行政院國家科學委員會補助專題研究計畫成果報告

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※ 三唯全像光學記憶系統的製作及其整合研究-子計畫-三：※
※ 微振鏡驅動與迴授控制電路之設計測試研究 ※
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計畫編號：NSC 89-2215-E-009-124
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計畫主持人：吳炳飛 教授
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執行單位：交通大學 電機與控制工程學系

中 華 民 國 90 年 10 月 25 日

行政院國家科學委員會專題研究計畫成果報告
The Design and Testing of Driving and Feedback Control Circuit for Micromirrors
微振鏡驅動與迴授控制電路之設計測試研究

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Abstract

This paper describes the development of a novel, flexible, with appropriate accuracy dynamic characteristics testing system for optical scanning micromirror. With the feedback control system, we can testing and measure dynamic behaviors such as transient response, scan speed, scan angle, scan repeatability, and scan non-linearity of the scanning micromirror devices. Moreover, the optical system performances such as scan spot size and even scan spot intensity can also be obtained.

Keywords: feedback control, scanning micromirror, scan non-linearity

中文摘要

本計畫研究重點在於設計一適用於微振鏡系統所使用之微振鏡驅動電路，並且結合其他光學元件，設計一具有迴授控制功能之動態量測系統。目前已完成適用於二種微振鏡之驅動電路設計製作與整體迴授控制量測系統架設，微振鏡對於各種驅動訊號的動態反應良好。光學量測系統亦可忠實呈現系統動態特性。

關鍵詞：迴授控制、掃瞄微振鏡、非線性掃瞄

1. INTRODUCTION

Various micromirror devices based on MEMS technology had been fabricated in last two decades [1]. For different application purpose, these micromirror devices had been designed with different geometry that are driven by various methods such as electrostatic, thermal, electromagnetic and piezoelectric forces. However, regardless the type of method one may use to drive the micromirror device, the dynamic characteristics of micromirror must be measured initially in order to have any practical applications. To accomplish the goal, in the past, researcher observes the behaviors of micromirror device by using high-speed image capture system. To overcome the low accuracy and measurement error from manual inspection, Kiang [2] had constructed a Fabry-Perot interferometer to characterize the scan repeatability of micromirror device. Furthermore, he also used position-sensing detector (PSD) to measure dynamic characteristics of the designed scan system. Note that the former scan system is complex and expensive and the latter scan system can only be used to measure the position of scan spot.

In order to overcome the above-mentioned disadvantages and obtain a good measurement quality, an all-in-one novel system for dynamic characteristics measurement of the scanning micromirror device is developed. By using the system, we can measure dynamic behaviors such as transient response, scan speed, scan angle, scan repeatability, and scan non-linearity of the scanning micromirror devices. Moreover, the optical system performances such as scan spot size and even scan spot intensity can also be obtained. In the present paper, the architecture, principle, and implementation of the whole measurement system is described. Furthermore, in order to demonstrate the feasibility of the system, we had also designed two micromirror devices, which were fabricated through MUMPs [3] to be our testing samples.

2. SYSTEM ARCHITECTURE

As shown in Fig. 1, the proposed measurement system consists of a laser diode, a linear CCD detector, control circuits and a set of optical components. The light is illuminated from a laser diode, collimated and focused by the lens and then reflected by the micromirror onto CCD sensing area. Automatic power control (APC) circuit is developed to ensure the constant output power of laser diode, and the digital integrated circuit is designed for signal processing of CCD detector. Note that the function generator is used to obtain various voltages to drive the micromirror device, and the computer is used to control the entire measurement procedure and record the data obtained from CCD sensor. By activating the laser diode and the scanning micromirror device, the behaviors of micromirror device could be transferred to the behaviors of scan spot on the linear CCD sensing area. In other words, by measuring of the scanning light performances on the CCD, the dynamic characteristics of the micromirror device can be obtained. Furthermore, since the CCD detector is also capable of sensing spot light intensity, size and position, we can obtain the dynamic characteristics described above through the process of the output signals of CCD detector.

