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Digital Micromirror Device-Based Robust Object Boundary Mapping Sensor

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ABSTRACT

This paper presents a novel, non-intrusive, non-contact object boundary mapping sensor using a Digital Micromirror Device (DMD) and real-time pixel processing. The presented sensor is ideal for use in environments where brightly illuminated or radiating objects are in a hazardous environment such as in environments with radiation, heat, cold, harmful machine parts, etc. Experimental results demonstrate the boundary mapping sensor for a rectangular target and a multi-square target illuminated by visible wavelengths.

Keywords: Optical Instrumentation, DMD, Boundary Sensor

1. INTRODUCTION

Boundary detection is an important field of research in image processing with applications including military, medical, and computer vision. Many earlier methods require post-processing of the image using software based algorithms. Current algorithms cover a wide range in terms of complexity, speed, and performance. Some methods involve finding the gradient of the whole image [1-3] whereas others rely on simple differencing of pixels [4-5]. Once the entire image data set is processed, an edge mapped image can be obtained. The quality of detecting a boundary in the original scene depends not only upon the algorithm used to detect edges, but also the imager hardware used to capture the original object. Most imagers currently use a CCD or CMOS technology imaging device. CCDs can have problems with saturation due to their limited dynamic range. CMOS imager chip device designs have been demonstrated in excess of 115 dB [6-7], but this increase in dynamic range comes at the cost of increased complexity and larger pixels. Both CCDs and CMOS optical detectors are limited by the wavelength range they operate over. In addition, for imaging applications where large amounts of data are stored for post processing, it would be beneficial to have an imager that finds and stores only the edges during the detection process. Thus by not requiring storage of the whole image per frame acquisition, less storage capacity is required and lower bandwidth is needed for edge focused image transmission. With this goal in mind, this paper extends the earlier proposed DMD-based imager [8-9] for use in real-time boundary mapping.

2. PROPOSED BOUNDARY MAPPING SENSOR

Shown in Fig. 1 is the proposed boundary mapping sensor. The imaging lens S1 and the Electronically Controlled Variable Focus Lens (ECVFL) form the imaging optics for this system. Adjusting the focal length of the ECVFL gives the system variable focusing capabilities. Light from the target enters the system by the optional xy-mirror scanner and is imaged by the imaging optics onto the DMD plane. The DMD forms a digital pinhole which scans across the 2-D image plane sampling the irradiance. The lens S2 collects light from the $+\theta$ state of the micro-mirrors that is directed to point photo-detector PD1 while the $-\theta$ state is collected by S3 and focused onto point photo-detector PD2. Next, the optical powers detected by PD1 and PD2 are normalized with respect to each other to account for variations in irradiance during the scan of the pinholes on the DMD. The normalized optical power reading signal from the pinhole scanning imager is split into three paths, namely, a direct path to the processing unit, a path with a 1 pixel delay time τ, and another path with a 2 pixel delay time. A 2×1 switch controls whether the signal delayed by 1 pixel or 2 pixels is sent to the

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processing unit. In the processing unit the absolute value of the difference of the direct power reading and the delayed power reading from the switch is computed. If this power reading is above a certain local threshold (i.e., a percentage increase over the previous value power level defined by the user) an edge is registered at this given DMD pinhole scan zone (i.e., pixel) location. Specifically, the location of this pixel on the DMD plane is stored in the control processor. In the case where the differenced power reading is below the threshold, no data is stored. This process continues until the whole image has been scanned by the DMD.

