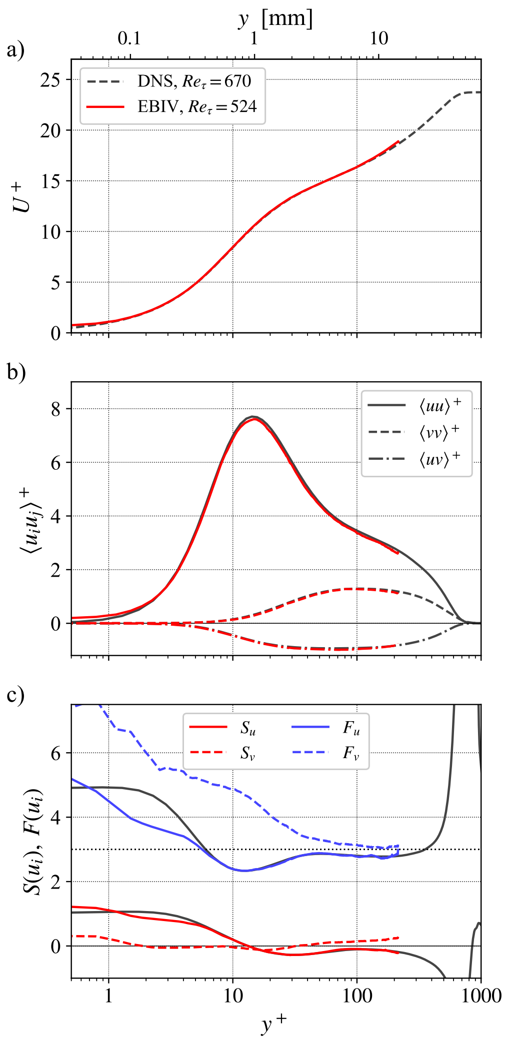


Figure 2: *Velocity statistics obtained with EBIV, using three records of 10 s duration (raw data ≈3GB), compared to DNS data of similar Reynolds number by Schlatter and Örlü (2010).*

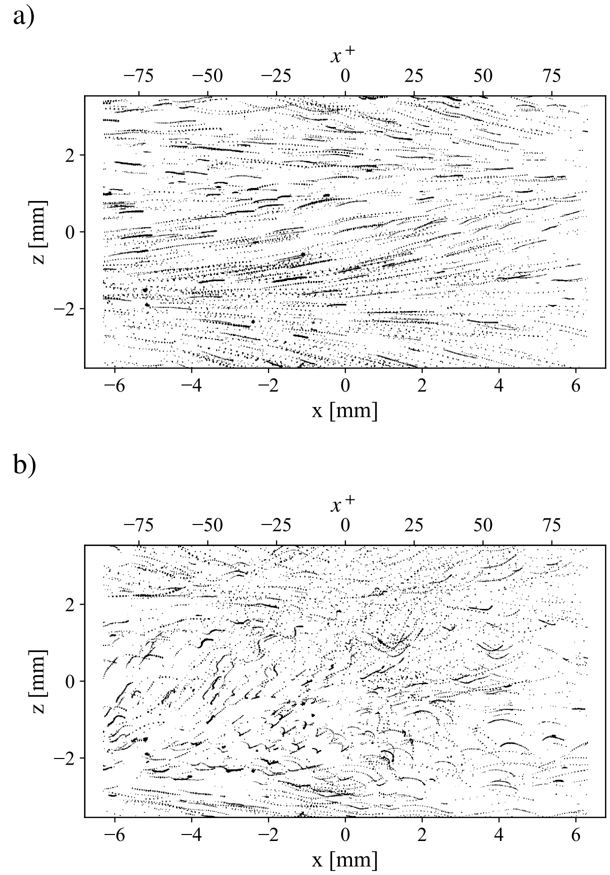


Figure 3: *Visualizations of the near wall flow ($y^+ < 8$) with mean flow left-to-right; (a) sweep event at $z = -2$ mm, (b) streaklines produced by a reverse flow event near the lower center (particles briefly moving upstream, best observed if animated).*

References

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