Preconditions for High Speed Confocal Image Acquisition with DMD Scanning.

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Abstract

Digital image-projection and several modifications are the classical applications of Digital Micromirror Devices (DMD), however further applications in the field of optical metrology are also available. Operated with certain patterns, a DMD can function, for instance, as an array of pinholes that may substitute the Galvanic mirror or the stage scanning system presently used for 2 dimensional scanning in confocal microscopes. The various process parameters that influence the result of measurement (e.g. pinhole size, lateral scanning pitch and the number of pinholes used simultaneously, etc.) should be configured precisely for individual measurements by appropriately operating the DMD.

This paper presents suitable conditions for the diffraction limited analysis between DMD-optics-CCD to achieve the best performance. Also sampling theorem that is necessary for the image acquisition by scanning system is simulated with OPTISCAN which is the simulator based on the diffraction theory.

1. Introduction

A confocal microscope works by geometrically matching conjugate point light spots in the diffraction limited optical imaging system. When the two coupled light spots (pinholes are utilized as point spots; one works for source and the other for detector) are well matched, confocal condition is satisfied and the image of source pinhole is exactly coincide with the detection pinhole with maximal intensity at the minimal size. If the conjugate points are displaced from the best focus locations, the detection pinhole is positioned in the midst of the broadened light cone and detected intensity decrease. In practice, for a reflection-mode confocal microscope, a point pinhole source is imaged(focused) onto the sample surface, which then reflects and is re-imaged the point pinhole detector. As the sample is moved (scanned) around the best focus point, then peak intensity should be detected only when the focus point (image of a point source in the sample) lies exactly on the surface of the sample.

In this paper, we introduce a confocal microscope design using DMD. The key element of this design is a DMD, which can make a 2D pattern of pinholes for 2 dimensional scanning. There are considerable relation between the size of mirrors and numerical aperture of the collimating lens (L3) in front of the DMD. The size of the mirrors opened simultaneously has to be smaller than a half width of the diffraction limited spot size focused by the lens L3. Satisfying this condition, the mirror of DMD can be considered as a point source and a point detector.

And the resolution of a scanning microscope like a confocal microscope is determined by, first of all, the sampling rate. According to the Nyquist's sampling theory (this will be presented at conference.), the object smaller than the twice a scanning pitch can not be resolved. Finally, the moiré interference can be created by the spatial periodicity mismatch between the DMD and the CCD pixel array. These phenomena are simulated with OPTISCAN, and the results of the simulation are compared with theoretical result.

2. System Description and Diffraction Limited Analysis

The DMD-scanning confocal microscope method is similar in theory to one using the moving stage or galvanic mirror for scanning. The micromirror of the DMD can serve as an array of point sources and the corresponding array of conjugate point detectors. The pinhole pattern can be changed by computer control. The basic idea is to have illumination from 'ON state mirrors' of the DMD toward the sample while 'OFF state mirrors' make light away from the sample. An array of 'ON state mirrors' is creating an array of bright point sources that is reflected from the sample and re-imaged back to the same mirrors used as the point detectors. Only the points under confocal condition have high reflection light. The array of 'ON state mirrors' is then turned off while the next set of mirrors at different (x,y) position is turn on. With high speed switching of the DMD micromirrors, a whole transverse (x,y) plane can be digitally scanned by the array of source pinholes.

Figure 1 shows the setup of the DMD scanning confocal microscope. A He-Ne laser of a wavelength of 633nm is used as the light source for alignment and measurements. The horizontally polarized laser beam is expended and collimated. And after passing through the PBS, the laser beam is directed to the DMD(TI,1024 x 768 mirrors of 13.68um x 13.68um) surface plane with mirror1 and mirror2. The light passing through the DMD is imaged by a combination of a L3(f=100mm) and objective lens(X50,NA0.8,infinity). To obtain diffraction limited performance of an objective lens(Obj.), an Obj. needs to be illuminated by perfect collimated beam through a L3. It is critical that the size(number) of micromirror cell as a point source be sufficiently smaller than the resolution of a L3 such that the micromirrors can be considered as a perfect point source. We call this as diffraction limited condition. If the size of source pinholes is larger than the resolution of a L3, the diffraction limited condition is not satisfied, then the source pinhole is not a point source for L3 any more but an extended source. According to this condition, it is reasonable that L3 (f=100mm) be corresponding to one micromirror (13.68um x 13.68um) as a pinhole.

