NISTIR 6016

Non-Mechanical Image Rotation Using an AODP *(Acousto-Optic Dove Prism)*

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September 1997

DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA ★

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Abstract - We report what we believe to be the first method for non-mechanical and programmable image rotation. The method uses a pair of crossed acousto-optic beam deflectors and a polygon mirror to emulate the mechanical dove prism. It is capable of fast (on the order of microseconds) image rotation to an arbitrary angle in a programmable manner. An experimental result to prove the concept is provided.

Rotation of an image to an arbitrary angle in a programmable manner is very important for various applications such as rotational invariant pattern recognition, computer graphics and beam steering of phased array antennas.

Most of the previous techniques [1-5] rely on a dove prism as shown in Figure 1 (a). By rotating a dove prism by an angle θ around the optical axis, an input image can be rotated by 2θ. However, such a mechanical process is slow and unreliable. Chiou and Yeh [6] demonstrated a non-mechanical method using a conventional dove prism inside a ring cavity to generate a series of rotated images.

In this Letter, we propose an image rotation method that is both non-mechanical and programmable to permit rotation of an image to an arbitrary angle in a controllable manner. It is based on an analysis of a conventional dove prism. As illustrated in Figure 1 (b), a dove prism can be divided into three parts: the first part is a wedge prism to direct the incident beam to the bottom (or top) of the second part which functions as a mirror to reflect the incoming light. The third part is another wedge prism to redirect the beam along the original direction. All these three parts rotate together.

Our approach for non-mechanical image rotation is shown in Figure 1 (c). Each of the rotating wedges (the first and third parts of a dove prism) is replaced by an xy acousto-optic beam deflector (xy-AOBD). The xy-AOBD consists of a pair of crossed AOBD's sandwiched together with transducers along orthogonal directions. By adjusting the frequencies of acoustic signals applied to the two AOBD's, beam direction can be changed along arbitrary directions, just as a wedge does.

The reflecting mirror (second part) is replaced by a circular cylindrical mirror to avoid the need for rotation. However, to prevent unwanted distortion due to the curvature of the circular mirror surface, the cylindrical mirror is discretized to multiple facets. Also, incoming light is focused to have a minimum size on the mirror surface. In this way, an image can be rotated fast

