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An Ultra-Cheap Light Field Microscope for Volumetric Cellular Imaging

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***Abstract*—We present a novel light field microscope (LFM) hardware design which benefits from scaled productions of cameras and other optical components. Our design has dramatically lower cost (< GBP 2000) yet only slightly compromised performance.**

***Clinical Relevance*—This novel LFM design enables transient volumetric imaging at a cellular resolution at a much lower cost.**

I. INTRODUCTION

Conventional microscopy techniques (two-photon, confocal microscopy) have high spatial resolution, but are prohibitively slow for real-time volumetric imaging as they require a single point scanned in a volume. For example, a two-photon microscope with an 8 kHz resonant scanner takes over 6 sec to scan a 1.0 x 1.0 x 0.1 mm volume [1], and costs over £100,000. Light field microscopy (LFM) is a scanless method that has been applied to live brain tissue imaging[3]. It enables high speed volumetric imaging[2]. However, state-of-the-art LFMs cost over £30,000, limiting the potential application domain. This study demonstrates an ultra-cheap LFM with cellular resolution (~10 um) and a total cost less than £2000.

II. METHODS

Our LFM follows the conventional configuration developed by Levoy et al. where a microlens array (MLA) is placed at the intermediate image plane of a wide field microscope and the image sensor is at the relay-lens-projected MLA's back focal plane (see Figure 1(A)[+])[2]. Synthetic refocusing and deconvolution were applied to reconstruct 3D volumes from the captured 4D (spatial coordinates Sx, Sy and angular coordinates Ax, Ay) light field [3].

To save cost and enable modularity, our LFM utilizes the UC2 toolbox[4] and replaces expensive metal optomechanical components with a 3D-printed plastic cube-based framework (see Figure 1(B)). To further reduce the cost, cheaper optical components were chosen while making compromises on spatial resolution, field of view, sensor signal-to-noise ratio, and distortion correction.

III. RESULTS

We used the LFM to image green fluorescent protein (GFP) labelled neurons in fixed mouse brain slices, and 0.5 µm yellow-green (486nm) fluorescent beads . From the LFM images we successfully implemented classical reconstruction techniques and obtained 3D image stacks (see Figure 1(C)). However, in some parts of the images, warping and aberrations exist due to small misalignments and low-quality components. Cost wise, we reduced the cost by an order of magnitude while retaining **basic performance and meeting the requirement for cellular resolution** imaging (see Table 1 and 2).

IV. DISCUSSION & CONCLUSION

The first version of our ultra-cheap LFM design already functions at cellular spatial resolution and more than 100Hz temporal resolution, though with some deficiencies, including (1) compromised spatial and axial resolutions and (2) warping and its induced aliasing and distortion. Future development of the platform will be aimed at mitigating these issues. For the hardware, (1) increase number of available microlenses in the field of view, (2) improve precision and reliability of the translation mechanism of cube inserts and sample/objective stage, and (3) design a vertical configuration and use mirrors to make the assembly more compact. To further improve the volumetric reconstruction, image post-processing to de-warp and de-alias may help. We could also complement LFM images with other imaging modalities (e.g. 2-photon or confocal microscopy) by image fusion using deep learning and further image post-processing.

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[*] Theoretically calculated resolutions
[**] Actual magnification, due to tube lens focal length being 200mm instead of 180mm.
[+] See Supplementary Materials for more information.

TABLE I. COST COMPARISON BETWEEN THE (A) DESIGNED MICROSCOPE[+] AND (B) THE STATE-OF-THE-ART LFM BY QUICKE[3]

	(a) Our microscope		*(b) Quicke's[3]*	
	Components	***Price***	***Components***	***Price***
Camera	CMOS: FLIR Chameleon®3 USB3.0	£361.25	sCMOS: Hamamatsu ORCA Flash 4 V2	~£15,000
Objective lens	20X Olympus Plan Achromat Objective lens	£353.85	25X Olympus Objective	~£10,000
MLA	Thorlabs MLA150-5C(-M)	£366.84	RPC photonics MLA-S125-f10	~£300
Miscellaneous[+]		£863.03		~£7,250
Total		£1,944.97		~£32,550

TABLE II. PARAMETER AND RESOLUTION COMPARISON WITH THE STATE-OF-THE-ART LFM BY QUICKE[3]

		(a) Our microscope	*(b) Quicke's*[3]
Parameters	*Objective magnification*	22.2x[**]	25x
	Objective NA	0.4	1.0
	Pixel size	4.8 µm	6.5 µm
	Pixel per lens	32×32	45×45
	Frame rate	149 frames/sec	100 frames/sec
Resolutions[*]	*Lateral resolution[*]*	6.75 µm	5 µm
	Axial resolution[*]	21.18 µm	7.81 µm

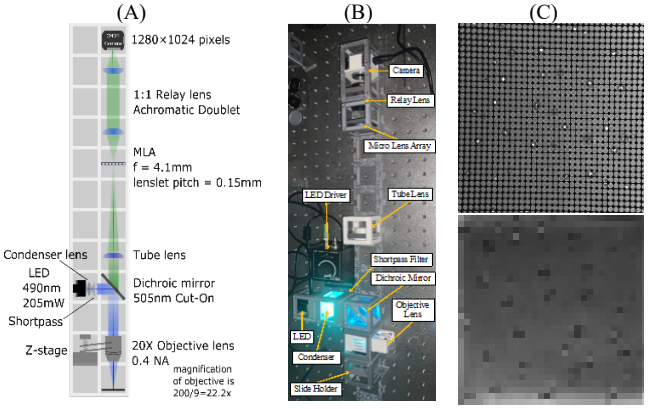

Figure 1. The **(A)** optical schematic, **(B)** photo of the light field microscope. **(C)** Top: raw LFM image of 0.5µm fluorescent microbeads, Bottom: corresponding ISRA-deconvolved reconstructed volumetric image (31× 31 pixel, gaze size 214 × 214 um) slice at the native focal plane with 5 iterations.

Supplementary Materials

More detailed methodologies and CAD files can be found via the link below.
https://github.com/schultzlab/ultra-cheap-light-field-microscope/

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