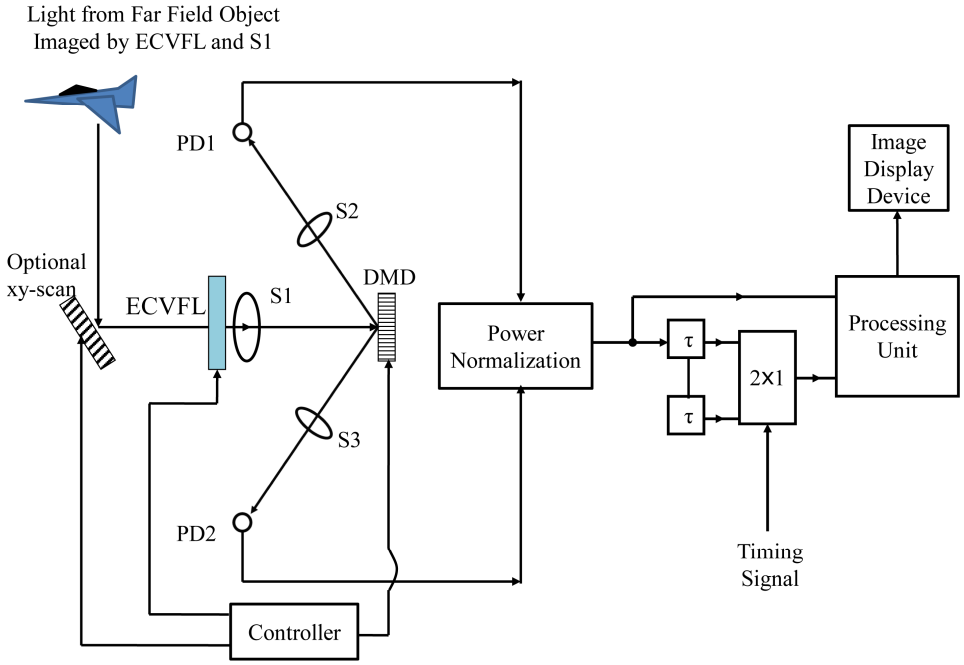


Fig. 1 The proposed single band DMD-based boundary edge detection sensor.

Fig. 2 shows a multispectral boundary detection sensor that can be used in image fusion. All the operations described for Fig. 1 can be implemented on an FPGA as well as other edge detection algorithms such as already been demonstrated in real-time by prior-art works [10-11].

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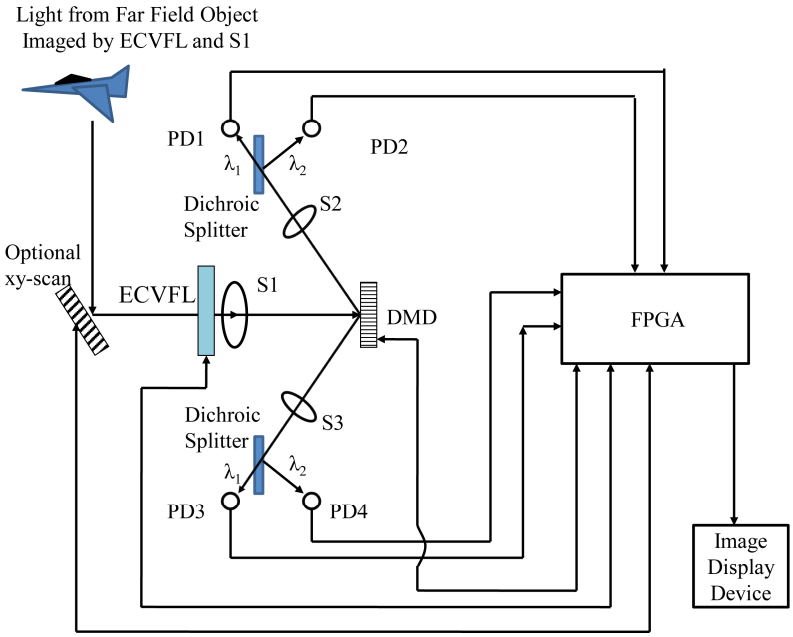


Fig. 2 The proposed multi-spectral DMD based boundary edge detection sensor for image fusion processing.

