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Performance Comparison of Area-scan and Event-based Image Sensors

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Summary: Conventional area-scan and event-based sensors are compared in their performance using the event detectability ECD, i. e., how much relative irradiance difference is required to detect an event and the latency to detect an event. In addition, the nonuniformity of event-based sensors is studied with respect to the false event detection probability (FDNU), the event detection nonuniformity (ECDNU) and the latency at different irradiation levels.

Keywords: Sensor characterization, event-based, area-scan, performance, comparison

Introduction

Event-based cameras are bio-inspired sensors that differ from conventional area-scan cameras. They asynchronously measure pixel brightness changes, and output a stream of events that encode the time, location and sign of the brightness changes. This offers several advantages: high temporal resolution, very high dynamic range (120 dB), low power consumption, and a compressed output stream. Therefore, they have a large potential for robotics and computer vision in challenging scenarios for traditional cameras. A first proposal for a performance characterization of event-based sensors was made in [1] and the concept of change detectability was introduced by [2] to compare area-scan and event-based image sensors.

Here we add an analysis of nonuniformities and a direct performance comparison between three event-based and three conventional area-scan sensors: a) Prophesee, gen. 3.1 (15 µm pixel); b) Prophesee, gen. 4.1 (4.86 µm pixel); c) DAVIS 346, (18.5 µm pixel) and area-scan sensors with pixel sizes and spatial resolution comparable to the Prophesee, gen. 4.1: d) Sony IMX174, (5.86 µm pixel) t_{exp} = 9 ms, max frame-rate 105 fps, corresponds to 9.5 ms latency; e) Sony IMX287, (6.9 µm pixel), t_{exp} = 3.03 ms, max frame-rate 321 fps, corresponds to 3.12 ms latency; f) Sony IMX537 with binning, (5.48 µm pixel), t_{exp} = 1.3 ms, max frame-rate 582 fps, corresponds to 1.72 ms latency.

Event-based sensor characterization

Experimentally determining the irradiation contrast ΔE necessary for generating one event for given mean irradiance level E and event threshold settings consists in gradually increasing the stimulus step until an event is generated. In a noise-free world, minimal found stimulus amplitude always results in an event when applied. In the real world conditions, the very same pixel will react differently to the same stimulus due to its, possibly different, initial condition, electronic noise, etc. Therefore, for event-based sensor characterization it has been proposed to operate with "event probability" instead [3, 1]. It is defined as $p = \frac{M}{N}$, where M the number of event responses, N the number of stimuli applied. Event probability dependency on the stimulus amplitude in the presence of noise has an "S"-shape, and is therefore named *S-curve*. The acquisition of S-curves has been done on an EMVA 1288 Standard conform setup as described in [2].

Event contrast detectability ECD

The S-curve shows how much irradiance change ΔE is required to detect an event. Here, the *event contrast detectability* ECD is defined as

$$\text{ECD} = \frac{\Delta E}{E_{50\%}} = \frac{1}{\theta} = \frac{1}{E_{50\%}\frac{\mathrm{d}S(E)}{\mathrm{d}E}}, \qquad (1)$$

where $E_{50\%}$ is the irradiance at the 50% probability of the S-curve and $\mathrm{d}S(E)/\mathrm{d}E$ the (steepest) slope of the S-curve at this point. ECD is the inverse of the *change detectability* θ defined in [2]. Graphically, ΔE means the distance between the zero and one probability crossings of the $\mathrm{d}S(E)/\mathrm{d}E$ line. Thus ECD is a good measure for the relative irradiance change required to detect an event. Depending on the required probability for event detection, the relative irradiance change might be smaller or larger than ECD.

Event detection with area-scan sensors

In [2] it was shown that any area-scan sensor can be used for event detection that there is a direct relation between signal-to-noise ratio and change detectability for area-scan sensors with

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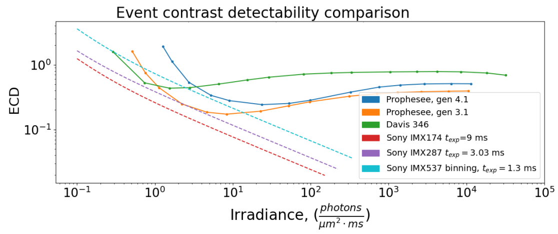

Fig. 1: Event contrast detectability comparison for area-scan and event-based sensors.

