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Removing wall redundancy in non-line-of-sight object-tracking using neuromorphic imaging

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Abstract: It is crucial to consider the influence of the relay wall in intensity-based non-line-of-sight (NLOS) imaging applications. In this work, we propose a neuromorphic imaging technique for NLOS object-tracking that is unaffected by the relay surface.

1. Introduction

Recent years have witnessed tremendous advances in the field of non-line-of-sight (NLOS) imaging [1], which have broad applications encompassing object tracking, 3D reconstruction, posture estimation, etc. The conventional camera for the frame-based method is focused on the relay wall to collect information, which results in a mixed pattern including useful speckle grains and redundant walls [2]. Therefore, the conventional method needs to first capture multiple frames for the pixel-wise mean image and computes the ratios in order to remove the redundancy of the relay wall [2]. As a result, speed and efficiency are highly limited. Neuromorphic vision sensors only respond to per-pixel brightness changes asynchronously [3] with a high temporal resolution, high dynamic range, and low latency, which promotes motion detection with speckles [4]. Moreover, neuromorphic imaging does not respond to the static relay wall, and speckle events of the moving object can be collected directly. In this work, we use neuromorphic imaging techniques to solve the relay wall redundancy in NLOS object-tracking.

2. Principle and experiments

A schematic of the NLOS tracking setup is presented in Fig. 1, which includes an illumination laser (Thorlabs, HNL100L) and corresponding beam expander (Thorlabs, BE10M-A). A diffuse reflective object is selected as the hidden object and is mounted on a motorized stage. A neuromorphic camera (iniVation, DAVIS 346) and a 20× objective lens (Newport, M-20X) are employed to simultaneously collect speckle event and frame images. Therefore, each realization of generated speckle pattern $I(u)$ in the virtual detector (VD) surface can be expressed as the squared modulus of the Fourier transform of the complex object field [5]

$$I(u) = |\mathscr{F}[f(x)]|^2, \tag{1}$$

where $\mathscr{F}$ denotes a Fourier transform, $f(x)$ is the field reflected by the diffuse object. u denotes a 2D coordinate in the measurement plane, and x denotes a 2D spatial coordinate vector in object space.

The NLOS tracking system can be simplified as a linear system and the object micro-motion can be calculated from the cross-correlation between two speckle patterns [2, 4]. For the frame-base method, the primary speckle component can be isolated by getting averaged out in the mean image I_{mean} and computing the ratio images [2]

$$I_k^{ratio} = \frac{I_k^{raw}}{I^{mean}}, \tag{2}$$

where I^{mean} is the pixel-wise mean image of the collected image sequence $[I_1^{raw}, I_2^{raw}, \ldots, I_k^{raw}]$.

The speckle patterns will shift as the object moves, and events $e_k = (x_k, y_k, t_k, p_k)$ will be generated when the brightness changes reach the threshold. A 2D intensity image can be formulated by accumulating the events within a certain time duration and can be expressed as [4]

$$I_{events} = \sum_{t_k \in \Delta t} p_k T \delta(x - x_k, y - y_k), \tag{3}$$

where T denotes the threshold, p_k stands for the binary polarity and δ is a Kronecker delta function.

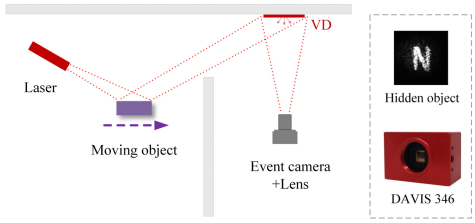

Fig. 1. Experimental configuration.

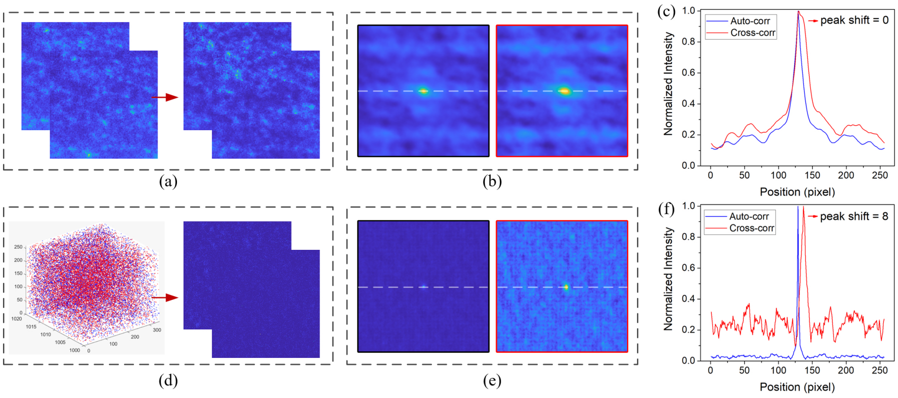

Fig. 2. Comparison results of the event-based and frame-based methods. (a) Two adjacent frames and corresponding ratio images. (b) Auto-correlation result of the first ratio image and cross-correlation result of two ratio images. (c) Intensities of the white dash line in (b). (d) Event data and corresponding accumulated images. (e) Auto-correlation result of the first accumulated image and cross-correlation result of two accumulated images. (f) Intensities of the white dash line in (e).

To demonstrate the efficiency of the event-based method, the comparison results with the conventional frame-based approach are presented in Fig. 2. For the NLOS tracking using the frame-based method, the peak shift of the cross-correlation is inconspicuous and the tracking results are inaccurate. The precise estimation of the primary speckle component and the removal redundancy of the relay wall are crucial for the frame-based method. The neuromorphic camera is sensitive to the brightness changes of moving speckle grains and has little response to the static relay wall. Therefore, by using wall-free events, an accurate cross-correlation result can be obtained. The event-based approach can avoid the disturbance of wall elements and has the capability to track moving objects efficiently.

3. Conclusion

The neuromorphic NLOS tracking method is proposed to directly obtain motion information without the disturbance of the relay wall. By using wall-free events, the NLOS tracking accuracy and computing efficiency can be further improved. The neuromorphic NLOS tracking method paves the way for NLOS imaging applications and provides a reference for complex scenarios sensing with bio-inspired sensors.

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