Article ID: 1004-4213(2011)11-1625-5

Micro Scanning Mirrors with Laser Diode for Pattern Generation

LI Zhao, YUAN Wei-zheng, WU Meng, YAN Bin,
QIAO Da-yong, LIU Yao-bo

(*MEMS/NEMS Lab, Northwestern Polytechnical University, Xi'an* 710072, *China*)

Abstract: A novel micro scanning mirror based on MEMS technology with a laser diode could be used in the projection of Lissajous patterns. Two micro scanning mirrors twisted in X-axis and Y-axis are used to deflect the laser beam onto the desired projection area to draw a 2-dimensional pattern. The optical scanning angle of the mirror can reach $\pm 12°$ in 15V square wave driving signal at twice the mirror's resonant frequency. Given the sinusoidal movement of the mirrors in each axis, the laser beam follows a Lissajous pattern. Through analyzing the principle of the generated patterns and simulating them with Matlab, oscillation frequency combination of 2 400 Hz(X-axis) and 2 425 Hz (Y-axis) for image generation is chosen. This combination can achieve 194×192 pixels at refresh frequency 25 Hz which is enough for movie frames. A method of projecting arbitrary images by modulating the laser diode through FPGA is given, which provides the basis for developing micro projectors.

Key words: Micro scanning mirrors; Lissajous pattern; Combination of oscillation frequency; Laser projection

CLCN: TP211+.6　　**Document Code**: A　　**doi**: 10.3788/gzxb20114011.1625

0 Introduction

There are a wide variety of applications that utilize scanning mirrors such as barcode readers, laser printers, microscopes, fiber-optic network components and laser projection displays[1-4]. However, due to large volume, high power consumption and slow response time, traditional macro-scale mirrors have limited the performance significantly. Over the past two decades, Micro-Electro-Mechanical System (MEMS) technology realizes the light weight, miniature, low energy consumption, fast scanning speed and mass production of scanning mirrors[5].

The Digital Mirror Device (DMD) produced by Texas Instruments uses addressable tilt mirrors to project images. The device has the advantages of light weight, miniature. However, as the amount of mirrors has to be equal to the number of the pixels, light sources with high luminosity which results in high power consumption were required[6]. A new micro scanning mirror which overcomes the drawback was fabricated in our lab.

The image projection is not based on the common line by line raster scanning of image. Instead, using two micro scanning mirrors twisted in X-axis and Y-axis respectively to deflect laser beam, 2-dimensional pattern is projected onto the desired area[7]. Given the sinusoidal movement of the mirror in each axis, the projected pattern is the typical Lissajous pattern[8]. As different oscillation frequency ratios generates different Lissajous patterns, X-axis 2 400 Hz and Y-axis 2 425 Hz are chosen to form a pattern which has suitable line density and refresh frequency. Based on the pattern, turn on or off the laser diode with digital control FPGA at the mapping time (the time can map the image to be projected) to achieve image projection.

1 Structure and characterization of the mirror

The structure of the mirror which SEM picture shows in Fig. 1 has three parts: 1) mirror plate (responsible for deflecting light beam); 2) torsional beam (playing the role as a torsional

Foundation item: The Program for the New Century Excellent Talents in University, Ministry of Education of China (No. NCET-10-0075) and the National Natural Science Foundation of China (No. 50805123)

First author: LI Zhao(1987—), male, M. S. degree candidate, mainly focuses on MOEMS. Email: memslizhao@163.com

Corresponding author (Contact author): YUAN Wei-zheng(1961—), male, professor, mainly focuses on microfabrication technology, modeling and simulation of MEMS/NEMS, and intelligent sensors. Email: yuanwz@nwpu.edu.cn

Received date: 2011-07-06　**Revised date**: 2011-08-19

spring); 3) comb finger consisted of moveable finger and fixed finger(generating the torque in the driving voltage).

