Simple intensity equalization methods in SLM generated multispots

Quan, Xiangyu

Kumar, Manoj

Matoba, Osamu

Awatsuji, Yasuhiro

Wake, Hiroaki

Simple intensity equalization methods in SLM generated multispots

Xiangyu Quan*[a], Manoj Kumar, Osamu Matoba [a], Yasuhiro Awatsuji [b] and Hiroaki Wake [c]

[a]Graduate School of System Informatics, Kobe University, Rokkodai 1-1, Nada, Kobe 657-8501, Japan
[b]Faculty of Electrical Engineering and Electronics, Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan
[c]Division of System Neuroscience, Kobe University of Graduate School of Medicine, Kusunoki-cho 7-5-1, Chuo-ku, Kobe, 650-0017, Japan

Abstract

Multispots in three-dimensions generated by phase mode spatial light modulators (SLMs) are very useful in laser processing or light induced biological treatments, such as optogenetics. So far, the intensity of the focus spots varies depending to the distance from optical axis. In order to equalize intensities in all generated spots, simple feedback method was applied. Further, look up table was created by dividing imaging area in sectors. Experiment results show improvement in the random spots at some degree, however, further analyzation is required.

Keywords: computer generated hologram, optogenetics, laser processing

I Introduction

Wavefront modulation using various kinds of spatial light modulators (SLMs) are studied, and used in many fields. In laser processing, spot by spot processing was replaced by line to line or plane to plane. Thus, high speed processing is possible. In recent years, light induced biological   researches are very active in worldwide. Such as in optogenetics, light with certain wavelengths can open or close ion gates on the cell membrane so the stimulated neural signal can be generated manually.   Using phase mode SLM can create high resolution, cell specific 3D multispots with few tens of milliseconds fps. However, the light intensity on every locations are not always the same. Whether it is because the diffraction efficiency drops by increased diffraction angle, or the limited aperture size works as a low pass angular spectrum filter, it always seems that spots created close to optical axis brighter than further ones. In order to solve this problem, some optimizations are made to SLM phase patterns. GS method is mostly used in such case. Some other methods are also applied to improve speed and accuracy. However, time consuming iterative algorithms are not always suitable to stimulate nerve cells in living animals, as the activity is quick and unpredictable. In order to speed up the optimization, we propose feedback system to quickly monitor generated spots and make appropriate changes.

And further, if we have this previous knowledge on the imaging system, look up table (LUT) can be applied instead of feedback process.

In this manuscript, two cases which using feedback and LUT are demonstrated. Enhanced intensity distribution in different locations are confirmed in both cases.

II Method

Figure 1 shows the principle of spot illumination on the desired location using an SLM. In order to put image of SLM on the back focal plane of the objective lens, 4f system has been applied to illumination light.
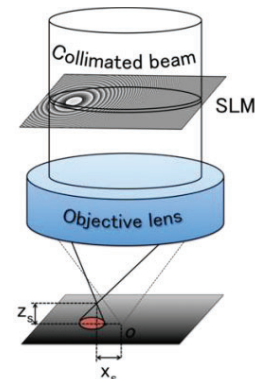

Figure 1. Principle of generating focused spot in 3D space.

if the incoming wavefront u_{in} has a specific phase distribution, described as

$$u_{in}(x) = \sum_k w_k exp\left(-\frac{i\pi x^2}{\lambda h_k}\right) exp\left(i2\pi x \frac{1}{g_{xk}}\right), \quad (1)$$

after the objective lens, the wavefront at the front focal plane (FFP) becomes

$$u_{FFP}(X) = \sum_k w_k exp\left\{\frac{i\pi}{\lambda H_k}[(X - G_{xk})^2]\right\}. \quad (2)$$

Here, $H_k = \frac{f_{OL}^2}{h_k}$, $G_{xk} = \frac{f_{OL}\lambda}{g_{xk}}$, and the kth focused spot falls on the position (G_{xk}, G_{yk}, H_k) in the sample space.

