MEMS-Based Low-Power Portable Vector Display

Kenneth Castelino, Veljko Milanović, Daniel T. McCormick
Adriatic Research Institute
828 San Pablo Ave., Ste. 115E, Berkeley, CA 94706
veljko@adriaticresearch.org

Abstract - We demonstrate a MEMS-based vector display system utilizing gimbal-less two-axis micromirror scanners for high-speed laser beam-steering. The system is capable of displaying freehand sketches, parametric curves, text, as well as multiframe animations at arbitrary refresh rates. The scanners can be operated in point-to-point vector scanning or resonant and rastering modes. Due to ultra-low power consumption of the MEMS devices, the system is highly portable, miniature and powered and controlled via a PC USB interface.

INTRODUCTION

Vector displays operate by scanning only the path required to trace out the objects being rendered while raster displays must scan the entire view field. Vector displays require significantly less memory, do not suffer from aliasing and pixelation effects and are superior to raster displays for applications such as compact heads-up and projection displays and laser light shows where wireframe images are sufficient. The requirements and limitations of the scanning system depend on the display mode. Vector display scanners require high-speed beam-steering capability for both axes, must be capable of large angle deflections over the entire bandwidth of operation and must achieve arbitrary refresh rates. Overall, vector display scanners are limited by scanner speed and image complexity. In contrast, raster scanners leverage the Q of devices and utilize devices capable of only narrow-band sinusoidal driving [1]. Due to the narrow-band nature these devices, the refresh rates are pre-determined for a given device design but image complexity is not a limitation. While resonant MEMS scanners [1] have been used to demonstrate laser raster displays for full-motion video [2], vector display systems still use macroscopic galvanometer scanners [3] due to lack of MEMS scanners capable of achieving large-angle deflections over a wide bandwidth. However, the main problems with galvanometer scanners are their large power consumption and size and the need for closed-loop control to provide acceptable performance in display applications.

We have developed gimbal-less two-axis MEMS optical scanners [4] (Fig. 1a) based on monolithic, vertical combdrive actuators. The gimbal-less design results in ultra-fast two-axis beam steering with large optical deflections of >20° over the entire device bandwidth, which is suitable for vector scanning. It is also possible to assemble different size mirrors (Fig. 1b) onto the actuators, which enables a controlled tradeoff between desired aperture and speed. Our current devices have resonant frequencies ranging from 1.4 kHz to 6.6 kHz, for mirror sizes ranging from 2mm to 0.8mm diameter, respectively. Settling times below 100μs were demonstrated [5], which is better than current state-of-the-art galvanometer scanners. More importantly, these speeds are achieved using an open-loop feedforward control scheme that extends the operating bandwidth well beyond resonance and greatly simplifies system / circuit design. Finally, the power consumption of our MEMS scanners (< 1mW) is several orders of magnitude lower than that of similarly performing galvanometer scanners and the devices can be run directly using signals from a PC audio port [5] or USB port (present work).

VECTOR DISPLAY SYSTEM

We have integrated the MEMS scanners into a compact vector display system that can be actuated using voltages from a PC audio or USB port (Fig 1c). A software user interface (Fig 2a) was developed that allows the user to draw arbitrary freehand or line sketches and compose various parametric mathematical curves like Lissajous and Spirograph patterns. It is also possible to input text strings which are vectorized or to load multiframe animations consisting of a list of points for each frame. The raw path data is then filtered depending on the type of filter that is chosen. The simplest filtering scheme applies a digital Butterworth or Bessel low pass filter while the feedforward filter uses information about the device resonant frequency and Q to compute a nearly optimal input waveform given the system bandwidth limitations. This scheme gives fast, sub-100 μs settling times [5] that are comparable with closed-loop PD control schemes. The filtered data is used to compute the necessary voltage signals for each axis, which are then sent using a PC audio or USB port to a demo box (Fig 2b) which includes amplification circuits to get sufficient voltage to operate actuators to full 20° deflection.

In order to tune the feedforward filter, it is necessary to obtain the device resonant frequency (ω_n) and Q. The software allows resonant frequency to be quickly estimated by sweeping frequencies and displaying deflections in response to each sinusoidal excitation. A more accurate estimate of ω_n and Q is done by displaying the step response of the device since the X-axis of the display provides a timescale depending on the refresh rate chosen. This oscilloscope-like mode of the vector display can also be used to study the effects of using different filtering schemes on the step response, which is directly displayed on a screen (Fig 2c). Some vector frames from single and multiframe animations are shown in Fig 3a-i. For multiframe videos, the control signals for each frame are resampled and concatenated depending on the refresh rate and animation time chosen. In all the above display modes, the mirror is not resonantly excited and hence deflects in one direction since $F \propto V^2$. It is also possible to operate the mirror in resonant mode, which results in bi-directional actuation of the mirror and also results in larger angular deflections due to the device Q. By actuating the two axes at different frequencies close or at resonance, it is possible to obtain an almost unlimited number of animations. Another variation is to modulate the signals on both axes at frequencies greater than 35-40 Hz so that persistence of vision gives rise to an intricate set of animations. A couple of still frames from such animations are shown in Fig 3j,k.