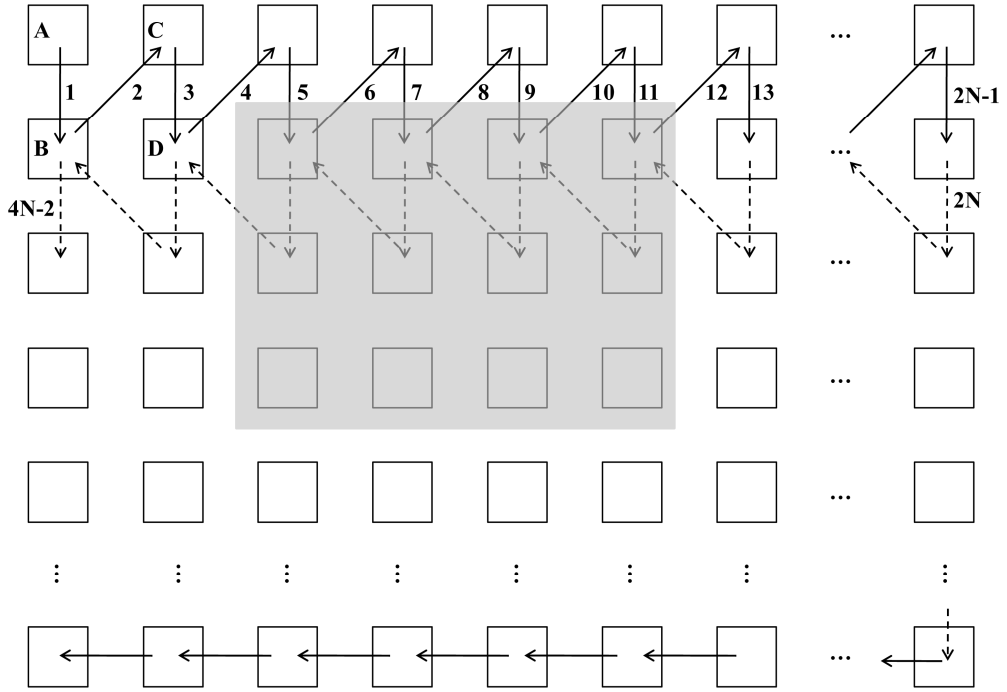


Fig. 3 The proposed smart DMD pixel scanning method for the boundary mapping sensor.

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The DMD scans the irradiance pattern of the image plane as shown in Fig. 3. Starting with pinhole "A", the optical power is measured and then the pinhole makes a vertical downward jump so that the pinhole is now at B. Next, the 2×1 switch is set so that the 1 pixel delayed power reading (i.e., power of A) is sent to the processing unit with the value of the power of B. It then detects whether there is an edge or not. Then the pinhole moves to C and the 2×1 switch is set so that the 2 pixel delayed signal (i.e., power of A) is sent to the processing unit with the power of C. This step is effectively completes a horizontal scan. Then the pinhole moves to D and the power levels of C and D are compared. This process continues as shown by the arrows in the picture. In effect the smart scan process performs a combination of a horizontal scan and a vertical scan at the same time. Note that for the last row of pixels on the DMD, a horizontal scan is required to see if there are any horizontal edges on from incident target at its bottom border. The smart scan method requires N+M-1 DMD image frames less than the classic image zone scan where one performs a standard horizontal direction scan and a separate vertical direction scan.

