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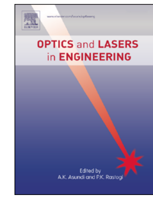

Optical characterization of high speed microscanners based on static slit profiling method

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A B S T R A C T

Optical characterization of high-speed microscanners is a challenging task that usually requires special high speed, extremely expensive camera systems. This paper presents a novel simple method to characterize the scanned beam spot profile and size in high-speed optical scanners under operation. It allows measuring the beam profile and the spot sizes at different scanning angles. The method is analyzed theoretically and applied experimentally on the characterization of a Micro Electro Mechanical MEMS scanner operating at 2.6 kHz. The variation of the spot size versus the scanning angle, up to $\pm 15°$, is extracted and the dynamic bending curvature effect of the micromirror is predicted.

1. Introduction

Microelectromechanical system (MEMS)-based optical beam steering devices are key components in a wide range of applications including displays, optical communications, imaging, printing and surgery. Their miniaturized nature reduces their cost and size as well as increases their agility and speed enabling new applications that were not possible using their original bulky form; these include handheld barcode readers, pico-projectors, confocal microscopy, Optical Coherence Tomography (OCT) and endoscopy [1–8]. For some applications, such as the high-definition displays, there is a need for more research in developing faster scanners with wider scanning ranges [9]. As a result, most of the developed MEMS scanners operate at resonance and are taking advantage of the scanning angle range magnification at resonance with respect to the quasi-static operation case. Therefore, the characterization of the scanned optical spot at various scanning angles should take place at high speeds.

Optical characterization of microscanners considers the measurement of the scanned beam spot size and intensity profile. In high-speed microscanner, the deformation of the optical beam with scanning takes place due to more than one reason. First, the diffraction of light can be very harmful if the aperture size of the scanner optics is not large enough with respect to the spot size of the optical beam [10]. Moreover, the effective size of the optical beam varies with the scanning angle in either a linearly translating curved micromirror or a rotating flat micromirror, as shown in Fig. 1. Second, rotating micromirrors suffer from static or dynamic bending of the mirror surface during the micromachining process or during the scanner operation, respectively [11,12]. Additionally MEMS mirrors are usually coated with a thin metal film to improve its reflectivity. This coating, in addition to the method of fabrication, can cause stress gradient across the mirror thickness leading to a permanent curvature of the reflecting surface, which may be compensated by the accompanying optics. More seriously, dynamic bending during the operation cannot be compensated. Indeed, a radius of curvature equal to or smaller than the scanned beam Rayleigh range can lead to a severe increase of the far-field beam radius and renders the beam spot size varying significantly during scanning [13]. At the same time, the theoretical formulas used for predicting the bending behavior of the structures imply many approximations that limit their accuracy [9,13,14]. Third, in translating curved micromirrors or micro-lenses, the transformation of the phase-front of the scanned beam varies with scanning. Although some techniques and curved surface profiles were suggested to reduce this effect [15], it could not eliminate it altogether.

On the one hand, the characterization of high-speed MEMS devices can be done using stroboscopic interferometry [16]. This technique is, however, very expensive due to the required optical setup and complexity of its assembly. Alternatively, the characterization of high-speed scanned intensity profiles can be done

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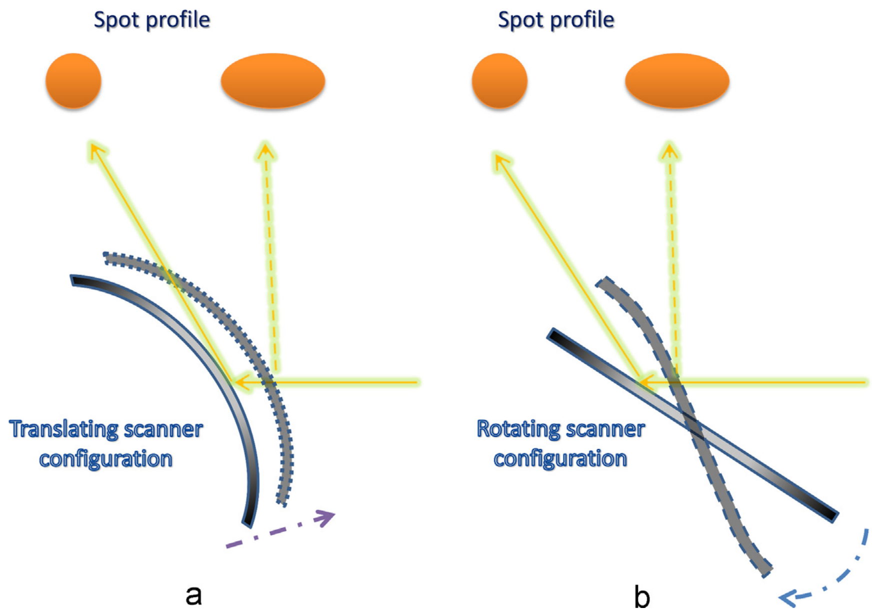