CONCLUSIONS

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

[1] Hakan Urey, “Torsional MEMS scanner design for high-resolution display systems,” Proc. SPIE Vol. 4773, Seattle, Washington, July 2002, pp. 27-37.
[2] R. Conant, P. Hagelin, U. Krishnamoorthy, M. Hart, O. Solgaard, K. Lau, R. Muller, "A raster-scanning full-motion video display using polysilicon mirrors," Sensors & Actuators A, Vol. 83, no. 1-3, 2000, pp. 291-296.
[3] Cambridge Technology, Inc., Cambridge, MA 02138.
[4] V. Milanović, D. McCormick, G. Matus, "Gimbal-less Monolithic Silicon Actuators For Tip-Tilt-Piston Micromirror Applications," *IEEE J. of Select Topics in Quantum Electronics*, vol. 10, no. 3, June 2004, pp. 462 – 471.
[5] V. Milanović, K. Castelino, “Sub-100 μs Settling Time for Gimbal-less Two-Axis Scanners", Optical MEMS 2004, Takamatsu, Japan, Aug. 2004.

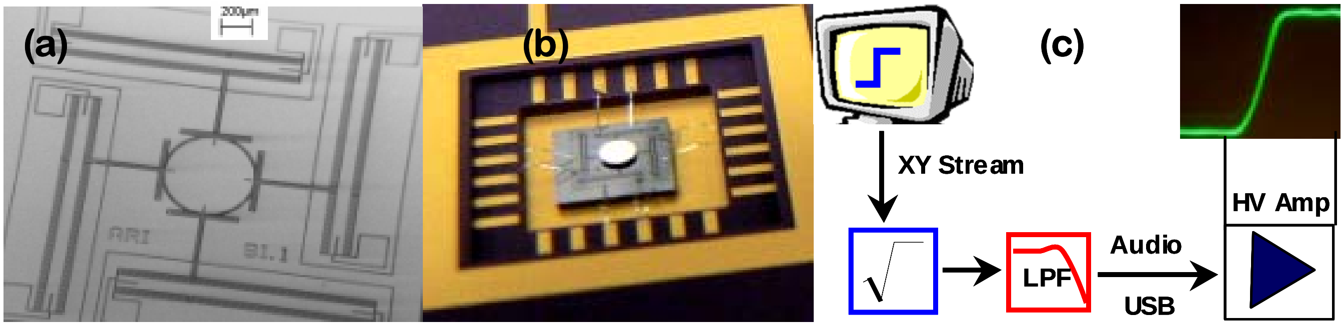

Figure 1. (a) SEM of a typical gimbal-less two-axis micromirror scanner with a monolithic 600 µm diameter micromirror (b) device with bonded micromirror (c) Schematic of vector-display system: the desired position stream is filtered and control signals sent using audio or USB ports after stepping up the 1V output signal from the computer using a high-voltage amplifier.

