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NEWS AND VIEWS

Toward unlimited temporal resolution: femtosecond videography for atomic and molecular dynamics

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To reveal the fundamental aspects hidden behind various biological, chemical and physical phenomena, the capability of acquiring images with an ultrafast temporal resolution is indispensable and highly desired. The imaging frame rate of traditional CCD and CMOS imager usually only reaches sub-MHz, which is limited by the tradeoff between sensitivity and integration time[1]. The pump–probe scheme is widely applied in scientific imaging for its high-temporal resolution of pico-second level[2]. Recently, to film the events in chemical reactions, pump–probe combined with scanning tunneling microscopy (STM) or X-ray schemes are proposed. They can take the snapshots with enhanced resolution to femtosecond for producing true molecular movies[3]. However, it is only applicable for respective events, hence, falls short of capturing non-repetitive or destructive events, which count the majority in nature. To address this problem, at present, a lot of work has been carried out. By virtue of temporal and spatial dispersion, high-speed image acquisition can be realized either with time-stretched pulses[4] or with split wavebands[5] for frame rates of GHz and THz, respectively. But these schemes are based on dispersive Fourier transform, which limits the their achievable frame rate to THz. With compressive sensing method, compressed ultrafast photography (CUP) achieves passive imaging with up to 100-GHz frame rate in single shot, which is also applicable for fluorescence imaging[6]. However, the streak camera used in CUP suffers from its poor spatial resolution and quantum efficiency.

In recent publication[7], Professor Marcus Aldén's group developed a novel laser-probe-based 2D videography method at ultrafast timescales (femtosecond and even shorter) with spectroscopic compatibility termed frequency recognition algorithm for multiple exposure (FRAME). FRAME employs multiple pulses (or daughter pulses split from one original pulse) to detect sequential evens. As Figure 1 shows, these pulses are ultra-short (fs) in time domain and spatially modulated with different masks. The ultra-short temporal duration guarantees a very short exposure time, which is essential in the detection of highly dynamic events. The spatial modulation, as shown in Figure 1b, makes the images captured by different pulses locate at different spatial frequency areas of the resulting image acquired by the

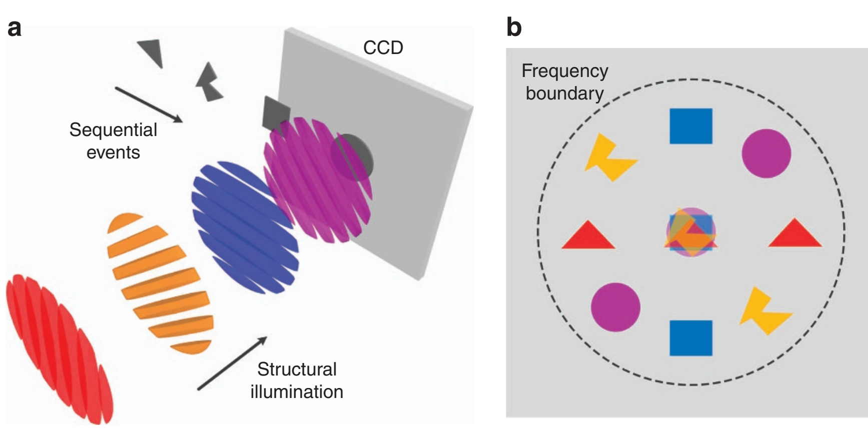

Figure 1 Principle of FRAME. (**a**) Ultrafast sequential events are separately imaged by the corresponding ultra-short pulses, which are spatially modulated by different masks beforehand. (**b**) The pulses are detected by a CCD camera during a single recording. Due to the spatial modulation of the pulses with different masks, images captured by different pulses locates at different areas in the frequency plain. Hence, multiple images of the sequential events can be recovered by digital signal processing afterwards.

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CCD camera. Finally, the images of different events can be properly separated by digital signal processing algorithms. Compared to previous work, the imaging speed of FRAME is only limited by the temporal duration of the laser pulses, which can reach attosecond regime. In addition, FRAME allows multiple 2D image recovery from single recording of a CCD camera. This releases the requirement on high electronic readout speed of the CCD camera, hence, allows FRAME to take advantages of the low-noise and high-sensitivity image sensor for a larger dynamic range and higher pixel resolution.

FRAME opens a gate for observing non-repetitive or destructive events with almost unlimited temporal resolution. Combined with existing laser and measure techniques, it is potentially applicable in various fields including biology, chemistry and physics. FRAME is a powerful tool for the researchers in different fields to access to the extreme dynamic of events, which are too fast to see with any other techniques before. This may lead to some new discoveries, which could even overthrow the established knowledge system.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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