3. IMPLEMENTATION

As described above, the computer is used to control the measurement procedure and record the data. At the initial stage of the measurement, the CPLD is used to generate sequential signals to drive linear CCD sensor and is used to activate APC in order to drive the laser diode. In each measure period, the computer is used to read the data from CPLD through printer port and record these data into the hard disk. The sub-systems is described as followings:

3.1. Automatic Power Control (APC) Circuits

Generally speaking, two types of circuits are used for driving the laser diode. One is the so-called Auto Current Control (ACC) circuit, and the other is Auto Power Control (APC) circuit. Typically, ACC is used for special cases such as the characteristic measurement of laser diode. Although this control method can support fixed current to drive laser diode, the output power of laser diode could vary due to the fact that the threshold voltage of laser diode could alter by environment temperature. In order to fix the output power of the laser diode so that can it can be adopted as the light source of measurement system, the APC circuit system is designed. Figure 2 shows the architecture the circuit. OP1 is used as the voltage buffer, and OP2 is constructed to be differential amplifier. The BJT played the role as the voltage-control-current source, which supports the driving current to laser diode. Finally, the photodiode senses the output power and generates the feedback current.

Assuming that we can drive the laser diode with fixed output power, we can then examine the operation of circuit if the noise disturbs the performance of the laser diode. Firstly, if the output power is higher than the desired output, the feedback current (i_m) generated by the photodiode would increase. Since the buffer follows the feedback voltage, thus the differential amplifier output voltage will decrease such that the output current (i_d) of transistor will decrease. That is, the output power of laser diode will decrease to the desired value. Here, the reference voltage (V_{ref}) is used to set to the design constant voltage to match the output power we preferred.

3.2. Signal Processing

To control the procedure of the measurement, the signal process of the system is developed. Firstly, a series of special sequential digital signals is generated to drive the linear CCD sensor. Figure 3 shows the timing diagram [4] of linear CCD sensor. Here, the sROG and sCLK are the driving signals, and sVOUT is the output signal. By activating the linear CCD sensor, the output signal of CCD and driving signals of micromirror can be stored in memory. In order to process the complex signals, we use Verilog hardware description language to embed and implement request functions into ALTERA CPLD [5]. For output signal process of CCD sensor, an ADC is used to convert signal to match the digital level set. Note that through the present method, a more flexible and easy to modify sensing system is obtained.

3.3. Optical System Configuration

Because the size of micromirror is small, a set of optical components is used to process the light generated by laser diode. Two lens with focal length of 1.5cm and 30cm are used to collimate and focuses the light onto micromirror. In addition, due to the fact that the linear CCD sensor is sensitive to light, we use a polarizor to modulate the light intensity to match its sensing range.

3.4. Computer Implementation and Data Storage

The computer used here is to record the measurement data in period. To obtain accuracy measure time reference, the time-interrupt program by using C language is implemented. When the measurement ends, we would read the data from printer port one-by-one and reassembly to correct data.

4. MICROMIRROR DESIGN

In order to demonstrate the feasibility of the measurement system, two thermally actuated scanning micromirror systems were designed. The micromirror had been fabricated through MUMPs process. Figure 4-1 shows the layout of the type-I micromirror device. The device consists of a 200 x 200um^2 mirror, a set of lateral thermal actuator array [6], micro-hinges [7] and a pre-designed lock mechanism. By releasing the device, we use the probe to flip up the micromirror and set the mirror into the designed initial angle by using T-shape hole and I-tether lock mechanism. By driving the thermal actuator array, the vibration of the micromirror generates the scan behavior. Since the surface of the micromirror is coating with gold as given in MUMPs process, the mirror can guarantee the high optical reflectivity. Figure 4-2 shows the CCD image of scanning micromirror after assembly is completed.

The layout of type-II micromirror device is shown in Figure 5-1. The main difference between these two designs is that we move the actuator array from the front side of the mirror to the rear side of the mirror so that the designed dice size area can be greatly reduced. Furthermore, the design can be easily adopted to implement a micro-scanning array chip by integrating laser diode for the reason that the mirror of type-II is closer to laser diode than type-I which has difficulty in covering the spot area of the light. Figure 6 gives the concept design of micro-scanning array chip. CCD image of type-II scanning micromirror is shown in Figure 5-2.

5. EXPERIMENTAL RESULTS

Upon the system is set, we are ready to measure the dynamic characteristics of the fabricated scanning micromirrors by applying various driving signals with different frequencies. The inputs and the results of the designs are given as follows:

5.1. Results for type I Micromirror

For type I micromirror device, the input signals and the experimental results of the system are given in Figure 7(a)-(d) where two different driving signals and frequencies are used. From the experimental results, we observed that scan behavior of type I micromirror device is non-linear for the driving voltages and the scanning angles. No matter what type of driving signals was applied, the scan path is remained approximately in square form. The scanning speed can reach over 50Hz as the scan angle amplitude did not decrease within 50Hz. In addition, the system has the threshold voltage for scan start/stop while the back-and-forth path of scanning device is altered. However, the scan repeatability is good during the entire experimental process.

