Event-Based Reflectance Separation

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Abstract. In this extended summary, we introduce our proposed method for diffuse-specular separation using an event-based camera. Our setup observes a scene of interest by using a standard camera and an event-based camera through a rotating linear polarizer. Our method combines the pixel values with low temporal resolution and low dynamic range and the events, *i.e.* the asynchronous changes of logarithmic radiance values, and achieves diffuse-specular separation with high temporal resolution and high dynamic range.

Keywords: reflectance separation · event-based camera · polarization

1 Introduction

The reflected light observed on an object surface consists of a diffuse reflection component and a specular reflection component in general. Separating those reflection components is important for preprocessing of various techniques in CV and CG. Because the contrast between specular and diffuse reflection components are large, diffuse-specular separation often requires High Dynamic Range (HDR) images. Therefore, diffuse-specular separation with high temporal resolution is an important issue to be addressed.

In this extended summary, we introduce our proposed method for diffuse-specular separation using an event-based camera. Our setup observes a scene of interest by using a standard camera and an event-based camera through a rotating linear polarizer. Our method combines the pixel values with low temporal resolution and low dynamic range and the events, *i.e.* the asynchronous changes of logarithmic radiance values, and achieves diffuse-specular separation with high temporal resolution and high dynamic range.

2 Related Work

Reflectance separation: For diffuse-specular separation, we can make use of the difference not only in the colors [4] but also in the polarization states [1] of diffuse and specular reflection components; specular/diffuse reflection components are polarized (partially polarized)/unpolarized (weakly polarized). The

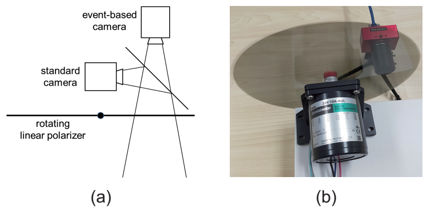

Fig. 1. Our setup for reflectance separation: (a) a sketch and (b) a prototype.

images with different polarization angles can be captured by using a polarization camera [5] as well as a pair of a standard camera and a rotating linear polarizer [6, 3]. However, diffuse-specular separation with high temporal resolution is difficult even if we use a polarization camera. This is because the contrast between specular and diffuse reflection components are large, *i.e.* specular/diffuse reflection components are often saturated/too dark, and therefore HDR images are required.

Event-based camera: In contrast to standard cameras which capture the radiance values of a scene, event-based cameras capture the changes of radiance values. More specifically, they capture the changes of logarithmic radiance values asynchronously, and therefore events have high dynamic range and high temporal resolution [2]. Our study is a novel application of event-based cameras; we utilize it for photometric analysis of diffuse-specular separation based on polarization.

3 Proposed Method

Setup: Fig. 1 (a) shows the sketch of our setup; a scene of interest is observed by a standard camera and an event-based camera through a linear polarizer rotating at high speed. Because specular/diffuse reflection components are polarized/unpolarized, the radiance values of specular/diffuse reflection components seen through the polarizer are variable/constant with respect to the rotational angle of the polarizer. Since event-based camera captures the changes of radiance values, specular reflection components can be detected from the events. Note that we use a standard camera for acquiring diffuse reflection components and for fixing the scales of specular reflection components.

Self-calibration: We self-calibrate the global parameters of our system: the angular velocity of the polarizer ω and the threshold for event occurrence δ [1]. At a point p on a static object, the radiance value $i_p(t)$ at time t is described by

$$i_p(t) = a_p \sin(\omega t + \phi_p) + b_p, \tag{1}$$

where a_p, b_p, and ϕ_p are the amplitude, bias, and phase of the radiance values. First, we estimate ω, a_p, b_p, and $\phi_p^{(s)}$ from the captured images via least

[1] If an event occurs when the radiance value is i_1, then the next event occurs when the radiance value is i_2 such that $\delta = |\ln i_2 - \ln i_1|$.

