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One-dimensional LED array integrated polymer composite scanner for 2D imaging

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ABSTRACT

A novel two-dimensional display that exploits the large deflection of composite-polymer (FR4) based mechanical actuator and high optical performance of inorganic LEDs is implemented. Structure of the display consists of a 1D semiconductor LED array integrated on a electromagnetically actuated platform. Refresh rate of the display is controlled by the resonant movement of the mechanical device, whereas the fast-scan is performed by the synchronous electronic modulation of the inorganic LED devices. Since composite polymer structural material is used as the mechanical structure, a proper refresh rate of 100 Hz is implemented by engineering the spring dimensions. Simultaneous motion of the slow-scan resonant movement along with the modulation of 1D LED array in perpendicular direction to the slow-scan axis enables the generation virtual pixels on a 2D image plane. Refresh rate is implemented at 99 Hz, giving a peak displacement of 2.45 mm at a drive power of 85 mW. Resolution of the display is 20 × 40 pixel on a physical size of 8 mm × 2.25 mm. When considering only the LED array, the proposed display consumes 14% more power compared to a conventional dot-matrix LED display of the same performance. The advantages of using a significantly less amount of LED devices results in a more reliable operation, in terms of low probability of dead-pixel failure, easily controllable LED-to-LED variations. Robustness of the display is proven by insignificant variations of the performance (quality factor, resonance frequency and peak displacement) parameters for 3 million cycles.

1. Introduction

Much effort has been devoted to the development of micro-scanner based two-dimensional (2D) displays [1–4] since this new generation of displays have the potential of being smaller, cheaper and more portable than those existing displays today. There are many techniques to implement such displays. One can utilize a 2D micro-scanner array (one reflective element for each pixel) as in Digital Light Processor (DLP) [1]. Another technique is to employ one bidirectional or two unidirectional raster-scanning mirrors [2,3] as in high-resolution micro-machined silicon based projection displays [4]. It is also possible to use a scanned one-dimensional (1D) array as in grating light valve displays [5] to produce a 2D image plane. It is perviously shown that by integrating 1D organic light emitting diodes (OLED) array on Fire Resistant 4 (FR4) actuator and by modulating these light sources in one axis (called fast scan axis) and by triggering this 1D OLED array integrated FR4 platform into its resonant movement in the axis perpendicular to the fast scan axis (called slow-scan axis), one can obtain a 2D image [6]. A similar technique which also benefits from a inorganic light emitting diode (LED) array put on a torsional scanning platform realizing a three-dimensional (3D) volumetric display is presented [7]. Another work integrating LED array with double-sided scanning mirrors to produce an autostereoscopic display exist in literature [8]. A diverse range of structural material is used in the fabrication of scanners such as silicon [4], steel [9] and polymer materials like Epocore [10] and FR4 [6,11] to name a few. In this work, we propose a novel method for realization of a low-cost 2D display using a scanned 1D array of solid-state LEDs along with its electronic modulation and position sensing circuity. Proposed method integrates LEDs in a hybrid fashion with an FR4 actuator, which is fabricated using a standard printed circuit board (PCB) technology, to create a 1D scanner and 1D pixel-array-based display. In the proposed work, the choice of polymer as the scanners' structural layer and the simplicity of the process, reduces the cost of fabrication drastically. Utilization of one-row of LED array reduces the cost arising from the usage of light sources. Additionally, reduced number of light sources, increase the reliability of the display significantly being less prone to generation of dead pixels and easily controllable LED-to-LED variations compare to conventional 2D dot-matrix LED displays.

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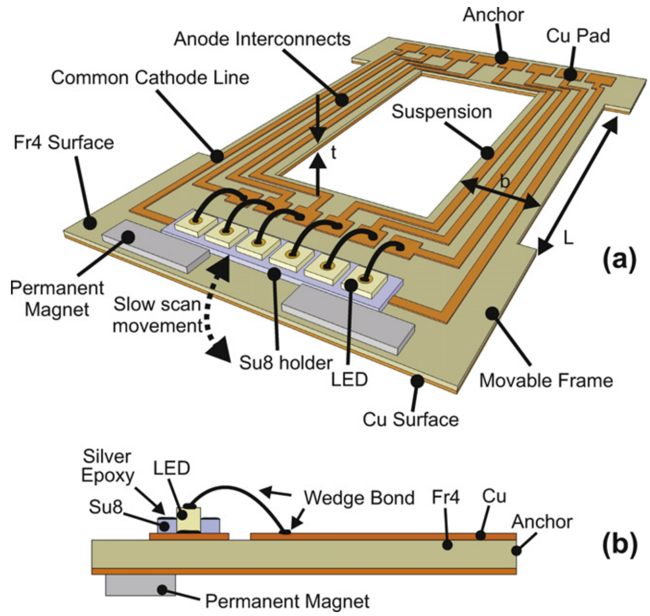

Fig. 1. (a) Conceptual drawing of the FR4 actuator integrated with LEDs. (b) Cross-sectional profile of the display.

