Improved Control of the Vertical Axis Scan for MEMS Projection Displays

Veljko Milanović
Adriatic Research Institute
828 San Pablo Ave., Ste. 109, Berkeley, CA 94706
veljko@adriaticresearch.org

Abstract - We demonstrate a MEMS projection display system with high speed, broadband, open-loop driving of the vertical axis which improves displayed image quality, increases the refresh rate capability and image brightness/efficiency. High speed capability in the vertical axis allows precise parallel line scanning as well as arbitrary line placement for features such as interlacing.

INTRODUCTION

Raster scanning for a video application presents a difficult high-speed requirement for the horizontal axis [1], even at lower resolution standards such as VGA (640x480 at 60Hz.) In a display application at VGA specifications for example, the fast axis should have a ~31.5kHz scan frequency, although using techniques such as displaying on the forward and backward trajectory can halve that frequency requirement. Often, the horizontal axis specification of a device is the determining factor for its overall performance due to the fact that it is difficult to achieve such high scanning rates (>15kHz,) large angles of deflection, relatively large mirrors, and minimal dynamic deformation during the scan. Ideally, motion of the horizontal axis scan would have uniform velocity across the active video region, i.e. a "triangle" waveform, requiring bandwidth far beyond the above scan rate. If we neglect this latter requirement however, and allow the horizontal axis to move with sinusoidal velocity, the problem becomes significantly simpler. In this regime of operation, raster scanners leverage the quality-factor (Q) of devices and utilize devices capable of only narrow-band sinusoidal driving [1]-[3]. Scanning at/near resonance allows design with very stiff suspensions to be used and in turn provides sufficiently high frequencies and angles.

At the same time, the frame refresh rate requirement creates a vertical axis period specification of 1/60Hz. Seemingly, this would be a relatively easy specification, which is exemplified in the frequently used naming of this axis as the "slow axis." However, the actual waveform requires a significantly higher bandwidth (at least 20X the refresh rate,) due to the fact that a highly linear scan is necessary, and that the retrace time (during which the display is off) should be as short as possible. In other words, we require a sawtooth waveform with at least 10:1 duty cycle. Achieving a high duty cycle is critical to obtaining high refresh rates as well as high brightness/efficiency, by minimizing the laser-off time. In Fig. 1 we show an example case where the ratio of active lines to retrace lines is 10:1, therefore forming a highly asymmetric sawtooth waveform. Fig. 1a shows the frequency content of an ideal waveform with these specifications, compared to a 1:1 triangle wave. Fig. 1b is the measured actual scan of a mirror where the vertical axis bandwidth is limited to only 400Hz. Though 400Hz is significantly higher than the 60Hz refresh rate, the waveform obviously suffers significant distortion from desired sawtooth, showing that such a bandwidth is inadequate for the application.

IMPROVED APPROACH

In order to improve the image quality, refresh rate, and brightness, in our work we implement the vertical scan with devices that have significantly higher bandwidths and also utilize custom feed-forward filters to increase the bandwith beyond first resonance, while preventing ringing. A comparison example of a measured device waveform is shown in Fig. 1b. Our methodology allows arbitrary line placement (in applications like interlacing,) and purely horizontal and parallel scan lines (instead of continuously increasing vertical scan.) Namely, a vertical axis waveform is actually made up of flat regions and small steps to provide purely horizontal scanning.

In the demonstrations, we utilize gimbal-less two-axis (2D) MEMS optical scanners [3] (Fig. 2b) based on monolithic, vertical combdrive actuators. Normally, they are designed for ultra-fast two-axis beam steering with large optical deflections of >20° over the entire device bandwidth. For video projection application at VGA and SVGA specifications, we design the horizontal axis (X-axis) significantly stiffer to provide high resonant frequency and larger angles, and drive it in resonance. Bode plot of a device with a 0.8mm diameter mirror is shown in Fig. 1c.

It is possible to assemble different size mirrors onto the actuators, which enables a controlled tradeoff between desired aperture and speed. Our gimbal-less two-axis devices have horizontal axis resonant frequencies ranging from 10.0 kHz to ~21.5kHz, for mirror sizes ranging from 1.2mm to 0.8mm diameter. The power consumption of these scanners (< 10mW) is significantly lower than comparably performing scanners.