5.2. Results for type II Micromirror

For type II micromirror device, the input signals and the experimental results of the system are given in Figure 8(a)-(c) where two different driving signals and frequencies are used. In Fig. 8(a), the relationship between scanning angle and driving signals is obtained. In the present experiment, we observe that the scanning angle follows the drive signal well except for the starting portion of the scan period. Here, the system possesses a threshold voltage (about 0.8V) for scan start/stop. As shown in (b) and (c), the scanning behavior is proportional to the driving signals when the applied voltage is higher than 0.8V. In other words, we have obtained a linear relationship for the driving signals and scanning angles. Furthermore, since the projection of light onto micromirror, the scan spot size would vary in a scanning cycle. These phenomena are also shown in Fig. 8(b), (c).

6. DISCUSSION

By examining two designed scanning micromirror devices with proposed measurement system, we are able to obtain dynamic characteristics of the mirrors. Although these two micromirror devices are similar in design, the initial angle of micromirror greatly affects the scanning behavior of the micromirror devices for the nonlinear behavior of micro-hinge implementation using surface micromachining technology. In conclusion, we had demonstrated the feasibility of dynamic characteristic measurement by using the designed system. The system is capable of measuring dynamic behaviors such as scan speed, scan angle, scan repeatability and scan non-linearity of scanning micromirror systems. Furthermore, we can measure optical performances such as scan spot size during the process of experiments. By using the proposed configuration, researchers can identify the dynamic characteristics of scanning micromirror with given accuracy and low cost.

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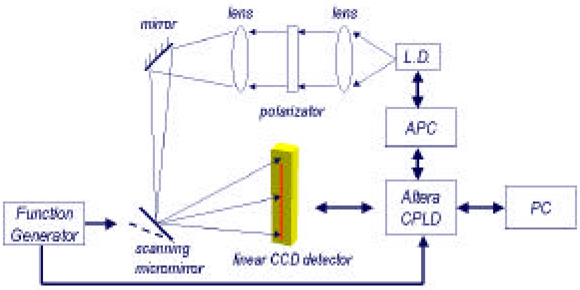


