Resonant MOEMS Scanner Design and Dynamics

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ABSTRACT

In scanning systems, the speed of scanning, scanner resolution, and power requirements can be substantially reduced by using high-Q resonant scanners. We discuss the scanner features and dynamic modeling of resonant scanners for display and imaging applications.

Displays and imaging devices are good application areas where MOEMS technology can provide important benefits. Texas Instruments Digital Micromirror Device (DMD) technology and Microvision Retinal Scanning Display (RSD) technology (see Figure 1.a) are the two commercially available MOEMS display technologies.

Retinal Scanning Displays (RSD) operate by raster-scanning a modulated (either directly or externally) point light source onto the viewer's retina. RSD operation and system architecture is discussed in detail elsewhere[1,2]. RSDs typically employ two uniaxial or one biaxial scanner where the horizontal scanner is operated at resonance, and the vertical scanner is driven by a sawtooth waveform[3,4]. The combined motions of the two scanners create a 2-D sinusoidal raster. MEMS technology can be used to fabricate the scanner, actuator, and scanner position sensors all integrated on the same chip in one package, which then becomes the heart of the scanning display system. Most of the MEMS scanners are low-inertia galvanometric or resonant type scanners.

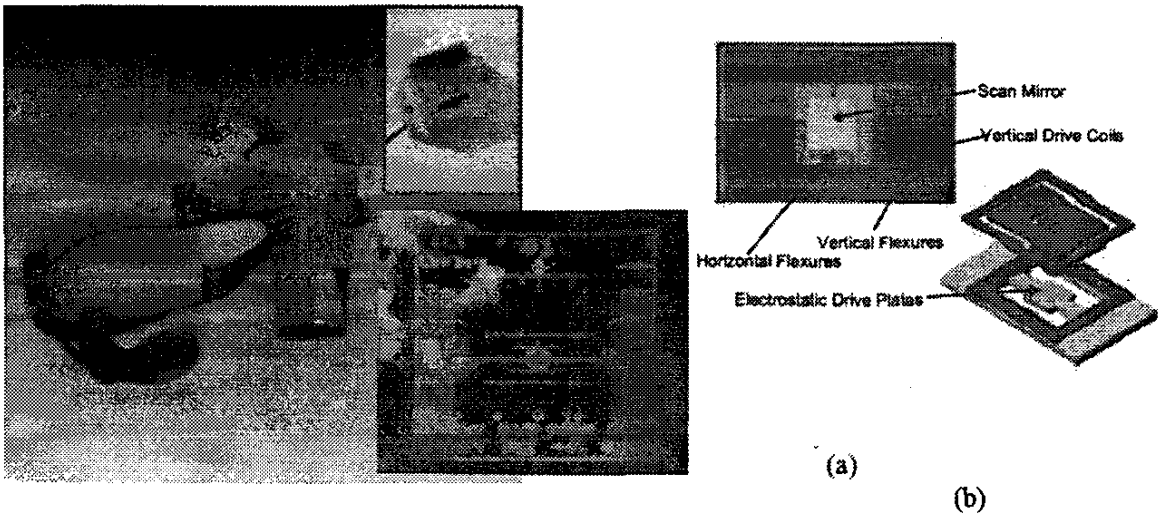

Figure 1: (a) Microvision NOMAD system, figure inset shows MEMS scanner package and an image captured using NOMAD system; (b)Biaxial MEMS scanner

Figure 1(b) illustrates the Microvision biaxial MEMS scanner. The torsional horizontal scan mirror is actuated electrostatically and the vertical scan frame is actuated electromagnetically using electroplated wires and permanent magnets on either side of the die.

In order to meet high-resolution and dynamic flatness requirements, RSD scan mirrors are much larger and thicker compared to DMD micromirrors or MEMS scan mirrors that are used in optical switching and other applications. The resultant large mirror inertia and stiff flexures require large mechanical torque. If the horizontal scanner is not operated in resonance, the voltage requirements for the electrostatic actuator can be in excess of 100,000 volts. Resonant operation takes advantage of the high Q-factor of the structure and reduces the voltage requirements to more practical levels. The resonant horizontal scanner is closed-loop controlled and its position and frequency is determined using piezoresistive strain sensors that are formed on the torsion arm.

Electrostatic actuation of torsional mirrors when a constant voltage is applied is studied in detail in the literature[5]. Dynamics of the resonant scanner is governed by the following equations:

$$I_m \ddot{\theta} + \frac{w_n}{Q}\dot{\theta} + w_n^2\theta = T_{es}$$

$$V_{in1}(t) = V_{DC} + V_{AC}Sin(w_n t)$$

$$V_{in2}(t) = V_{DC} - V_{AC}Sin(w_n t)$$

$$T_{es} = \varepsilon_o L(V_{in1}^2(t) - V_{in2}^2(t))\frac{\partial C(\theta)}{\partial \theta}$$

where θ is the rotation angle, w_n is the undamped natural frequency of the torsional mode, L is the length of the electrostatic plate, and $C(\theta)$ is the time-varying capacitance under the mirror that is a function of plate width and ε of the medium, and V_{in1} and V_{in2} are the typical voltage waveforms applied to the drive plates. Non-linear time-varying capacitance requires numerical analysis.

The dynamic study of the resonant scanner involves computing the mode frequencies for different oscillation modes, optimizing the DC and AC voltage amplitudes and waveforms for best drive efficiency. Furthermore, simple numeric model allows us to scale the size and frequency of operation and compute the drive voltage and power requirements for scanners for different display formats.

Simulation results will be presented at the conference.

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