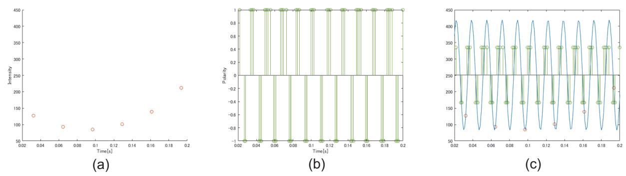

Fig. 2. The result of the self-calibration: (a) the observed pixel values, (b) the observed events, and (c) the estimated radiance values.

squares. Because our setup does not synchronize the devices, the radiance phase $\phi_p^{(s)}$ includes the shift of the time axes between the rotating polarizer and the standard camera. Second, we estimate δ and $\phi_p^{(e)}$ from the events on the basis of the consistency between the acquired events and the radiance values. Here, the event phase $\phi_p^{(e)}$ includes the shift of the time axes between the rotating polarizer and the event-based camera. We use the estimated global parameters ω and δ for the following reflectance separation.

Reflectance separation: When we can use only the images captured by the standard camera, three frames are required for diffuse-specular separation. This is because there are three unknowns in eq.(1): a_p, b_p, and $\phi_p^{(s)}$ except for the global parameter ω. Specifically, we can estimate those unknowns via least squares, and then consider a_p and $(b_p - a_p)$ as the specular and diffuse reflection components respectively. When we can use both the images and events, we can separate reflection components only from a single image and at least neighboring four events. This is because there are four unknowns: a_p, b_p, $\phi_p^{(s)}$, and $\phi_p^{(e)}$ in total [2]. Moreover, if the pixel values at a certain pixel are saturated, we can interpolate/extrapolate the radiance values during saturation from non-saturated pixel values in neighboring frames and the events. Hence, the events increase not only the temporal resolution but also the dynamic range of separation.

4 Experiments

Setup: Fig. 1 (b) shows the prototype of our setup. We used DAVIS346 from iniVation, which can capture coaxial standard images in addition to events. We rotated a linear polarizer in front of the camera at approximately 30 revolutions per second by using a synchronous electric motor.

Results: Fig. 2 shows the result of the self-calibration by using the pixel values and events observed at a point on a static object. We estimated the angular velocity of the rotating polarizer ω and the amplitude, bias, and radiance phase from (a) the pixel values, and then estimated the threshold for event occurrence

[2] Since the events capture the changes of logarithmic radiance values, n events give only $(n-1)$ constraints.

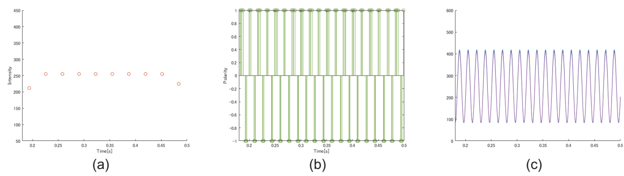

Fig. 3. The result of the interpolation of radiance values during saturation: (a) the observed pixel values, (b) the observed events, and (c) the comparison.

δ and the event phase from (b) the events. In Fig. 2 (c), the observed pixel values, the observed events, and the estimated radiance values are superimposed.

Fig. 3 shows the result of the interpolation of radiance values during saturation: (a) the observed pixel values, (b) the observed events, and (c) the comparison between the estimated and the ground truth radiance values. Here, we observed a point on a static object, and then considered the radiance values estimated from non-saturated pixel values in the other frames as the ground truth. We can find that the estimated radiance values (purple line) almost overlaps the ground truth radiance values (blue line) in (c).

5 Conclusion and Future Work

In this extended summary, we introduced our proposed method for diffuse-specular separation using an event-based camera. Our method combines the pixel values with low temporal resolution and low dynamic range and the events, and achieves diffuse-specular separation with high temporal resolution and high dynamic range. Our future study includes the application to and evaluation on dynamic scenes.

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