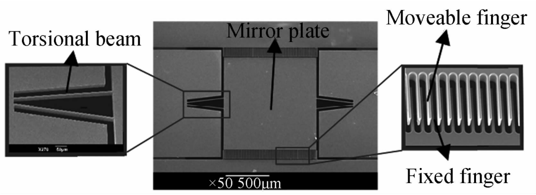

Fig. 1 SEM picture of the micro scanning mirror

By applying an voltage between the mirror plate and the comb fingers, an attractive force is generated resulting in the twisting of the mirror. The amount of the torque is given by the expression, where N is the number of the comb fingers[8].

$$M(\theta)=2N\frac{1}{2}\frac{\mathrm{d}C}{\mathrm{d}\theta}V(t)^2 \tag{1}$$

The actuated scanning mirror exhibits a hysterical behavior and generates subharmonic oscillations, so the driving signal′s frequency should be twice the resonant frequency in order to get large deflection angle[8]. Fig. 2 shows the frequency responses of two different size mirrors ((a) size of mirror plate: 3×3 mm^2, (b) size of mirror plate: 1×1 mm^2). There is a hysteresis in the mirrors because of parametric excitation

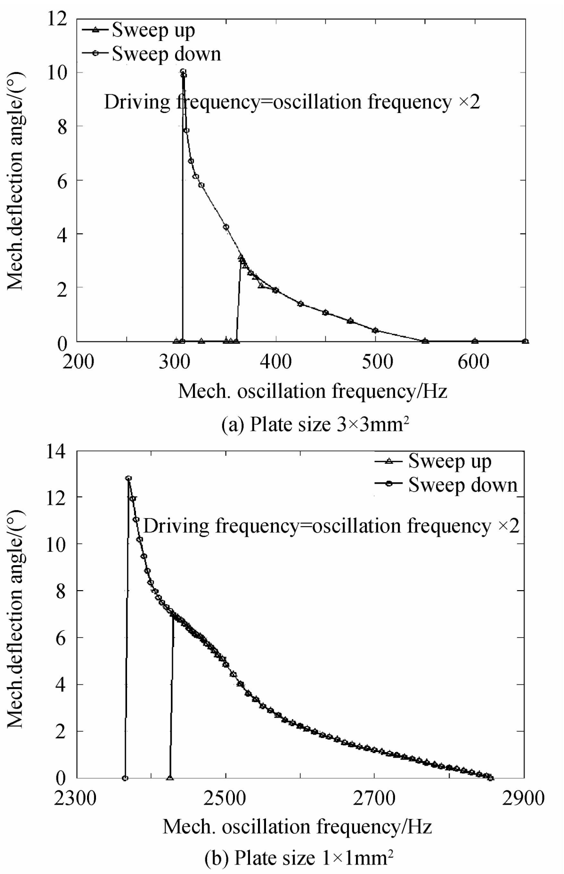

Fig. 2 Frequency responses of the mirrors

system. A higher amplitude can be gotten when driving signal frequency sweeps down. This should be considered when designing the control circuit.

2 Basic principle of laser display

2.1 Scanning principle

A laser beam deflected by two mirrors successively scans the projection screen both in horizontal (X) and vertical (Y) direction, as is schematically depicted in Fig. 3. The projection takes place on a flat screen in distance l from Y-

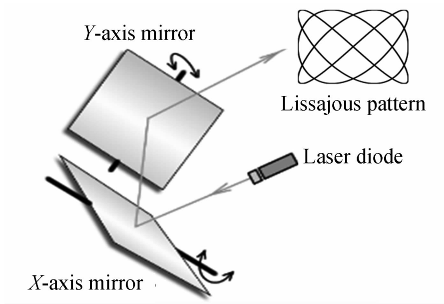

Fig. 3 Schematic of combination of two mirrors

axis mirror. The position $x(t)$ and $y(t)$ on the screen are mathematically described in Eq. (2)[9]

$$\begin{cases} x(t)=l\tan\theta_x=l\tan(\theta_{x\max}\sin(2\pi f_x(t-\\ \quad \psi_x)))\approx x_{\max}\sin(2\pi f_x(t-\psi_x)) \\ y(t)=l\tan\theta_y=l\tan(\theta_{y\max}\sin(2\pi f_y(t-\\ \quad \psi_y)))\approx y_{\max}\sin(2\pi f_y(t-\psi_y)) \end{cases} \tag{2}$$