The light reflected from the object is traced back through the optical components onto the DMD surface. For the reflected light, the DMD serves as a detection pinhole array that filters out the light scattered from the out-of-focus part of the object and allows only the in-focus reflect light to be directed to the detector. Thus the returning light is reflected by the PBS to be focused onto the CCD camera(SVS285,1360 x 1024 pixels of 6.54um x 6.54um) by imaging lens4(L4) and lens5(L5). Finally, when the light field from the DMD is imaged onto the CCD, it is needed to match one spot to 4 pixels or more pixels to remove the moiré interference pattern that is created by the spatial periodicity mismatch between the DMD and CCD array and the aperture stop is used for vignetting problem.

3. Simulation of DMD based lateral scanning

For the scanning method microscope, it is important to test various scanning patterns (e.g., arrays, lines, and points) and used different sizes of pinhole points(cell) and different scanning pitches. If a pinhole size is too large then the diffraction limited condition is not satisfied, and too small size of pinhole causes a low throughput efficiency.

According to the sampling theorem, the object which has higher frequency than the Nyquist's sampling frequency (N_q) cannot be resolved by detector array. And if the frequency of the object has the value between N_q and 2N_q then original frequency of the sample is not detected but new frequency called moiré interference pattern. It is simulated that the moiré pattern of period 600um when the frequency of the sample is 200um and that of detector is 150um. This result is exactly corresponding to the theoretical result.

4. Summary

In this paper, design and simulation of the confocal microscope system with DMD are presented. All optical components are simulated with lens design tool (ZEMAX) and only the lenses which achieve diffraction limited performance are selected. And the optical components and the size of micromirrors are related to each other by the diffraction limited condition. To achieve the best optical performance, this diffraction condition has to be satisfied. The Nyquist's sampling theorem and moiré interference pattern are simulated with OPTISCAN and the result was exactly corresponding to theoretical result. It remains as a future work to realize this discussion and analysis to real experimental setup. Finally, this research is supported by KOSEF (Korea Science and Engineering Foundation).

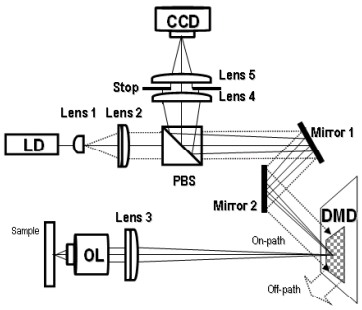

Fig.1. Schematic diagram of confocal microscope with DMD.

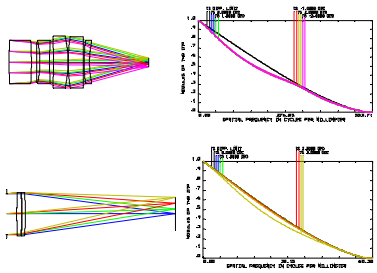

Fig.2. Layout and MTF performance of Lens L2 and L3

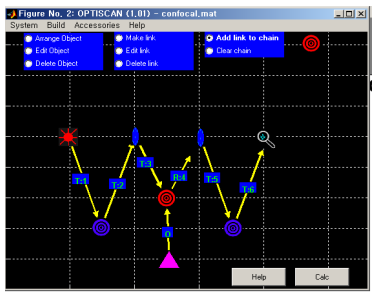

Fig.3. Simulation layout of confocal system with OPTISCAN

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