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MEMS Based Color-VGA Micro-Projector System

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Abstract

This paper presents a complete portable laser-based projection system using twofold of one dimensional magnetic actuated MEMS linear scanning micro-mirrors. Dedicated high speed electronics was developed to drive the MEMS, detect the mirror scanning position at any time and synchronize the two mirrors and the laser pulsation. The achieved projection system head is 4.5cm^3 and is able to project colorful static images and videos (50fps) with projection size of 50cm diagonal at 50cm distance with VGA (640x480px) resolution.

Keywords: MEMS; scanning mirror; micro-projector; laser-scanning; resonant mirror; magnetic actuation

1. Introduction

MEMS scanning micro-mirrors were developed using various actuation techniques, including thermal, electrostatic, piezoelectric and magnetic. The initial technology choice strongly depends on the applications and the required performances in terms of scanning speed, scanning angle, shock resistance, power consumption and packaging compatibility. In this work, magnetic actuated MEMS micro-mirrors have been developed for the laser scanning projection purpose. Design characteristics and achieved performances of the magnetic MEMS are presented. MEMS-dedicated driving electronics and complete digital and analog electronics circuit for projection purpose are also described.

2. MEMS scanning micro-mirror technology

2.1. MEMS design

Mono-crystalline silicon MEMS micro-mirrors (Fig. 1, left) were used as key components of the micro-projection system where those mirrors act as scanning deflectors in order to project a two-dimensional image. High performance magnetic actuated MEMS mirror were developed for this work, where a magnetic field is created by external permanent magnets and Laplace force is acting on the edges of the mirror, along a metallic coil where the driving voltage is applied [2]. A specific MEMS micro-mirror design was developed to achieve both a high frequency of 19.5 kHz and a large scanning angle of 40 optical degrees for a reflective scanning surface of 1mm side (Fig. 1, right) [1]. A second MEMS mirror actuated under static operation was designed and optimized to allow 50Hz image refreshment, while designed for large scanning angle and low power consumption. The fabrication process for both mirrors was optimized in parallel to the MEMS design to achieve a fabrication yield greater than 95%. MEMS specific design allows a flatness in scanning operation greater than $\lambda/10$ in the visible range, avoiding any projection distortion from the MEMS. The mirrors were also designed to sustain acceleration of 2000g, key requirements for handheld mobile projection application.

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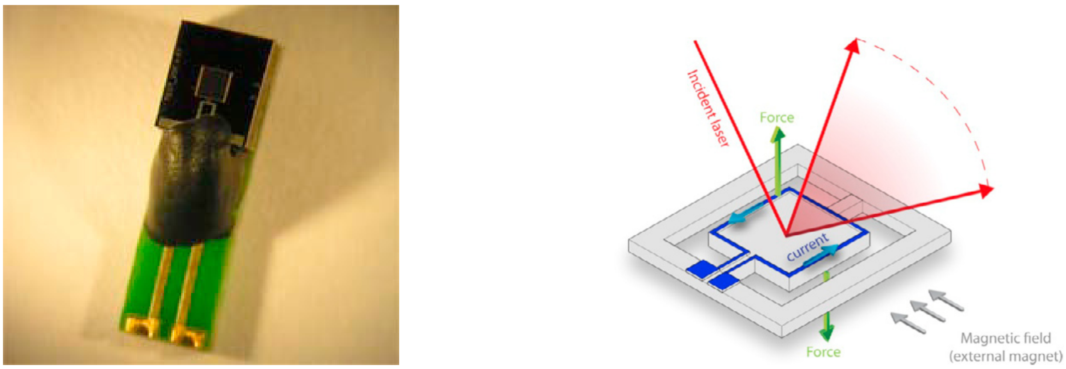


Fig. 1. left) MEMS scanning mirror mounted on permanent magnet, right) working principle of a 1D MEMS scanning mirror

2.2. MEMS performances

The performance of the MEMS mirrors are presented in Fig 2. The slow axis mirror is actuated under static operation and presents in Fig. 2, ultra-low power consumption down to 10mW for 25 optical scanning degrees. In the projection system, the slow axis mirror is actuated to follow a smoothed sawtooth shape. The 19.5 kHz fast axis MEMS mirror presents a scanning angle up to 40 optical degrees. Dedicated electronics was designed to drive the two MEMS mirrors in raster scanning operation, the fast axis MEMS mirror is generating lines and the slow axis mirror is providing the 50Hz image refreshment. The electrical response of the high speed resonance MEMS to an AC actuation signal is innovatively detected and measured by processing the induced voltage created by the motion of the driving coil in the magnetic field.