Fig 1. Measurement system architecture

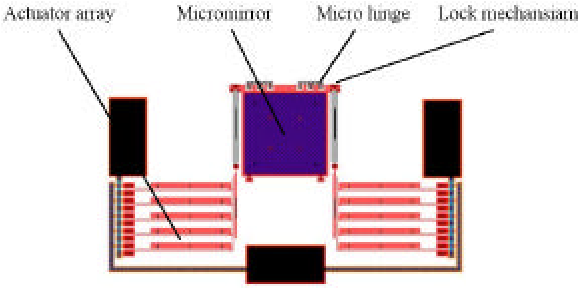


Fig 5-1. The layout of micromirror

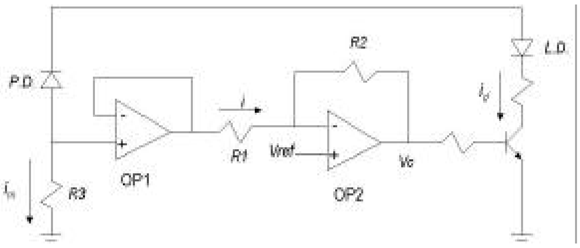


Fig 2. APC circuit

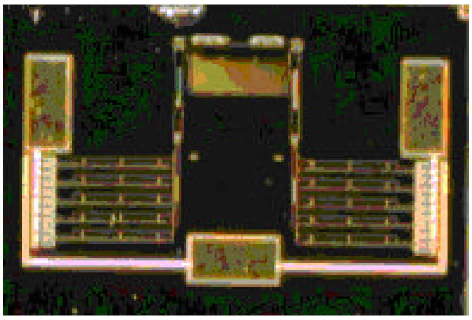


Fig 5-2. CCD image of type-II

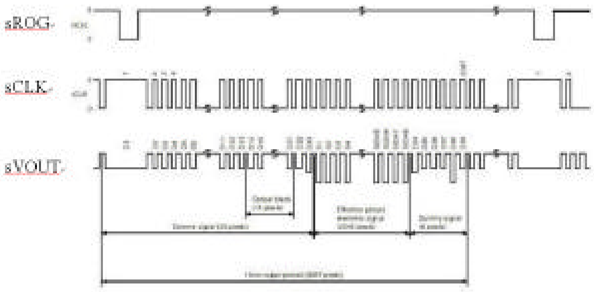


Fig 3. Timing diagram of SONY ILX503A linear CCD sensor

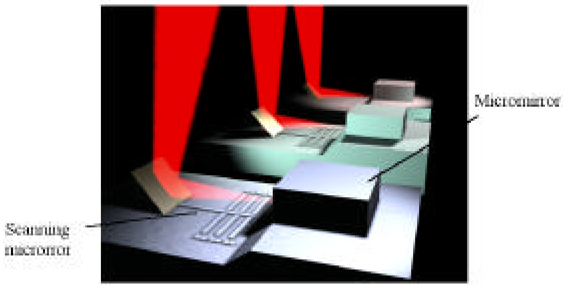


Fig 6. The micro-scanning chip

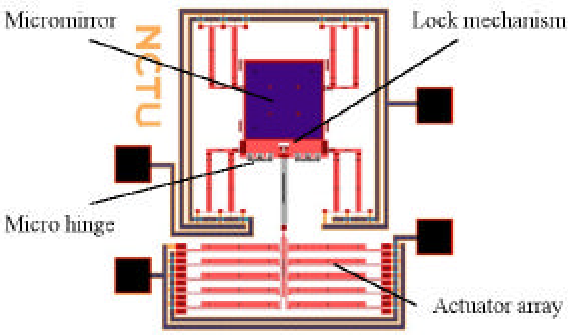
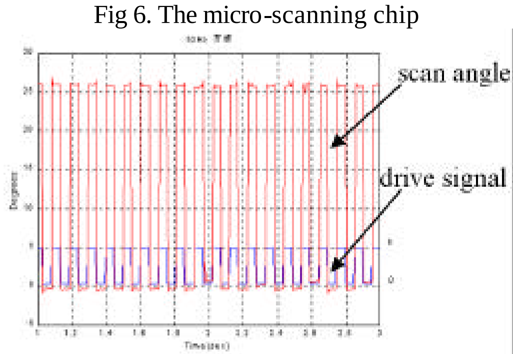


Fig 4-1. The layout of micromirror



(a) input : 10Hz, square wave, 0~5V

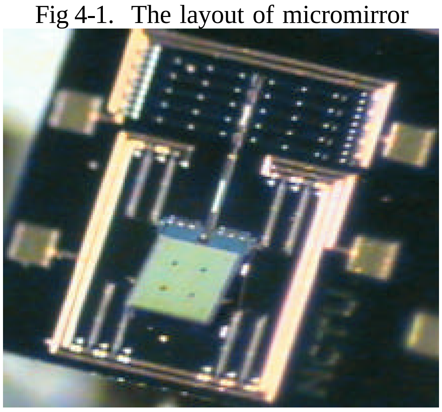
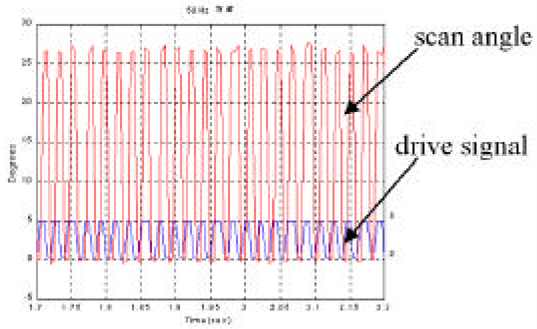
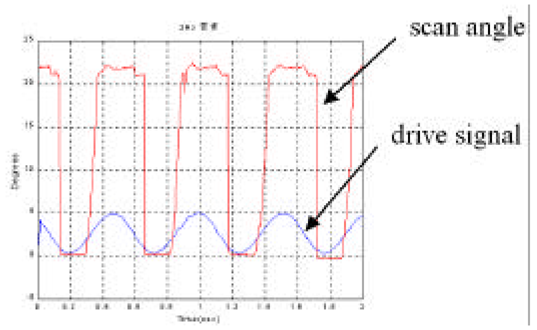