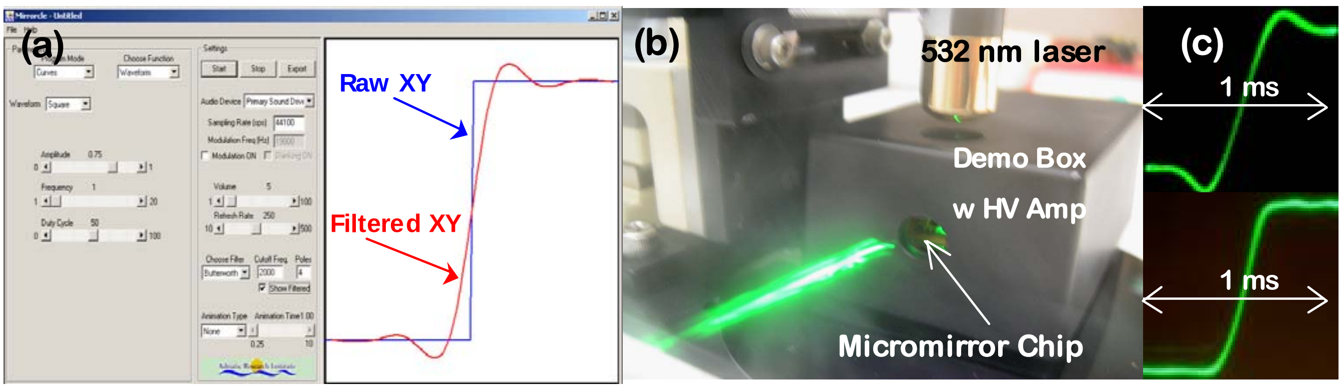

Figure 2. (a) Software user interface for creating sketches, text, animations. The user can set the refresh rate, filter parameters and visualize the filtered waveform. (b) Demo box into which micromirror scanner is inserted has 2 audio-transformers for 100:1 voltage gain and distributes the audio channel control signals to the XY actuators. (c) Displayed response for the step in (a) with Butterworth (top), Bessel (bottom) filters. X-axis timescale (1ms) is determined by the refresh rate and used to find settling time, ω_n*, Q of the device.*

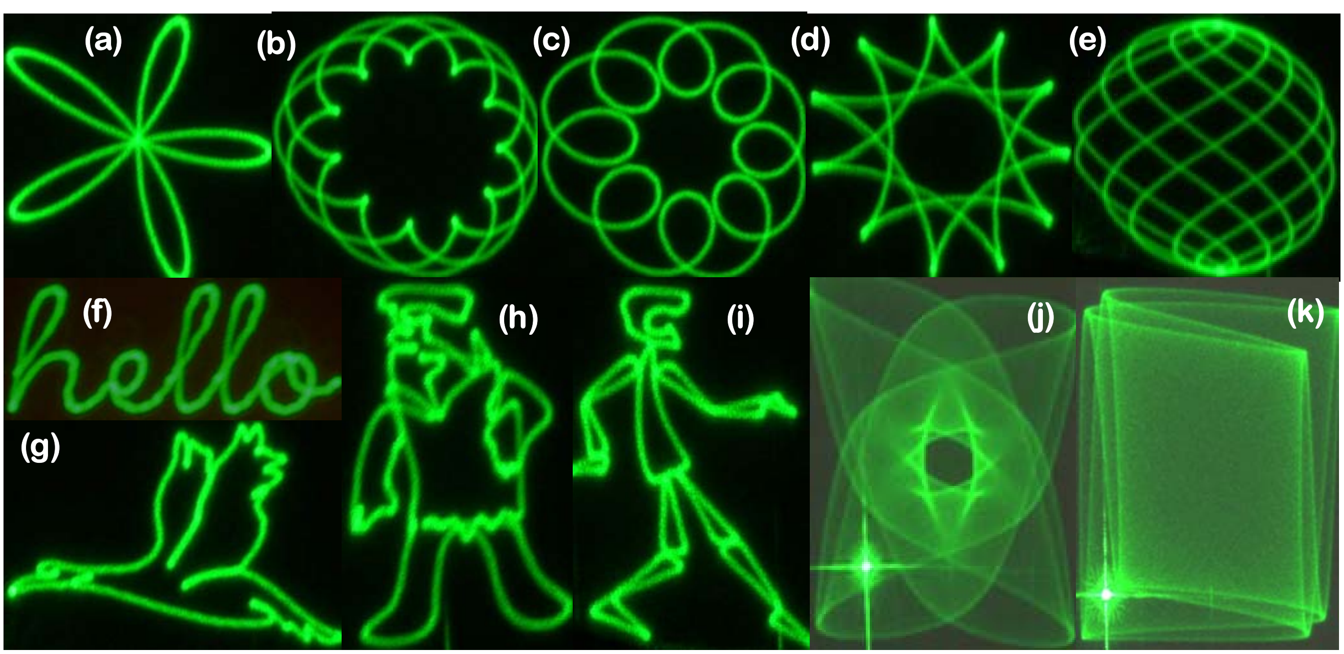

Figure 3. Sample vector sketches, (a-e) parametric mathematical curves: (a) rose, (b) epicycloid, (c) epitrochoid, (d), hypocycloid, Lissajous pattern with sinusoidal signals on both axes and modulation on the x-axis. (f) Vector rendering of text; (g-i) Sample frames from various multiframe vector animations. The animation time and refresh rate can be set independently and the above were rendered at 40 Hz refresh rate. (j,k) Sinusoidal excitation of the device at or near resonance on both axes results in various static patterns and animations. More involved animations can be obtained by adding a low frequency modulation signal to either or both axes. The deflection in these cases is amplified due to Q of the device and is bi-directional.