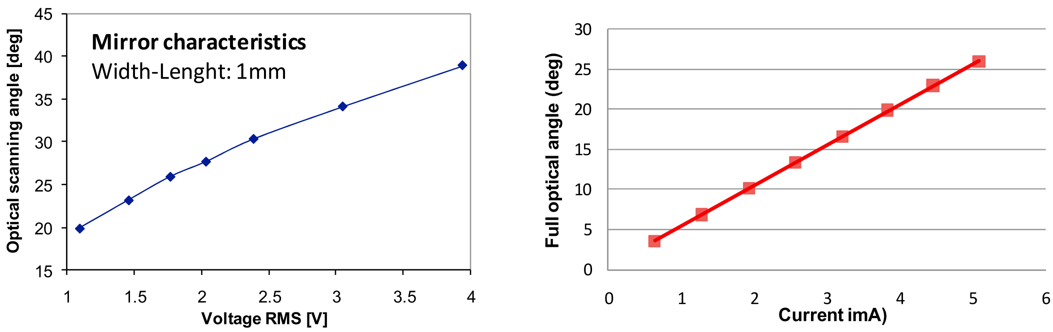


Fig. 2 Left: fast axis MEMS mirror scanning angle v.s applied signal, right: Slow axis MEMS mirror scanning angle v. applied current

3. Micro-projector design architecture

3.1. Projection system architecture

As shown on Fig. 3, the image is produced by directing the color laser beam onto the fast frequency axis mirror, which reflects onto the slow frequency axis mirror, placed perpendicularly to the first one. The MEMS mirrors frequencies and driving modes are designed to achieve scanning of the complete image area with a raster-like pattern. Each pixel is then produced by modulating the three R-G-B lasers with the corresponding colors knowing the mirrors scanning angles and therefore at the desired pixels projection places. The electronics system and mirrors frequencies were designed to ensure that each pixel is effectively displayed once per image.

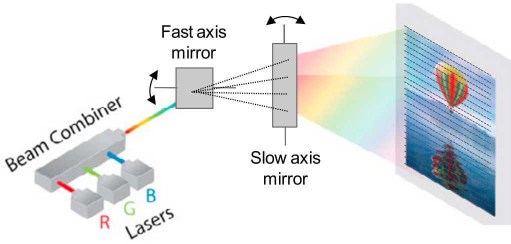


Fig. 3 Raster scanning type projection system using three colors lasers, Red, Green and Blue

3.2. High speed mirror closed-loop control

In order to get the widest projection angle for the smallest electrical current, the high-speed MEMS mirror must be actuated at its resonant frequency. The electrical response of the fast axis resonant MEMS to its AC actuation signal is detected and measured by processing the induced voltage created by the motion of the driving coil in the permanent magnetic field. The closed-loop process is done in two steps:

The mirror is actuated at a probe frequency, known to be within the resonant frequency range;

The induced voltage is amplified and compared to a fixed voltage. As that mirror is a resonant system, when actuated within its mechanical resonance frequency range, the measured induced voltage will show its maximum at the mirror resonance frequency that will be used as a feedback loop.

In order to find the fast MEMS mirror resonant frequency, it is actuated at a set of frequencies around the nominal frequency. When the probing frequency falls within its mechanical resonance frequency range, the real resonant frequency is measured. Then, in order to track that frequency, which will slightly evolve with time and temperature, it is regularly re-probed.

3.3. Slow mirror position constraint

The slow axis MEMS mirror is designed to be voltage-driven in static position. For optimum raster scanning projection, the mirror is driven with a smoothed sawtooth. The design was made so that the intrinsic mechanical resonant frequency of the mirror is much higher than the actual off-resonance driving frequency. This design minimizes the effect of the MEMS quality factor on the sawtooth actuation waveform, by avoiding parasitic mechanical frequency coupling. Furthermore, as the high speed mirror imposes its position by being driven at its resonant frequency, the slow mirror is held at its starting position in order to wait on the fast mirror start. This synchronization guarantees fixed position and orientation of the image.

