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Event-based automatic focusing under photon-limited conditions

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Abstract: We present an efficient autofocusing method using the event sensor. Taking advantages of the event sensing with a high dynamic range, our method could achieve rapid autofocusing under photon-limited conditions.

1. Introduction

Autofocusing is widely used in various imaging systems to ensure that sharp images can be captured for further analysis [1, 2]. Many autofocusing methods have been proposed and a majority of them rely on a z-stack of high-quality focal images, which are not always accessible. For example, in microscopy imaging, intense illumination may damage the specimen, so the autofocusing procedure usually has to work in photon-limited conditions. When using conventional frame-based sensors, we usually need to increase the exposure time or gain, at the expense of a low speed and a high noise level. The event sensors, on the other hand, have much higher sensitivity and dynamic range, which make them work well in the dark. The event sensors have been applied to various tasks, including feature tracking, motion estimation, and speckle analysis [3–6]. In this work, we demonstrate the photon-limited autofocusing in bright-field microscopy using the event sensor.

2. Method

Unlike conventional imaging sensors that record the absolute intensity of the scene, the event sensor is bio-inspired to capture brightness changes. When the sensor pixel detects brightness changes beyond the threshold, it records an event, which is represented as $e_i = (x_i, y_i, t_i, p_i)$, where i is the event index, (x_i, y_i) are the pixel coordinates on the sensor, t_i is the trigger time, and $p_i \in \{+1, -1\}$ represents the brightness increase or decrease.

During the axial scanning procedure, the brightness has the largest variations when it comes close to the focal plane, triggering a large amount of events, while at the focal position very few events are triggered. Knowing the scanning speed, each focal position f_z corresponds to a certain timestamp f_t. In our proposed method, we integrate the events within a fixed time window Δt by counting the number of events. Through a fast axial scan, we can quickly determine the two timestamps with the largest brightness change, forming a time window T. Then the focal position f is found at the time that minimizes the number of events within this window:

$$f_t = \arg\min_{t \in T} \Big(\sum_{x_i, y_i} \sum_{t}^{t+\Delta t} [e_i] \Big), \tag{1}$$

where $[e_i]$ represents the number of event occurrences.

3. Experimental results

In the experiment, we use a commercial bright-field microscopy (Eclipse Ni-U, Nikon) with a 40× objective lens. The sample (HIGHRES-2, Newport) is continuously shifted using a linear translation stage (WN262TA20, Winner Optics). The event sensor (DAVIS346, iniVation) is connected to the TV port of the microscope. In the axial scanning procedure, we first position the sample at about 150 µm above the focal plane, and then translate the sample axially by 300 µm. The scanning speed is set at 300 µm/s, so that the scanning process is completed in 1 second. We first present the results using a full illumination from the built-in 100 W Halogen lamp. The z-stack of focal images captured using a conventional active pixel sensor is shown in Fig. 1a. The exposure time is 1 ms and the frame rate is 25 fps. Since the event sensor automatically detects the brightness changes in the scene, it does not require setting the exposure time or frame rate. The proposed method using an integration time of 50 µs is numerically compared with the conventional autofocusing methods introduced in [2] and the results are shown in Fig. 1b. When the sample is illuminated by sufficient light intensity, both frame-based autofocusing methods and the proposed event-based autofocusing method could indicate the correct focal position, except for histogram

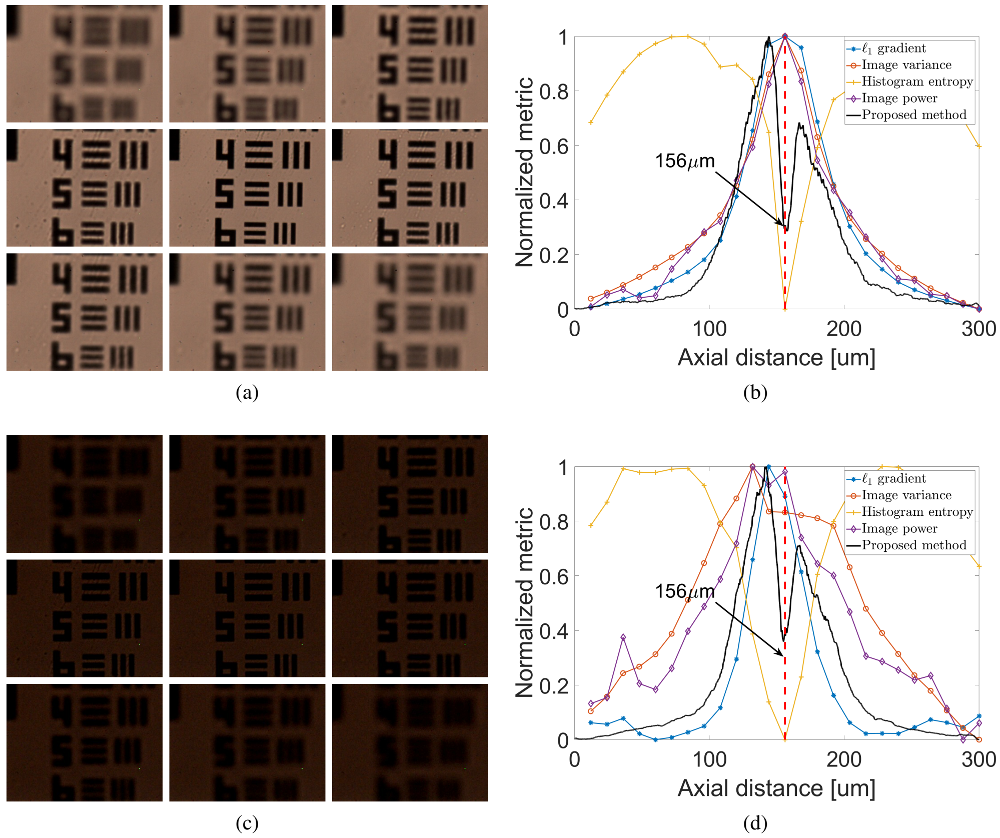

Fig. 1: Experimental results under sufficient illumination and photon-limited conditions

entropy method due to the simple pattern of the resolution target. All methods except histogram entropy indicates the focal position to be 156 µm. Then, we repeat the experiment but decrease the illumination power of the lamp to 20% using the intensity dial. The focal images captured using the same settings are shown in Fig. 1c. Due to the original images are too dark under the photon-limited conditions, we increase their intensity values by a factor of 2 for a better visual inspection but the image qualities are still poor with low signal-to-noise ratio. The corresponding numerical results are shown in Fig. 1d. Conventional frame-based autofocusing methods fail to give correct focus results since they depend on the high-quality focal images. On the other hand, the proposed event-based method could still have accurate result since it only detects brightness changes regardless of the absolute intensities.

4. Conclusion

In this paper, we propose a new autofocusing method using the event sensor. Experimental results show its superiority in photon-limited conditions.

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