DISPLAY SYSTEM

We have integrated the MEMS scanner into a compact projection display system (Fig. 2). Video inputs are digitized based on input selection/settings controlled by a PC. Digitized video with sync information is processed by the FPGA DSP unit. This unit also controls the timing and drive signals for the MEMS scanner. It synchronizes the output video data (to laser modulation output) with the mirror position which is governed by the D/A channels and high voltage amplifiers (HVA). Specific X-axis and Y-axis drive signals are prepared in the PC for a specific device and video specifications (refresh rate, etc,) and downloaded to the FPGA memory for continuous readout.

While the X-axis data does not require any filtering or special treatment, the vertical (Y-axis) data is prepared based on the knowledge of the Y-axis capability of the device and in such a way to optimize speed and positional precision, while avoiding ringing. The simplest filtering scheme applies a digital approximation of a Bessel low pass filter while the feed-forward filter [5] uses information about the device resonant frequency and Q to compute a nearly optimal input waveform. A comparison of measured vertical axis waveforms for those two cases is shown in Fig. 1b. The prepared X-axis and Y-axis drive data is then downloaded to the FPGA processing board.

CONCLUSIONS

An ultra-low power portable laser vector display system was demonstrated using MEMS gimbal-less micromirror scanners.

[1] Hakan Urey, “High performance resonant MEMS scanners for display and imaging applications,” Proc. SPIE, Vol. 5604, Philadelphia, Pennsylvania, Oct. 2004
[2] A. Yalcinkaya, *et al*, “Two-Axis Electromagnetic Microscanner for High Resolution Displays,” J. of MEMS, vol. 15, no. 4, Aug. 06.
[3] Y-C Ko, *et al*, “Eye-type scanning mirror with dual vertical combs for laser display,” Proc. of SPIE, vol. 5721, 2005.
[4] V. Milanović, *et al*, "Gimbal-less Monolithic Silicon Actuators For Tip-Tilt-Piston Micromirror Applications," *IEEE J. of Select Topics in Quantum Electronics*, vol. 10, no. 3, Jun 2004.
[5] V. Milanović, K. Castelino, “Sub-100 µs Settling Time for Gimbal-less Two-Axis Scanners", Optical MEMS 2004, Takamatsu, Japan, Aug. 2004.

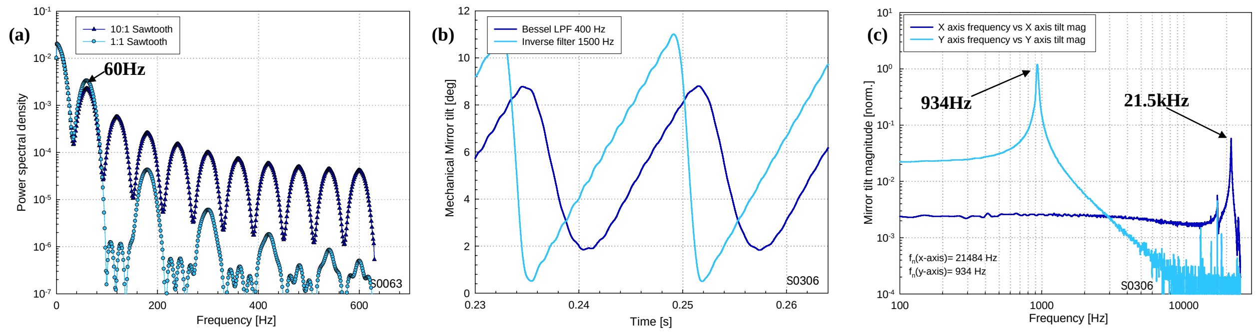

Figure 1. (a) Power spectral density (PSD) of a sawtooth waveform for the vertical scan. The 10:1 ratio sawtooth has a broad power spectrum well beyond the 60Hz refresh rate. (b) Amplitude of the small signal freq. response of a device used to demonstrate SVGA-specification display. (c) vertical axis scan improvement by using a customized inverse filter.