3.4. Pixel position computation

The resonant frequency actuation of the fast axis mirror is used to compute the instantaneous beam angle. As shown in [1], the mirror oscillation is sine-like; this implies that the laser beam speed (and hence the perceived luminosity) on an orthogonal screen will also be of sine-like shape. Then, in order to beam regular-size pixels, the instantaneous beam angle is transformed to the projected position by computing its sinus by using a single “arcsinus lookup table” for the four sinus quadrants. The horizontal pixel coordinate is then determined from this projected position. The vertical pixel coordinate is then simply determined by incrementing the line count synchronously with the high-speed MEMS movement.

3.5. Image acquisition and pre-processing

The VGA resolution (640x480 pixels) input video stream is fed into the system through a standard VGA connector. It is digitized using a specialized IC and processed by an FPGA. The video frames are preprocessed and stored into two DDR SDRAM memories, alternatively. When one memory is used to store the incoming video frame from the VGA connector, the other one is used as input to the MEMS-based display. This method was developed for two reasons: firstly, the mirrors movement are not synchronized with the video flow: it is not possible to pipe directly the acquired image to the laser projection as the mirrors will not be at the position of the pixel currently being acquired; secondly, the needed bandwidth for each memory is divided by two when two memories are used. This was mandatory because of the very high rates needed. The delay between the input video stream and the display is then always of exactly one complete frame.

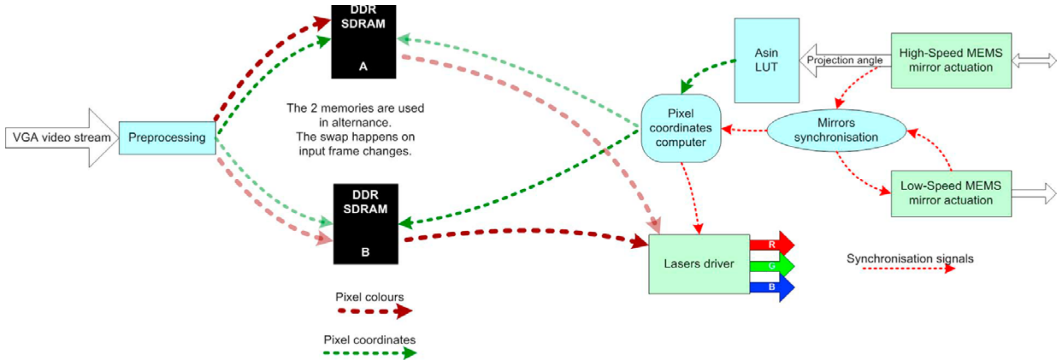
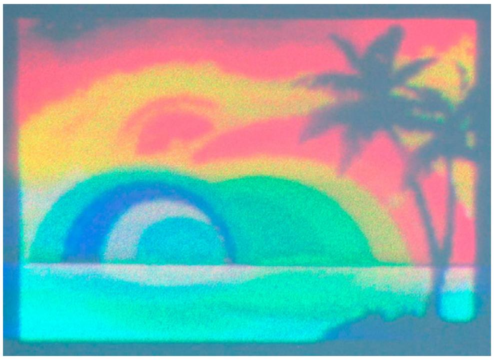


Fig.4 Bloc scheme of the FPGA-based projection system

4. Micro-projector performances

The complete system was able to project full video with 24 bits colors with 640x480 pixels resolution at 50 frames per second as shown in Figure 5 and in Table 1.



Resolution	640x480 px
Frame rate	50 fps
Colors	3x8 bits (16.7 million colors)
Constant focus range	0.2 – 8 m
Laser pulsing	100 MHz
FPGA Frequency	133 MHz

Fig. 5 Laser Projection: Left) static bitmap projected image

Table 1. Laser projector capabilities

Conclusion

Complete "plug-and-play" laser MEMS-based micro-projector was demonstrated in this work with VGA-resolution with a refreshing rate of 50Hz, 16 million colors and always-in-focus performances. Unique characteristics of developed MEMS mirrors and high performance algorithm were developed and implemented to allow raster scanning type projection system and video streaming. The resulting screen size is 50 cm (diagonal) at 50 cm distance, with high contrast and brightness levels, enabled by the use of laser light sources. The developed micro-projector is then suitable for embedded and information displays applications. Further miniaturization of the complete micro-projector is under development in CMOS technology.

Acknowledgements

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