The above equation is Lissajous equation. The superposition of the movement of both directions deflected beam describes forms Lissajous pattern on the projection screen. There are three factors ($x_{\max}:y_{\max}$, $f_x:f_y$, $\psi_x-\psi_y$) which determine Lissajous patterns. For the consideration of simplifying the control circuit, time shift ψ_x and ψ_y have the equal value, so do the $x_{\max}$ and $y_{\max}$. Therefore just through selecting the appropriate combination of two mirrors′ oscillation frequency, Lissajous pattern which has the feature of stability, sufficient line density and high refresh frequency can be achieved for image projection[9].

2.2 Oscillation frequency selection

Three important conditions have to be considered before selecting the two mirrors′ oscillation frequency.

1) Sufficient line density which determine the resolution of displays[10-11] for image projection.

2) Enough refresh frequency at least 24 Hz in order to form consecutive images.

3) The oscillation amplitude should be as high as possible for a large projection area.

Two mirrors oscillating at about 2 400 Hz (frequency response is shown in Fig. 2 (b)) are adopted for frequency selection. Considering the "hysteresis" phenomenon, and adding the frequency sweeping function into the control circuit to ensure high oscillation amplitude, the first oscillation frequency 2 400 Hz is chosen, 2 400 can be split into prime numbers.

$$2400=2\times2\times2\times2\times2\times3\times5\times5 \quad (3)$$

Next step is the calculation of the other mirror′s frequency. The refresh frequency f_r is the greatest common divisor of two frequencies and the line density of Lissajous pattern is dominated by proximity to 2 400. The nearer to 2 400, the higher density of pattern could be gotten. Unfortunately, the refresh frequency decreases with increasing density of the Lissajous pattern. This means, a compromise between refresh frequency and achievable resolution has to be made. Choosing the $f_r=25$ Hz (movies require at least 24 frames per second), removing the number $25=5*5$, the number 96 left. Then the number 96′s closest prime number 97 multiplied by 25 can result in 2 425. The effect of combination shows in Fig. 4. Here pixels (shown in Fig. 5) are defined as the number of cross points of horizontal line or vertical line and the Lissajous pattern. The numbers of pixels are used to evaluate the density of the pattern. The number of cross points in X-direction is $2\,425/25*2=194$, and $2\,400/25*2=192$ is the number in Y-direction. So the pixels of the Lissajous pattern are 194×192 which is enough for display.

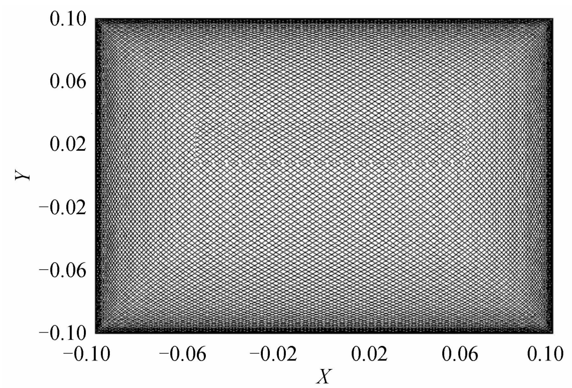

Fig. 4　The pattern ($f_x=2$ 400 Hz, $f_y=2$ 425 Hz) simulated by Matlab

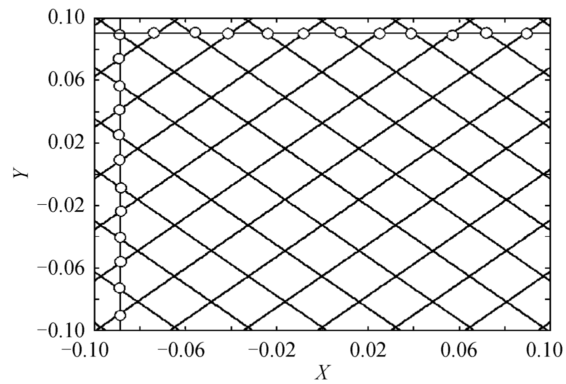

Fig. 5　The schematic of pixels ($f_x=2$ 400 Hz, $f_y=2$ 425 Hz)