Figure 1 - Paek et al

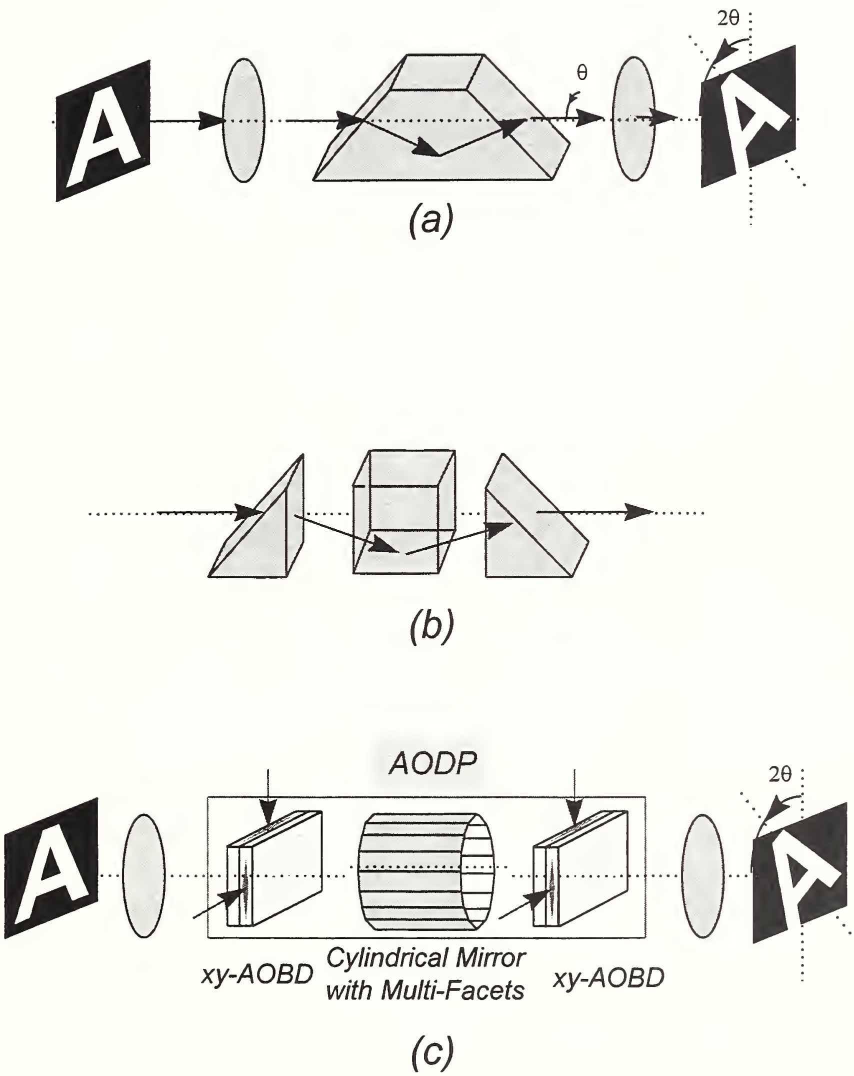


Figure 1. Image rotation methods : (a) conventional mechanical method using a dove prism, (b) three parts of a dove prism and (c) the proposed non-mechanical image rotation using an AODP (acousto-optic dove prism).

(on the order of microseconds) to an arbitrary angle in a programmable manner, without requiring any moving parts. Since the concept is based on the conventional dove prism, a name acousto-optic dove prism (AODP) has been proposed.

To prove the concept of the proposed AODP, we constructed an experimental setup as shown in Figure 2. A 5 mW HeNe laser is used as the light source. After beam expansion and spatial filtering, the magnified collimated beam illuminates an input resolution target. The light passing through the input transparency is deflected by a pair of crossed AOBDs (slow shear mode TeO_2 crystals with a large input angular bandwidth) and is focused by a lens (focal length = 36 cm) on the surface of the cylindrical polygon mirror. In this initial demo intended for proof of our concept, only two mirror facets oriented at a right angle are used. After the multi-facet mirror, the beam is reflected back to pass through the same lens and xy-AOBDs and is detected by a CCD after a beam splitter.

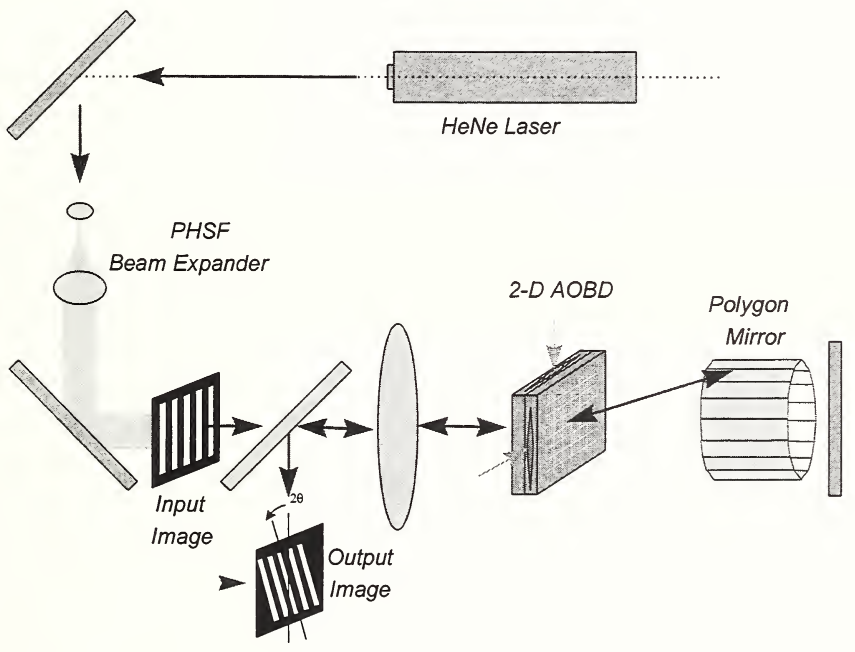
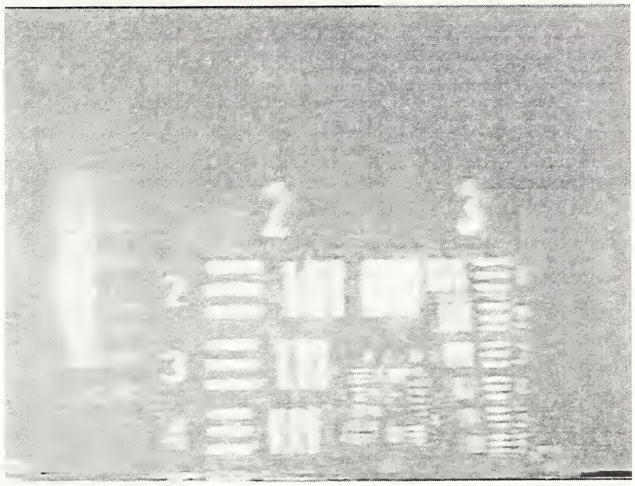


