Snapshot Compressive Volumetric Light-sheet Microscopy

Xukang Wang, Yang Liu, Xiaofei Han, Jinli Suo, and Qionghai Dai*
Department of Automation, Tsinghua University, Beijing 100084, China
** qhdai@tsinghua.edu.cn*

Abstract: We proposed a snapshot compressive volumetric light-sheet microscopy method for high-speed three-dimensional imaging of zebrafish and cleared mouse brain.

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Three-dimensional imaging is of great interest to the biomedical and neuroscience communities [1]. Light-sheet microscopy (LSM) stands out for its optical-sectioning ability and low photo-damage, since only a selected plane, line or lattice of the sample is exposed to the excitation light [2]. LSM has been applied to perform volumetric imaging of zebrafish and cleared model organisms by scanning a z-stack of the sample. However, the imaging speed is limited by the throughput of cameras, which operates at most 100 frames per second with full frame or higher with reduced region of interest (ROI). By incorporating compressive sensing [3] technique for sub-Nyquist sampling along the axial dimensional, we achieve volumetric light-sheet microscopy in a snapshot. Specifically, we encode multiple (B) slices of the z-stack images with known random binary patterns in a single measurement, as shown in the coding part of Fig. 1(a). Then a rank-minimization-based method, decompress snapshot compressive imaging (DeSCI) algorithm, is used to recover the collapsed signal [4], as shown in the decoding part of Fig. 1(a).

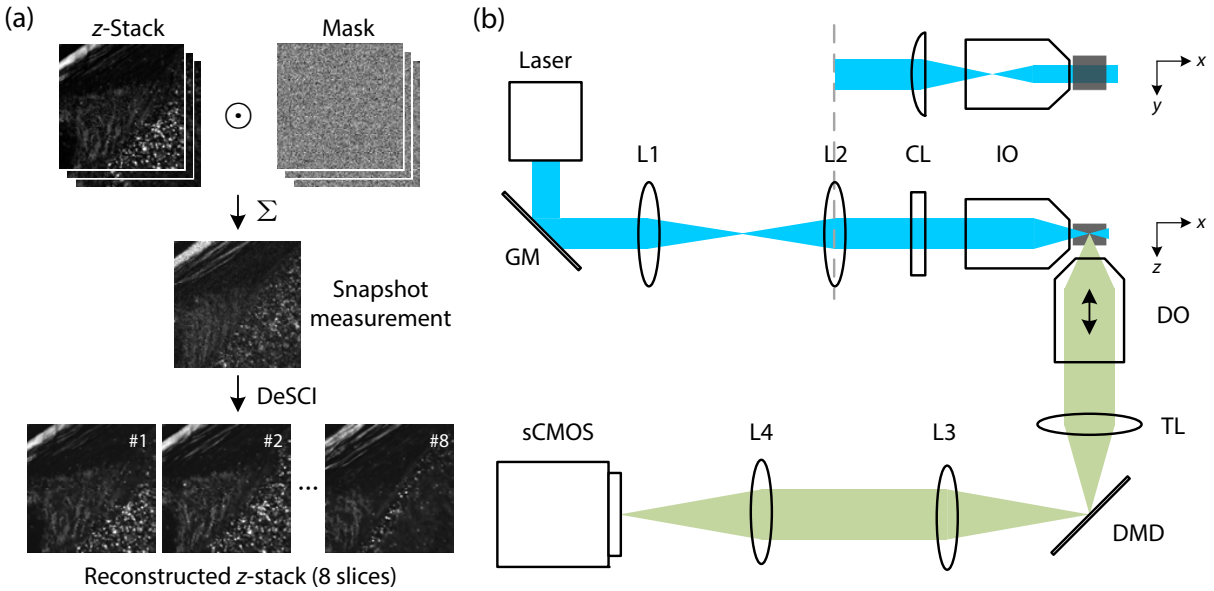

Fig. 1. Schematic (a) and experimental set-up (b) of the snapshot compressive volumetric light-sheet microscope.