If combining a high resonant frequency (about 2 400 Hz) mirror with a low resonant frequency mirror (about 320 Hz), the pattern is a little different with the pattern in Fig. 4. The procedure of frequency chosen is almost the same to previous one. Only one step which needs to be paid attention to is that ensures the eventual number is near the 320. Therefor, the closest prime number will be limited. 13 is used in multiplying 25, the $325=25\times13$ is gotten. The pattern generated by combination $f_x=2$ 400 Hz and $f_y=325$ Hz is shown in Fig. 6. The result is shown in the following. The pixels (shown in Fig. 7) of this pattern is 26×192. Apparently this combination is not suitable for image display. High resonate frequency mirror is better than low frequency mirror. Naturally the combination of the same low frequency mirrors is also not appropriate.

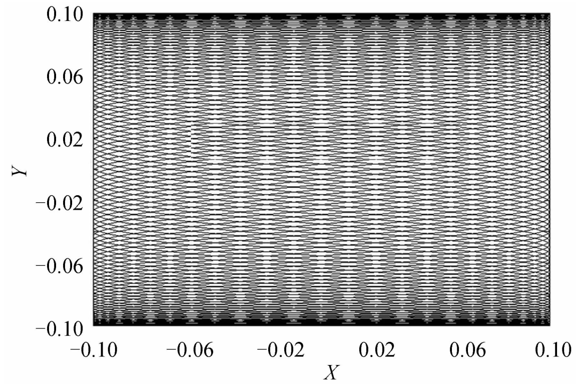

Fig. 6　The pattern ($f_x=2$ 400 Hz, $f_y=325$ Hz) simulated by Matlab

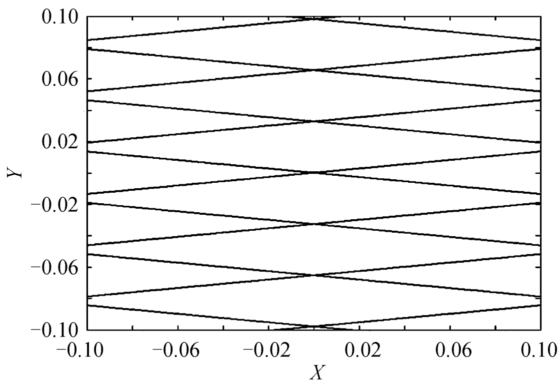

Fig. 7　The schematic of pixels ($f_x=2$ 400 Hz, $f_y=325$ Hz)

2.3　Lissajous pattern projection

Fig. 8 shows the experiment setup. Laser beam emitted by a laser diode is directed to X-axis mirror, Y-axis mirror and a projection screen successively. Function generators provide driving signal (square wave, voltage is 15 V)[8] and different oscillation frequency ratios generates different Lissajous patterns (Fig. 9). The area of the patterns is 15×12 cm^2 at the distance of 2.5 m when the driving voltage is 15 V. An optical system should be used to magnify the the pattern.