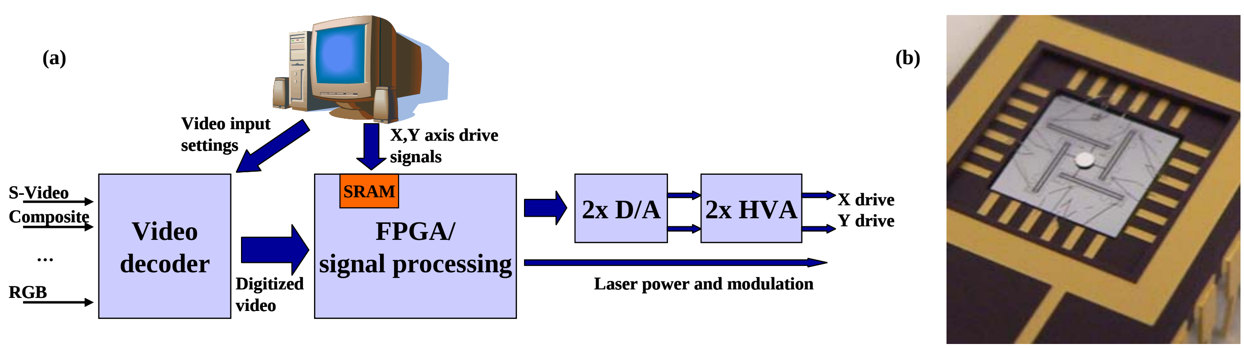

Figure 2. (a) Schematic diagram of the MEMS projection display hardware setup. Video inputs are digitized based on input selection/settings controlled by a PC. Digitized video with sync information is processed by the FPGA DSP unit. This processing unit also controls the timing and drive signals for the MEMS scanning mirror, synchronizing the output video data (laser modulation) with the mirror position which is governed by the D/A channels and high voltage amplifiers (HVA). Specific X-axis and Y-axis drive signals are prepared in the PC for a specific device and video specifications (refresh rate, etc,) and downloaded to the FPGA memory for continuous readout. (b) A two-axis scanning device with a 0.8mm mirror.

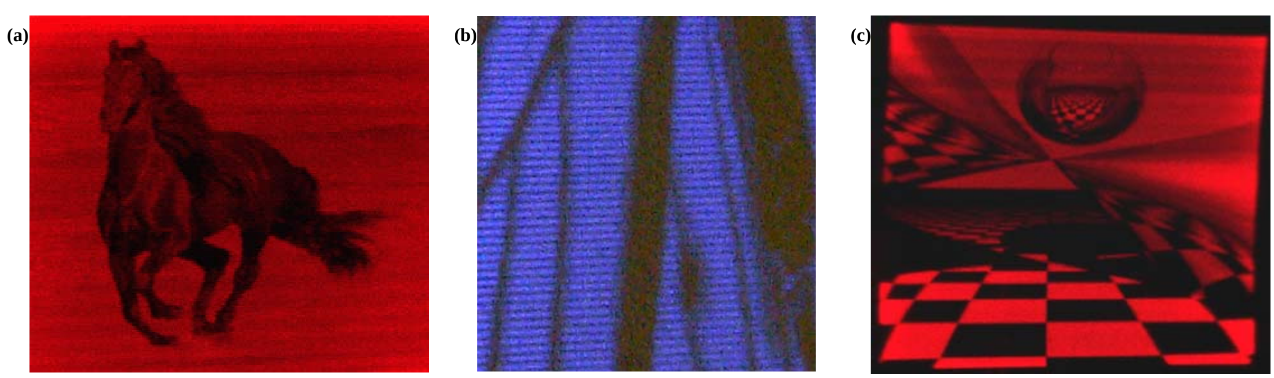

Figure 3. Examples of images displayed by the projection system. (a) Portion of a 320x240 image with a 635nm laser showing 32 grayscale levels. (b) Close inspection of a small segment of an image displayed with a 405nm laser shows horizontal, parallel lines. This is due to flat segments in the vertical scan followed by small steps which move the Y-axis from line to line. (c) a VGA (640x480) demo showing the computer's 2nd monitor through the projection display. Image has 14 grayscale levels due to speed limitation of our 635 nm laser. Full field can be displayed on each refresh, or half a field with interlacing.