For feedback method, first we set $w_k = 1$ for all spot. Then from the obtained results, we analyze average intensity for all spots, and set $w_k = \frac{I_k}{I_{average}}$ to new pattern. This cycle usually only needs to be performed once. Without feedback, we divide an image in sectors, and give w_k according to previously known spots' distributions to creating LUT. This does not require feedback, and usually LUT only depends on the optical set-up.

III Results and Discussion

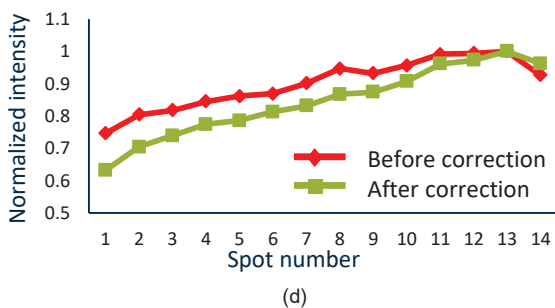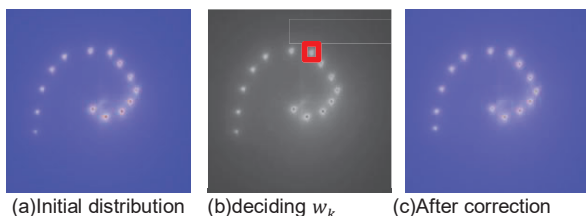(a)Initial distribution   (b)deciding w_k (c)After correction

(d)

Figure 2 Feedback method to correct intensity, and the experiment result.

In order to simplify the experiments, we set $h_k = \infty$ in eq. (1). With optical axis on the center of the Figure 2 (a-c), randomly generated 14 spots have uneven intensity distributions. As mentioned in the method section, we analyzed the average intensity among 14 spots, and decide w_k according to actual intensity. For weak spots, w_k becomes bigger than 1, and vice versa. As in Figure 3(d), after feedback, the plot line has flattened compared to initial distribution. 10% of improvement happened to the first spot which was furthest from the center. However, the graph could not make perfect flat line due to limitations of phase mode SLM.

The LUT was made by scanning the whole imaging area with a single spot as in Figure 3(a). And to each sectioned area, w_k is decided according to spot intensity placing within the area. The array of w_k is then made. After applying the w_k to new pattern, disproportional spot intensity on the right side is improved at some degree. However, the effect is further to be analyzed.
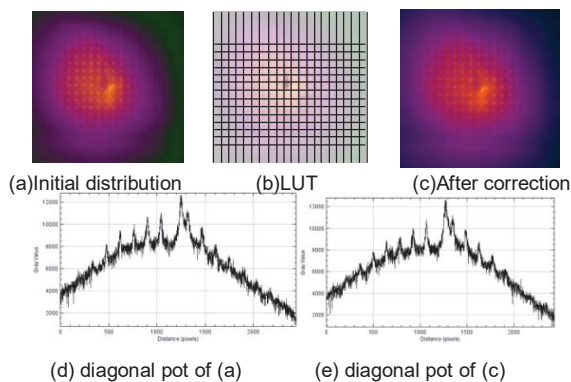

(a)Initial distribution   (b)LUT   (c)After correction

(d) diagonal pot of (a)   (e) diagonal pot of (c)

Figure 3 LUT method to correct intensity, and the experiment result.

References

Hayasaki, Y., Sugimoto, T., Takita, A. and Nishida, N., 2005. Variable holographic femtosecond laser processing by use of a spatial light modulator. *Applied Physics Letters*, *87*(3), 031101.

Quan, X., Kumar, M., Matoba, O., Awatsuji, Y., Hayasaki, Y., Hasegawa, S. and Wake, H., 2017. 3D stimulation and imaging-based functional optical microscopy (SIFOM) of biological cells. *Opt. Lett.* 43, 5447-5450

Takahashi, H., Hasegawa, S. and Hayasaki, Y., 2007. Holographic femtosecond laser processing using optimal-rotation-angle method with compensation of spatial frequency response of liquid crystal spatial light modulator. *Applied optics*, *46*(23), 5917-5923.