3. EXPERIMENT

The system of Fig. 1 was implemented with S1 having a focal length of 15 cm and without the optional ECVFL. A visible band TI DMD was used which has 1024 by 768 micromirrors, a pixel pitch of 13.68 μm, and $\theta = 12^{\circ}$. Two Newport Model 918D-UV detectors connected to a Newport 2931-C Power Meter. The hardware implementation of the delays, switching, and logic gates were simulated non-real-time using the National Instruments (NI) LabView program. For the first imaging object, a collimated 500 mW $\lambda = 532$ nm laser source is used to illuminate a rectangular target. The collimated irradiance falling on the target was 1.7 mW/cm^2. Fig. 4(a) is a CCD image of the target at the plane where the DMD is located. Fig. 4(b) shows the detected edges using the DMD-based boundary mapping sensor if a traditional horizontal scan is performed instead of the proposed Fig.3 smart scan method. In this case, note that the horizontal edges of the observed target are not detected by the proposed boundary mapping sensor. Similarly, if only a classic vertical scan is performed via the sensor, the vertical edges of the target would not be detected. Using the scanning technique of Fig. 3, both the horizontal and vertical edges are detected and the boundary of the target is shown in Fig. 4(c). Since the experimental sensor setup used took a while to implement its full object scan, it was susceptible to vibrations in our laboratory environment (no air isolation table used), and this caused the few extra pixels sticking out of the target edges as seen in Fig. 4(c). The experimental scan speed is slow due to using a computer to communicate with and process the information from DMD and power meter as opposed to using an embedded hardware implementation. Current DMD technology can achieve image reset speeds of 32,552 frames per second. Using a DMD with 1024 by 768 pixels and scan pinhole sizes of 15x15 micromirrors (i.e., 205.2 μm by 205.2 μm) and 5x5 micromirrors (i.e., 68.4 μm by 68.4 μm), the proposed processor image zone scan time is approximately 216 ms and 1.93 seconds, respectively. Improved DMD parallel processing electronics is envisioned for future versions of advanced digital spatial light modulator technologies, thus providing near real-time image processor target boundary detection speeds.

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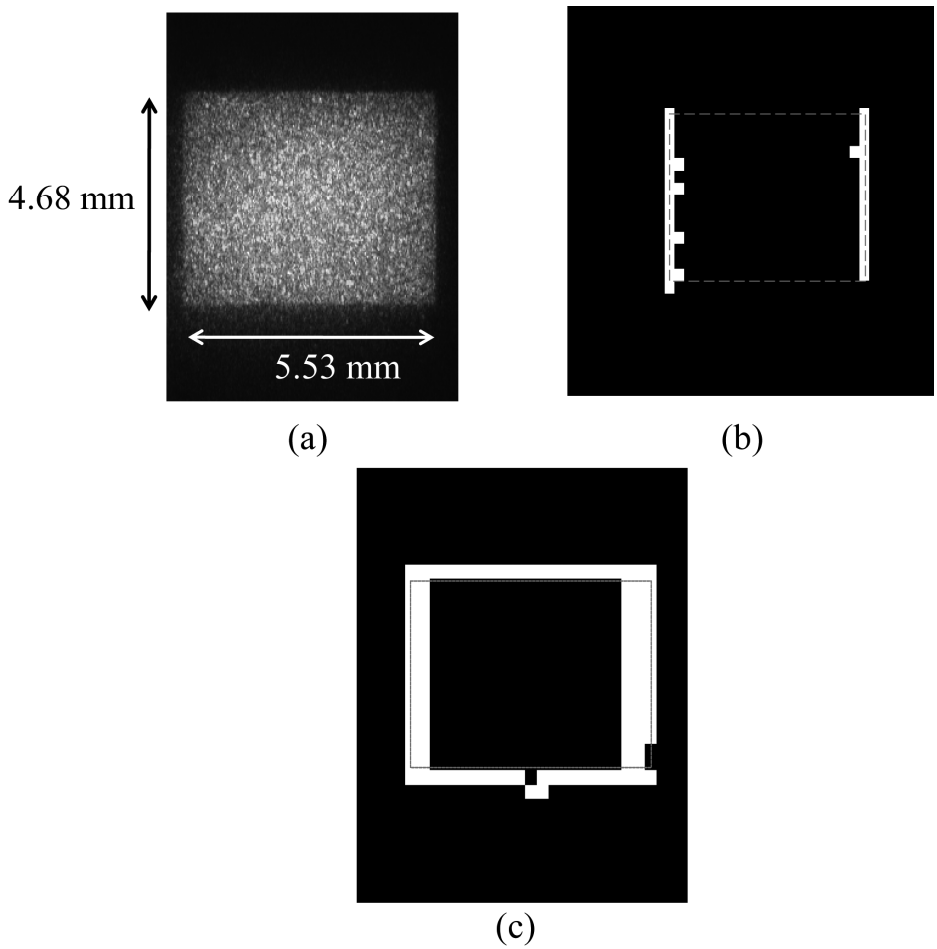