Fig. 1. Beam spot size variation as a result of using linearly moving curved micromirrors in (a), and rotating flat micromirrors in (b) with dynamic deformation.

using expensive high-speed cameras with a capture rate that is much higher than the scanner's resonance [17]. This can be a challenging task especially when the scanner's resonance frequency is in the order of 100 kHz. Moreover, having the wavelength of the light in the infrared spectrum adds more complication to the techniques based on a camera as the sensor cost will be very high. Therefore, there is a need for a characterization technique suitable for high-speed MEMS scanners based on non-complex optical setup and preferably using a single detector.

In this work, a novel optical characterization method for high speed optical scanners is presented. The method allows for extracting the beam spot size and intensity profile at various scanning angles, while the scanner is operating at its high speed. The method is based on spatial sampling of the scanning spot using only a slit, a high speed detector module and a data storage device, like a computer, or an oscilloscope. The rest of this article is organized in four sections. In Section 2 , the proposed method is presented and the theoretical background is discussed. In Section 3, a simulation study for the method is given highlighting the methodology to choose the setup parameters. Experimental measurements and characterization for a one-dimensional microscanner using the presented method is also presented in Section 3. Finally, the work is concluded in Section 4.

2. Proposed characterization method

2.1. Basic principle

Conventional methods for static beam profile characterization are either based on a camera or a mechanical scanning of knife edge/slit [18]. For the latter case, the slit moves in-between the beam and a single detector as shown in Fig. 2(a). The slit samples the beam at different locations in the space and the beam power at this location passing through the slit hits the detector. The detector signal with time is corresponding to the beam intensity

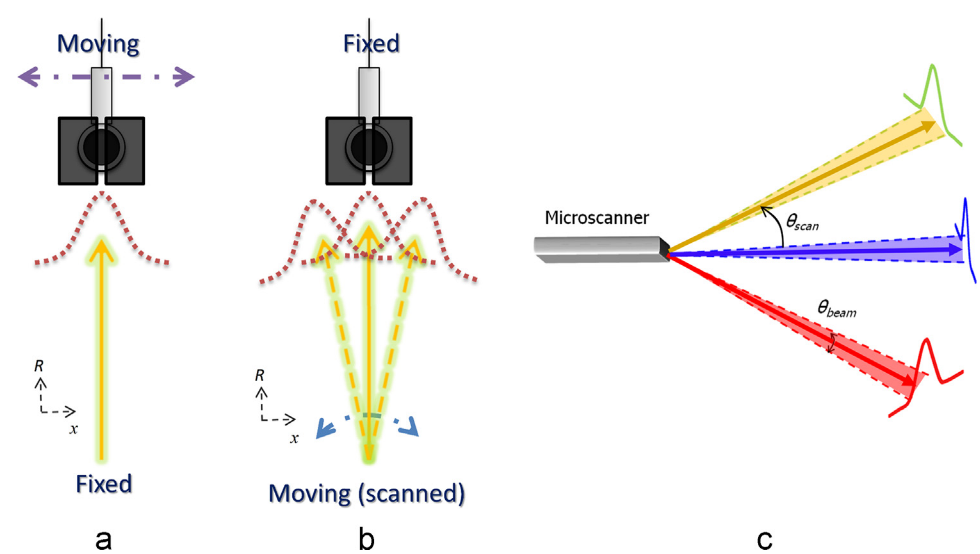

Fig. 2. (a) Conventional beam characterization method for a static beam by the linear motion of a detector covered by a slit. (b) Proposed method for characterizing a scanned beam as a function of the scanning angle utilizing a fixed detection system and an angularly scanned beam. A Gaussian profile for the beam intensity is given in the figure for illustration. (c) An output beam from a microscanner at a given radial distance has a divergence and a scanning angle.