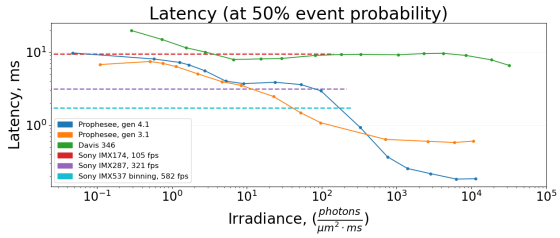

Fig. 2: Latency comparison for event-based and area-scan sensor

a latency, which is the inverse of the maximum frame rate of the sensor:

$$\text{ECD} = \frac{2\sqrt{\pi}}{\text{SNR}(\mu_p)} = 2\sqrt{\pi}\frac{\sqrt{(\sigma_d^2 + \eta E A t_{\text{exp}})}}{\eta E A t_{\text{exp}}}. \quad (2)$$

The equation on the right gives ECD for a linear sensor with the variance σ_d^2 of the temporal dark noise and a quantum efficiency η according to the EMVA 1288 standard [4].

Results

Standard linear industrial area-scan sensors can detect events at lower relative irradiance changes but lack the high dynamic range of event-based sensors (Fig. 1). Event-based sensors have the additional advantage that the latency at high irradiation levels can be significantly lower than for area-scan sensors, where the latency is constant and just the inverse of the frame rate (Fig. 2).

The nonuniformity measurements of event-based sensors show several interesting effects.

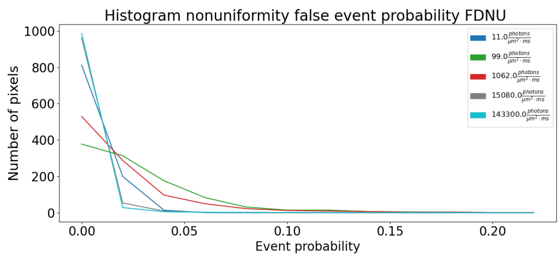

Fig. 3: Histogram of the false event detection probability under static irradiation for positive events with the Prophesee generation 4.1 sensor.

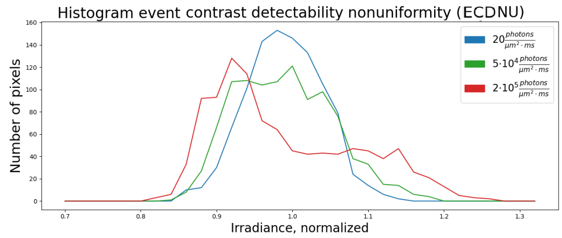

Fig. 4: Histograms of irradiance nonuniformity for 50% positive event probability for the Prophesee generation 4.1 sensor at irradiances as indicated.

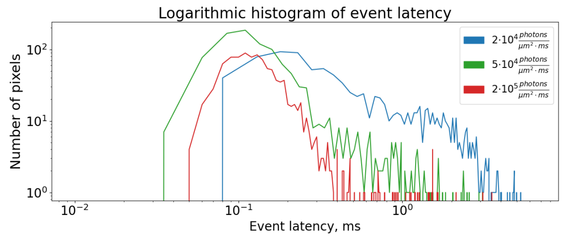

Fig. 5: Logarithmic histograms of positive event latency for 50% event probability at irradiances as indicated for the Prophesee, generation 4.1 sensor.

The false event detection probability nonuniformity (FDNU), when no irradiance change happens, is irradiance dependent and can be quite high (Fig. 3). The event contrast detectability nonuniformity (ECDNU), defined by the irradiance required for each pixel to reach a 50% event probability, is in the order of 10%. The distributions widen at higher irradiance and become skewed (Fig. 4). The histogram for the latency measured at each pixel shows an even wider distribution (Fig. 5). At low irradiance a significant fraction of the pixels have a latency which is more than ten times higher than the average latency.

References

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