Fig. 4 (a) The rectangle target object rotated so that its horizontal and vertical sides align with the horizontal and vertical axes of the DMD. (b)The proposed sensor edge detection operation implemented using a classic horizontal scan and (c) the proposed smart scanning method that captures all the target edges.

For the next demonstration the rectangular target was replaced by a square frame target with a small square placed inside it as seen in Fig. 5(a). This target was illuminated by a $\lambda = 632.8$ nm HeNe laser source which had an irradiance of 0.72 mW/cm^2 after collimation. Fig. 5(b) shows the recovered boundaries of the target using the smart scan method for the proposed boundary detection sensor. As can be seen from Fig.5(b), the demonstrated sensor detects the boundaries mapping the multiple areas of high optical irradiance.

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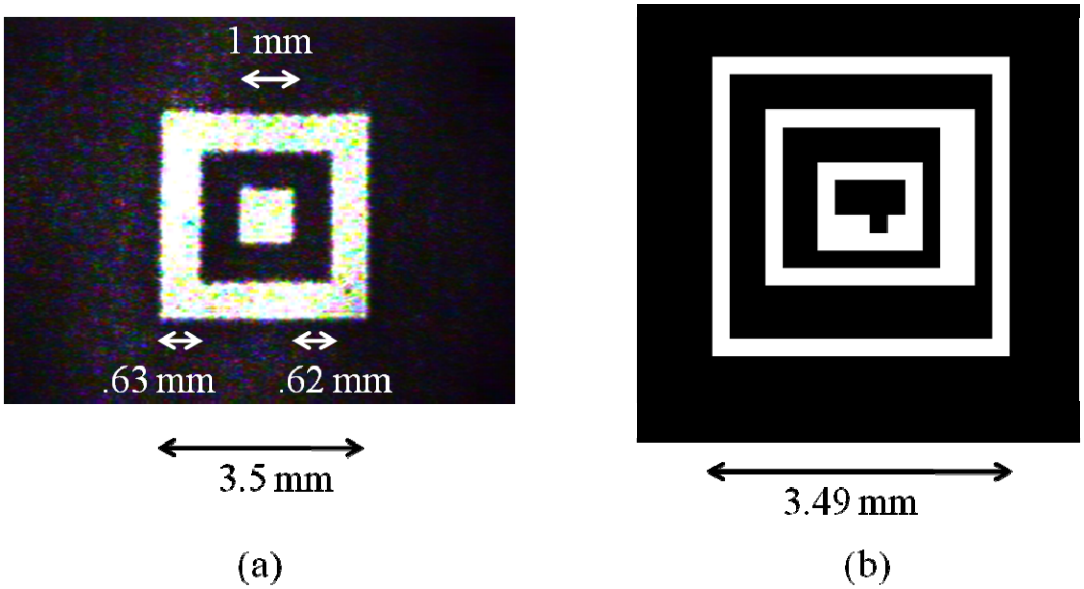


Fig. 5 (a) CCD observed test object with two separate bright areas indicating multiple boundaries. Fig. 5 (b) The proposed sensor experimentally mapped edges of the test object.

4. CONCLUSION

For the first time, to the author's knowledge, proposed is a novel boundary mapping sensor using a DMD-based 3-D irradiance mapper and real-time pixel differencing hardware. A basic experiment has been successfully conducted to demonstrate boundary detection of a rectangular target and a framed square target for visible wavelengths of 633 nm and 514 nm.

5. ACKNOWLDGEMENTS

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