2. Operation principle and design

2.1. Mechanical actuator

Proposed display structure is depicted in Fig. 1(a). This system consists of a U-shaped composite polymer (FR4) actuator that is suspended with two flexures to the anchor. Flexure width, length and thickness are shown in Fig. 1(a) as b, L and t, respectively. One-dimensional array of surface emitting LEDs are placed on the actuator surface. The operation of the devices relies on the mechanical resonant movement of the mechanical platform at a specific frequency in the slow-scan (out-of-plane) direction as shown in the figure. Electronic modulation of the light sources is performed in the fast-scan axis, which is perpendicular to the slow-scan movement. Simultaneous control of fast and slow axis movements in a synchronized way paints a two-dimensional image plane generated by virtual pixels [6].

The refresh rate and the resolution of the targeted 2D display is defined by the mechanical actuator and the number of LEDs integrated onto the surface of this actuator. Therefore, it is crucial to design the actuator such that it will have a reasonable refresh rate as well as a large shuttle deflection. Considering the actuator as a combination a lumped shuttle mass at the tip of two cantilevers, the resonance frequency (slow-scan mode) related to the out-of-plane movement of the mechanical platform can be approximated as

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{2k}{m_L + m_{eff} + m_P}} \quad (1)$$

where $k = (1/4)(t/L)^3 bE$ is the spring constant of one suspension, E is the Young's modulus, m_L is the total mass of the LEDs, m_{eff} is the effective mass of the moving FR4 structure and m_P is the mass of the permanent magnet. The resonance frequency of the FR4 scanner is designed according to the Eq. (1) by proper sizing of the structure. The design with two suspended flexures facilitates placing other mechanical vibration modes of the devices to a sufficiently far frequency on the spectrum and increases the resonance frequency which drops to a lower value due to the relatively heavy permanent magnet (≈180 mg) that dominates the denominator of the fraction in Eq. (1). The design is confirmed by finite element simulations as shown in Fig. 2. Targeted resonance frequency is in vicinity of 100 Hz and finite element simulations reveal an out-of-plane deflection at $f_0 = 96$ Hz, as shown in Fig. 2(a). Adjacent mode in the frequency spectrum occurs at $f_1 = 672$ Hz, as given in Fig. 2(b), where the actuator shuttle is deformed because of the out-of-phase movements of each suspension. The actuation setup, briefly sketched in Fig. 2, does not favor the excitation of in-plane modes, because of the negligible electromagnetic interaction between the permanent magnet and the anchored coil. Therefore parasitic vibrations parallel to the surface of the coil are eliminated both by mechanical spring design through b/L ratio and by the coil arrangement that induces the electromagnetic force.

2.2. Magnetic actuation force

FR4 scanner is set in scanning motion at its fundamental resonant mode using electromagnetic actuation [8,12]. Mechanical platform is excited in the slow-scan axis by utilizing electromagnetic force induced due to interaction of an off-chip electro-coil and a mini permanent magnet. An alternating current passing through off-chip electro-coil and the DC magnetic field develops a frequency-dependent actuation force. This magnetic force acts against the spring force and bends the flexure resulting in deflection of the fabricated cantilevers. Assuming a uniform magnetic field, the total attraction force between the electro-coil and the actuator is

$$F = BIL\cos\theta \quad (2)$$

where B is the magnitude of the DC magnetic field generated by the permanent magnet, I is the time dependent current flowing through electro-coil as shown in Fig. 2, L is the effective length of the current

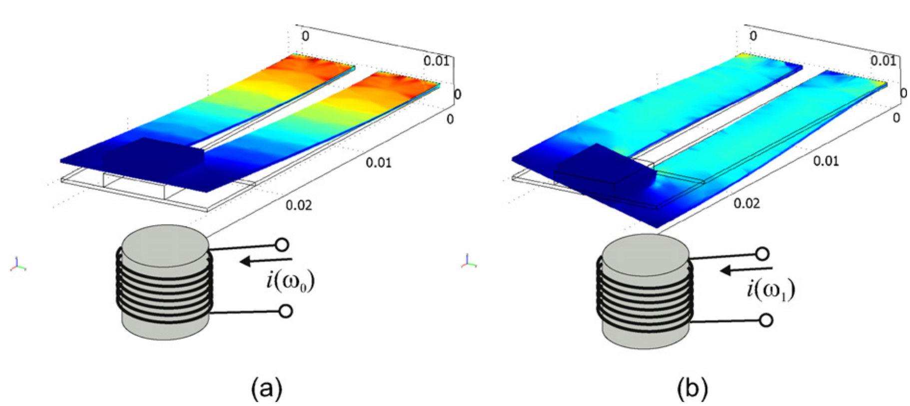

Fig. 2. Finite element simulation of the mechanical scanner. (a) Out-of-plane bending movement as the fundamental mode at 96 Hz. (b) Second mode due to out-of-phase deflection of springs at 672 Hz.