The experimental set-up is shown in Fig. 1(b). An axially scanning light-sheet is created with the cylindrical lens (CL) and the galvo mirror (GM), which is synchronized with the detection objective (DO) mounted on a piezo-motored z-dimension translation stage. Each z-stack image of the sample is coded with a distinct random binary pattern on the digital micromirror device (DMD). The scientific CMOS (sCMOS) camera is used to capture the relayed image from the DMD. Since a single measurement on the DMD encodes B slices of the z-stack images, the DMD operates B times as high as the frame rate of the sCMOS camera. In this way, the throughput of the LSM system could be promoted by a factor of B, that is $100B$ full-frame slices per second for a typical sCMOS camera. We use $B = 8$, which means a singe measurement encodes 8 slices in both our simulation and experiments. If

we capture 80 z-stack images, we could achieve a volume rate of 10 Hz, which is sufficiently high for three-dimensional fluoresence microscopy.

Simulation of the z-stack light-sheet microscopic images is performed to validate the proposed method. We use the images of a cleared mouse brain (CX3CR1-GFP) captured from a conventional LSM system. The pixel resolution of the images is 256×256. Eight slices with z-step of 5.4 μm are coded into a snapshot measurement and DeSCI is performed for reconstruction, as shown in Fig. 1(a). There are significant differences between adjacent slices and DeSCI could recover them with high fidelity. The simulation results of the proposed method are shown in Fig. 2. Generalized alternating projection based on total variation (GAP-TV) minimization method [5] is also performed for comparison. GAP-TV could recover the overall structure of the sample, but suffers from severe blur artifacts. However, DeSCI could recover both the structural information and fine details of the sample. It can be seen that neurons (peak spots) are clearly recovered in Figs. 2(d) and (h), comparing with Figs. 2(a) and (e). We conclude that the proposed method could be employed for high-speed three-dimensional imaging.

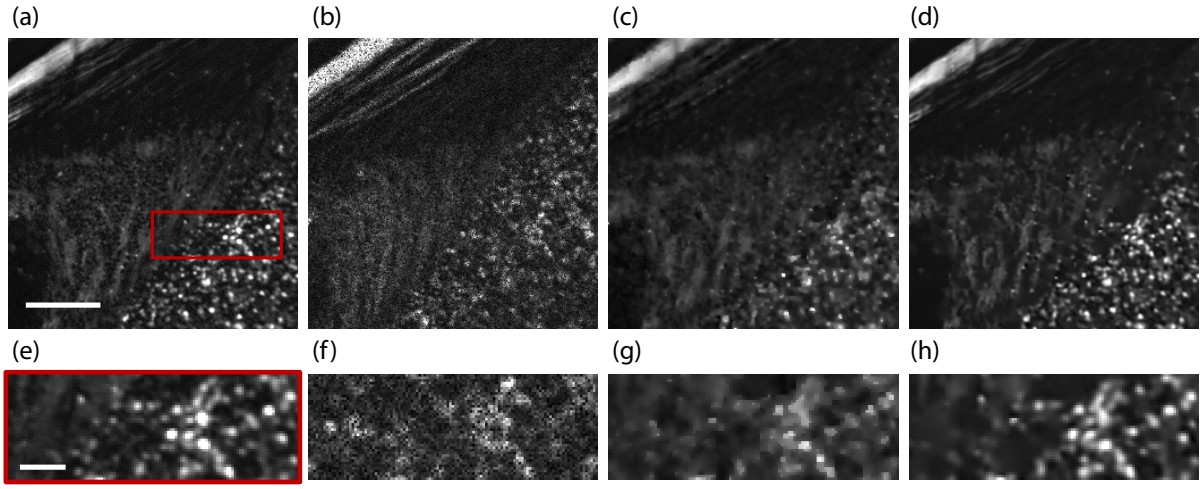

Fig. 2. Simulation results of the proposed method. (a) Original image (the 1-st frame) from a cleared CX3CR1-GFP mouse. (b) Coded frame from 8 z-stack slices. (c)-(d) Reconstruction results of GAP-TV [5] and DeSCI [4]. Scalebar: 200 μm. (e)-(f) Close-ups of (a)-(d), correspondingly. Scalebar: 50 μm.

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