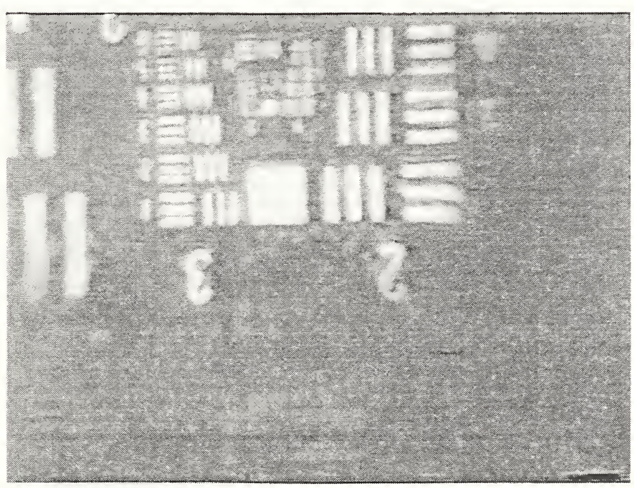
Figure 2. Experimental setup. Two orthogonal mirrors are used as a polygon mirror in this proof-of-concept experiment.

Figure 3 illustrates an experimental result obtained from our optical system. Since the two mirrors are at a right angle, the two images are rotated by 180 degrees (twice the angle between the two mirrors). A real-time image rotation has been achieved within 10 μsec with a 6 mm aperture in front of the AOBDs. Also, rotations to other angles have been separately confirmed.

Figure 3. Paek et al



(a)



(b)

Figure 3. Experimental results of non-mechanical image rotation. The rotation angle of the two images and (a) and (b) is 180 degrees which is twice the angle between the two mirror facets at a right angle.

The noise contribution to the image is mainly due to unwanted reflection from the surfaces of optical components such as the beam splitter, AOBDs and the lens. Also, a slight defocusing of the images is attributed to the distance between the two AOBDs. These noises can be greatly reduced if thin sandwiched xy-AOBD's (shown in Figure 1 (c)) are used. A custom-designed xy-AOBD with a compact size (10 mm X 10mm X 2mm) and with xy transducers on the same crystal is currently being fabricated.

The number of different rotation angles available in this system is given by the following equation:

$$N = \frac{\pi \cdot \Delta f \cdot d_{min}}{v}, \quad (1)$$

where Δf, d_{min} and v represent acoustic frequency bandwidth, minimum feature size of an input pattern and acoustic velocity, respectively. Interestingly, the number is independent of the focal length of a lens and wavelength of the light. For a typical example, $\Delta f = 50$ MHz, $d_{min} = 0.1$ mm and $v = 600$ m/sec, N becomes approximately 25.

To further increase the number of rotation angles, several methods can be used: First, a special lens design can be employed to reduce the fixed distortion effect of a cylindrical mirror. Second, higher-order diffracted beams can be used instead of the first order to increase the diffraction angle of an AOBD. In this case, the thickness of an AOBD needs to be thin to reduce the Q factor [7] and to permit higher-order diffractions. Taking the third order diffraction, for example, would permit rotation to 75 different angles, which is normally sufficient for rotationally invariant pattern recognition. In this case, other unwanted diffraction orders can be discarded simply by choosing the appropriate length of the cylindrical polygon mirror.

The AOBDs in this system need to accept an input beam with broad angular bandwidth of approximately ± 3 degrees. A special group of AOBDs (typically, slow shear wave Tellurium dioxide crystals) that accept a circular laser beam are commercially available.

In conclusion, we have proposed and demonstrated what we believe to be the first non-mechanical image rotation method that can be programmed to permit rotation of an image to an arbitrary angle within a few microseconds time. The method can be useful for various information processing applications such as rotationally invariant pattern recognition and computer graphics.

This work was supported by the Office of Naval Research (ONR) under Contract Number NC0014-97-F-0021.

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