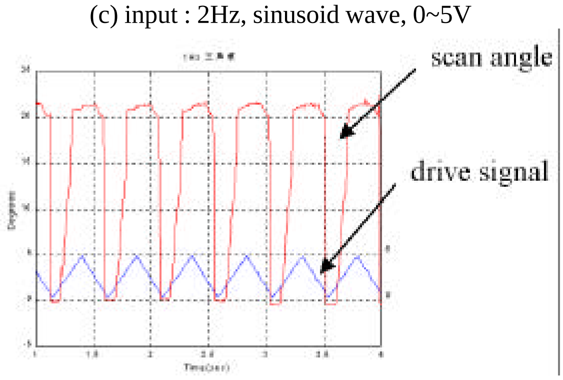
Fig 4-2. CCD image of type-I micromirror



(b) input : 50Hz, square wave, 0~5V

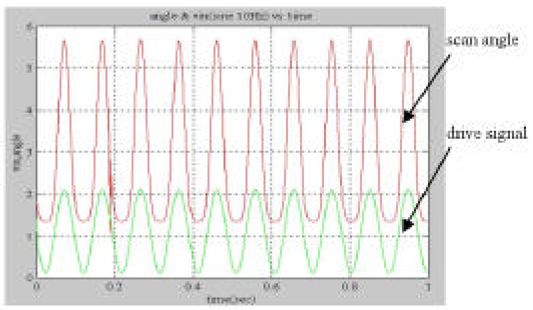


(c) input : 2Hz, sinusoid wave, 0~5V

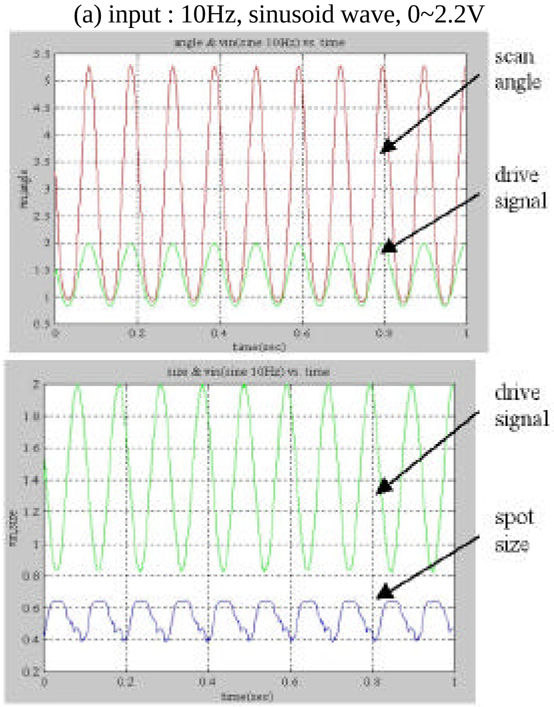


(d) input : 1Hz, triangle wave, 0~5V

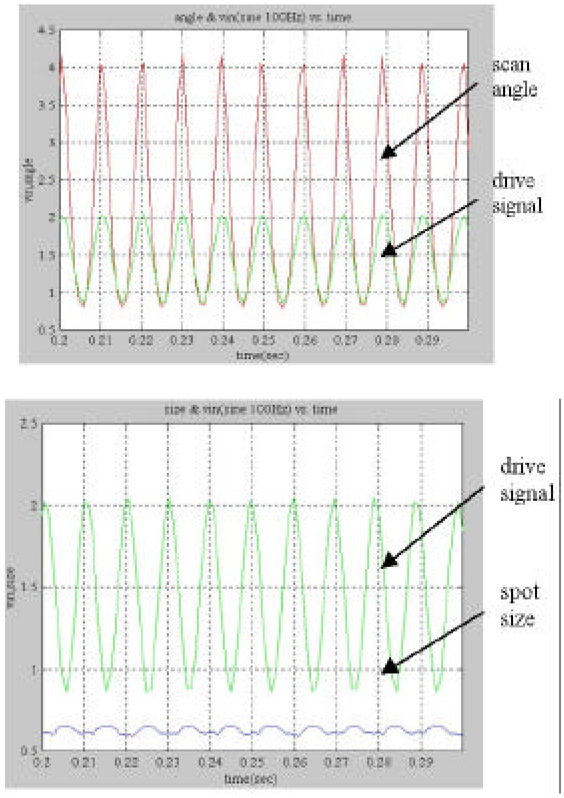
Fig. 7. Inputs and experimental results for type I micromirror device



(a) input : 10Hz, sinusoid wave, 0~2.2V



(b) input : 10Hz, sinusoid wave, 0.8~2.2V



(c) input : 100Hz, sinusoid wave, 0.8~2.2V

Fig. 8. Inputs and experimental results for type II micromirror device