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Actuation voltage signal-shaping for smooth scanning beam locus of a light steering system with a dual-axis analog MEMS pointing mirror

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ABSTRACT

This paper presents an electromagnetic actuation scheme for driving a dual-axis analog MEMS pointing mirror that is used in multiple light steering applications. In this study, a light steering system, which consists of dual-axis analog MEMS pointing mirror and a laser diode as a light source, is established and its actuation scheme is proposed to provide a framework for generating high performance display. The main feature of the proposed actuation scheme is to determine the shapes of electromagnetic actuation voltage signals based on the mirror dynamics and employment of the Laplace Transform. Simulation and experimental studies were conducted to evaluate the proposed actuation strategy. It is shown from both results that it is a simple but viable solution for operating light steering systems.

1. Introduction

Head Up Displays (HUDs), are one of arising technologies in automotive industries. The technology was motivated and developed for pilots in military aircrafts for easy target detection. The primary display module in a HUD was combined with a cathode-ray tube (CRT) and cockpit windows in aircrafts and developed for automotive applications with a micromirroring device and laser modules. However, three primary components including a projector unit, a combiner, and a control unit, are common in the display modules spanned different applications [1].

The projection unit is composed of optical collimators and a display unit (such as a CRT, a liquid crystal display (LCD), or a laser system), and the image is displayed on a windshield. The combiner redirects the projected image from a projection unit, and a driver or a pilot perceives the image at the infinity location. The control unit drives the interface between the projection unit and the display data.

Recently, the HUD technology has been developed by many automotive companies and parts suppliers. To improve the brightness of display, a single chromatic light source or a laser has been used with micromirroring devices (microelectromechanical system (MEMS) mirrors, for example). The development and application of a MEMS has been expanded to HUD technology field and the fabrication technology has been improved too [2]. The MEMS technologies for optical applications has been also reported for various micro-mirror arrays by graytone lithography which can be used for diverse brightness modulating analog HUD display devices [3]. To enhance the writing performance in a spatial light modulator, the deflection angles and phase were modulated and used for a high resonant frequency region [4].

MEMS-based optical scanners have been widely used in light steering applications such as laser and/or raster scanning displays. On the other hand, they present a number of challenges due to their design and operation [5,6]. In particular, satisfying the requirements for a high performance display is essential in the implementation of MEMS-based optical scanners, where high scanning speeds and wide deflection angles must be secured according to the specific features of the application. Since deflection angle as well as scanning frequency are primary factors considered in optical scanner operation, development of an actuation mechanism coupled with the structural design for optical steering systems is receiving a great deal of attention in electrostatic [7–11]; thermal expansion [12,13]; electromagnetic [14–17]; piezoelectric [18–23] areas.

As previously stated, the image quality is mainly affected by factors such as scanning frequency of the mirror, mirror scanning angle and laser spot size [5], [17]. Thus, their control is of importance to enhance scanner display performance. In this paper, a scanning angle control scheme of an electromagnetically driven dual-axis analog MEMS micro-mirror [24] is proposed and implemented in the operation stage.

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Most of the actuation techniques applied for MEMS-based mirror systems presented in a number of references are meant for selecting operating frequencies for the mirror system structure (see [16], for example). Little attention, however, is given towards the actuation signal waveform shape which may affect the behavior of the mirror system, and consequently, images made from reflected beams off the mirror system. Thus, in this study, an actuation voltage signal-shaping scheme for obtaining a desired scanning (reflected) beam locus is proposed and implemented for a light steering system with a MEMS-based micro-mirror. In Section 2 an overview of the dual-axis analog MEMS pointing mirror based light steering system is presented. As the scan angle control, an electromagnetic actuation scheme for high performance display is discussed, as well as experimental results, in Section 3. Finally, conclusions are drawn in Section 4.

2. LSS

2.1. Basic features of LSS

The LSS in this study consists of a micro-mirror and laser system as a monochromatic light source. As shown in Fig. 1(a), a dual-axis MEMS analog pointing mirror from Texas Instruments™ [24] was adopted, which is a micro-mirror designed for use in multiple light steering applications such as optical networking, free space optical communication, optical alignment, and so on. Refer to [25] for its operation.