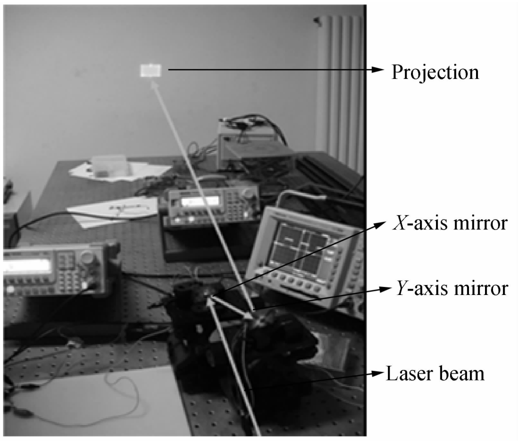

Fig. 8 A photo of the experimental setup

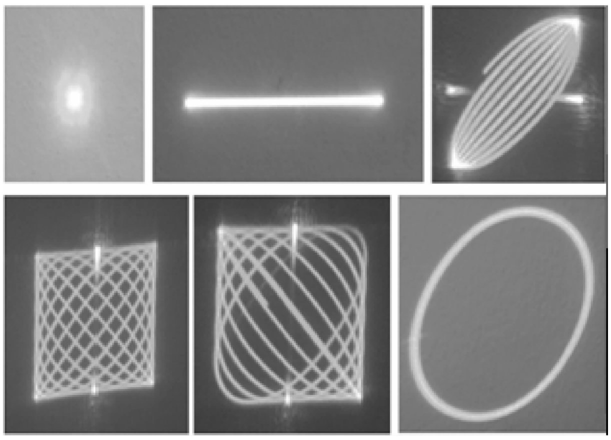

Fig. 9 Laser projection of Lissajous patterns

2.4 A method for image projection

As shown in Fig. 10, the mapping time which maps the desired image pixels information is sent to digital controllor FPGA by PC with USB

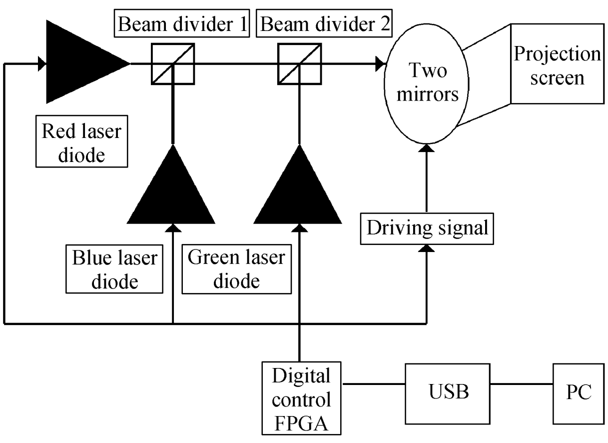

Fig. 10 Functional diagram for projection system

interface. Then turning on or off laser diodes according to the mapping time through the FPGA, the image should be projected onto the screen. If three color laser diodes could be controlled at the same time, a colorful image could be seen. Considering the are of the mirror plate and the image resolution, the laser spot size should be small and the laser power should be high. The patterns in Fig. 10 were the produced by the laser which had spot size 2×2 mm^2 @ 3 m and power 20 mW.

3 Conclusion

A micro scanning mirror for Lissajous pattern projection is presented. Through simulating Lissajous pattern with Matlab, a suitable oscillation frequency combination of two mirrors for image generation is chosen and a method for image projection is put forward. Further work is aimed at improving the mirror′s reflectivity through coating the Au film on the mirror plate and realizing the image projection.

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基于微扫描镜的激光投影

李昭,苑伟政,吴蒙,燕斌,乔大勇,刘耀波
(西北工业大学 微/纳米系统实验室,西安 710072)

摘　要:利用微机械加工技术制造出一种新型微扫描镜,结合半导体激光器,可用于投影显示.激光器发出的光束被两个分别沿着 X 轴、Y 轴扭转的镜面相继反射,扫描出二维图形.实验测得扫描镜在 15 V 电压,频率为扫描镜谐振频率 2 倍的方波信号驱动下,镜子的光学扫描角度达 $\pm 12°$.由于每个镜子都沿各自轴以简谐规律扭转,扫描所得投影为李萨如图形.通过分析图形的形成原理并用 Matlab 仿真,选出了适用用于任意图案显示的扫描镜谐振频率组合(X 轴 2 400 Hz, Y 轴 2 425 Hz).该组合可以形成 194×192 个像素点,刷新频率为 25 Hz.在此基础上提出了一种通过调制激光开关来进行投影显示的方法.

关键词:微扫描镜;李萨如图;振动频率组合;激光投影