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Spectrum synthesis with computational neuromorphic imaging

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Abstract: We propose a method for spectrum synthesis via computational neuromorphic imaging (CNI), employing stochastic variational inference to extract spectral profiles from dynamic light-sample interactions. It provides new insights into biological analysis and CNI applications.

1. Introduction

Advancements in biological imaging, particularly for organoid imaging, strive to address the challenges of traditional methods [1]. Organoid imaging faces challenges due to the dense, three-dimensional structure of the specimens, which complicates staining processes and leads to significant delays and technical difficulties [2]. Uneven staining often occurs with these protocols, as dyes fail to penetrate to the core, leading to underexposure at the center and overexposure at the peripheries. This staining dilemma highlights the limitations of fluorescent imaging, such as its demanding intense preparation and issues with dense structure visualization.

As a response, direct brightfield imaging has become the preferred method for its simplicity and cost-effectiveness. Nonetheless, it struggles to distinguish features in complex samples like biopsy specimens, complicating analysis. The use of computational neuromorphic imaging (CNI) with event cameras has emerged as a solution [3], as they produce minimal heat, have a high dynamic range (HDR) for capturing light intensities across a scene, and are sensitive in low-light conditions, reducing photon toxicity risks. Moreover, spectral information offers a deeper look into cellular dynamics and metabolic changes in tumor development, aiding the understanding of growth and proliferation [4]. The absorption spectrum particularly helps in overcoming brightfield imaging's limitations. Here, combining event cameras with spectral analysis provides a comprehensive view of organoid and drug interactions, marking progress in tumor metabolism research and automated drug screening, and confirming the effectiveness of event cameras and spectrum synthesis in biological imaging.

2. Method & Results

In our study, we explore how a horizontally moving white light source interacts with a sample. The light traverses a diffraction grating, resulting in a spectrum that illuminates the sample, as depicted in Fig. 1 (a). This spectrum, with its initial intensity distribution denoted by $I_0(\lambda)$, interacts with the sample in a way that is captured by event sensors (see Fig. 1 (b)). These sensors track the modulation of light intensity, providing data that is influenced by both the sample's unique spectral absorption properties, $S_{x,y}(\lambda)$, at each point (x,y), and the shift in the spectrum, ξ. The relationship between the light intensity at any sensor point and these variables is described by the equation $I(x,y,\xi) = I_0\big(\lambda(x,\xi)\big)\cdot S_{x,y}\big(\lambda(x,\xi)\big)$.Here, $\lambda(x,\xi)$ connects the position and spectral shift with the corresponding wavelength. By observing how this shifted intensity generates events, symbolized as

$$E(x,y,\xi) = \begin{cases} 1 & \frac{\partial I(x,y,\xi)}{\partial t} > c \\ -1 & \frac{\partial I(x,y,\xi)}{\partial t} < -c \end{cases}, \tag{1}$$

where $E(x,y,\xi)$ represents event stream and c is the pixel-wise threshold. In this context, our data simulation employs the "v2e" tool [5], which translates video frames to realistic Dynamic Vision Sensor events.

To synthesize the spectral profiles from these events, we utilize Stochastic Variational Inference (SVI), refining our model iteratively based on the evidence lower bound (ELBO), represented by

$$\mathrm{ELBO}(\theta) = \mathbb{E}_{q_\theta(S)}[\log p(E,S) - \log q_\theta(S)], \tag{2}$$

which measures the fit of our model against the observed data, allowing us to adjust the variational parameters θ effectively. We highlighted our findings by presenting the light source characteristics, denoted as $I_0(\lambda(x,\xi(0)))$,

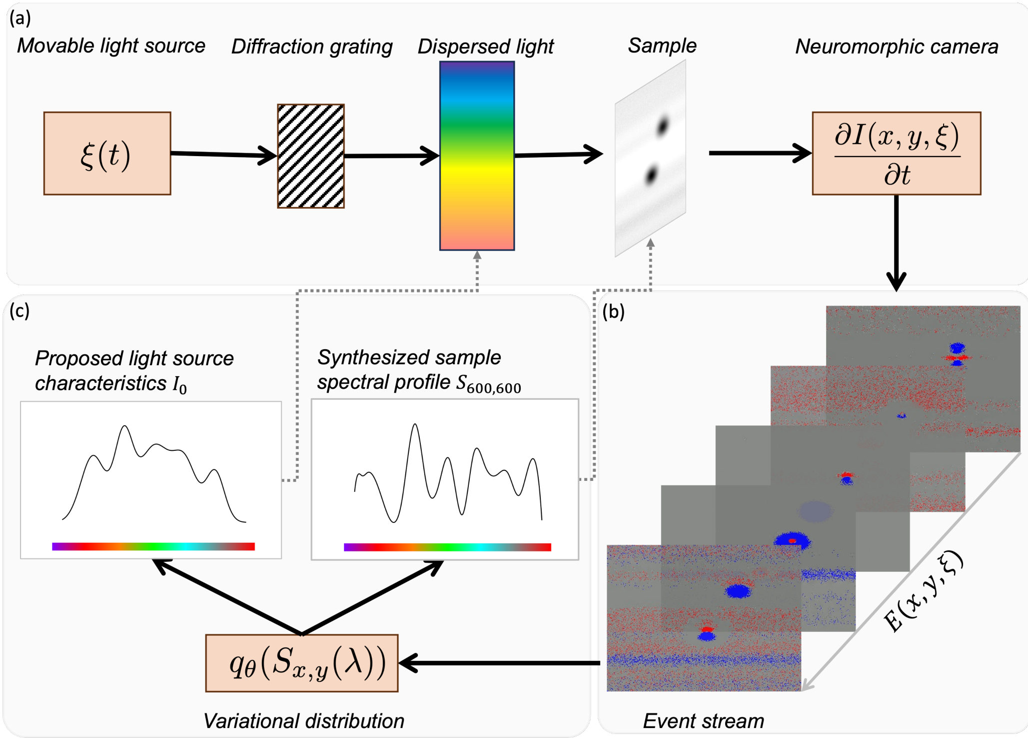

Fig. 1. This diagram illustrates the process of capturing spectral data, depicted in three parts: (a) outlines the progression from a moving white light source, through diffraction, and interaction with the sample, to detection by a sensor; (b) presents the event stream captured by the sensor, with positive and negative events represented by red and blue points, respectively; (c) displays the application of the SVI technique to analyze the event stream, resulting in the proposed characteristics of the light source and the detailed spectral profile at a selected pixel.

and the spectral profile synthesized at a specifically chosen pixel location, as illustrated in Fig. 1 (c). These results demonstrate the practicality of using a neuromorphic camera with an SVI-based method to identify spectral properties. It paves the way for transformative applications in biomedical analysis, particularly in advancing oncology research, where detailed spectral information can provide critical insights into cellular and molecular dynamics.

3. Conclusion

This paper introduces a novel model for spectrum synthesis within the context of the CNI paradigm, emphasizing the synthesis of spectral events from intensity modulations. Future work will focus on refining this model and exploring its applications in various scientific and industrial domains.

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