The micro-mirror, which is placed on a gimbal-type plate, is rotated bi-directionally on two independent axes of rotation. An electromagnetic drive voltage actuates rotation of each axis; the operating mechanism is illustrated in Fig. 1(b). There are two independent sets of coil drives, each of which provides horizontal and vertical directional movement of a beam reflected off the mirror, respectively. When, within a coil drive set, a positive voltage is applied to one side of the coil, a lower voltage is returned from the other side of coil. This generates magnetic forces with oppose each other, in turn, rotating the mirror in one direction. Accordingly, a beam reflected off the mirror makes a movement (locus) on the screen.

The micro-mirror system, from the viewpoint of each axis, is approximated by an ideal torsional spring and mass system that is independently rotated on each axis by the independent actuation [26]. The motions are driven by electromagnetic excitations; the dynamic equations of motion are represented as:

$$J_x\ddot{\theta}_x + b_x\dot{\theta}_x + k_x\theta_x = K\upsilon_x \tag{1a}$$

$$J_y\ddot{\theta}_y + b_y\dot{\theta}_y + k_y\theta_y = K\upsilon_y \tag{1b}$$

where J_x and J_y are the moments of inertia, b_x and b_y the damping coefficients, k_x and k_y the stiffness' of the spring. θ_x and θ_y are the outputs of the system under excitation voltages of υ_x and υ_y, and K is the proportional constant.

Due to the dynamic characteristics of the mirror system, the electromagnetic actuation conditions need to be considered, which accordingly affect image generation. The conditions include the magnitude, frequency, and shape of the excitation voltage signal for each axis of rotation, and frequency ratio between two axes. These issues will be discussed in later sections. Before progressing

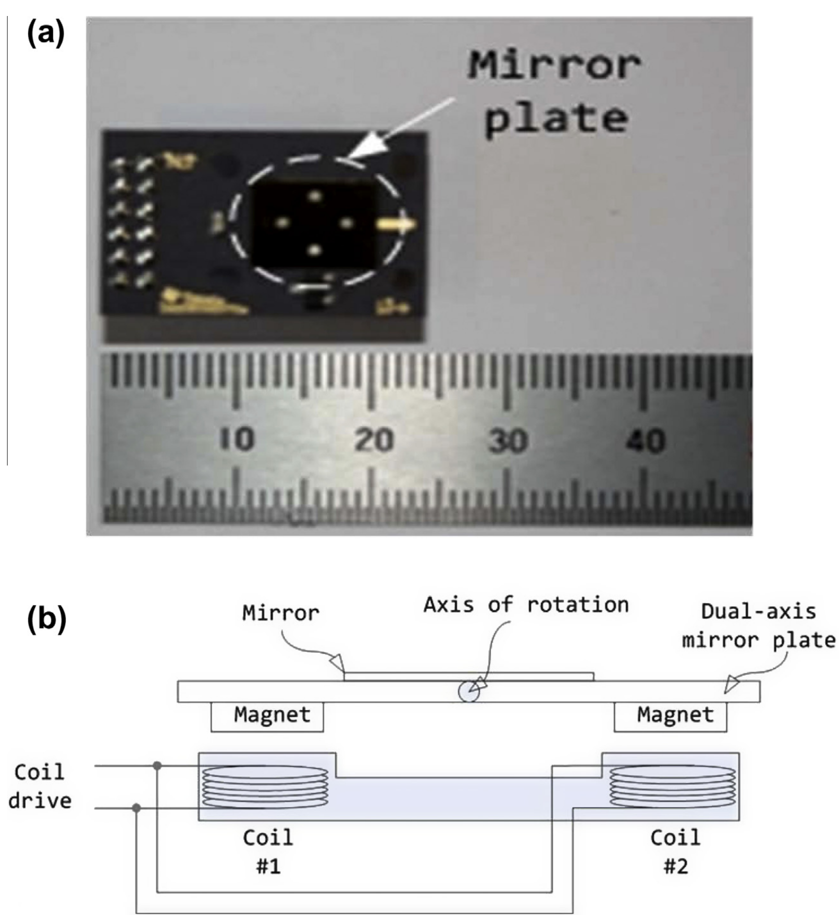

Fig. 1. Micro-mirror system (a) Photograph (b) Schematic view.