Demonstration of CAOS Smart Camera Imaging for Color and Super Blue Moon Targets

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Abstract: Highlighted is the CAOS smart camera design suited for extreme dynamic range sensing. Experiments for the first time show CAOS imaging of a visible band color target and the super blue moon observed in Ireland.
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1. Introduction

Targets of interest in the industrial and defense sectors occupy diverse spatial and spectral signatures. These scenes of extreme contrast, e.g., over > 140 dB linear dynamic ranges can have target signature spectra distributed over the UV to SWIR space (300 nm – 2700 nm). In addition, targets can appear with extreme brightness and have a variety of shapes and sizes in the image space. A camera that is highly programmable in the pixel specific spatial and spectral domain with extreme linear dynamic range capabilities is highly desirable for sensing and tracking such high value targets. Recently proposed is such a desirable camera sensor called Code Access Optical Sensor (CAOS) [1] that is able to intelligently sift through image space and take deep dives into the information space to pull out spatial and spectral target information that otherwise appears saturated or is hidden deep in the information noise. Experiments have been conducted to demonstrate smart and multi-spectrum designs with imaging over the visible (white light) and Near-IR bands (e.g., 1450 nm) with linear dynamic ranges reaching 136 dB [2-4]. It is well known that a lower spatial resolution color image versus a high spatial resolution monochrome (i.e., Black and White) image provides more powerful pattern recognition via human vision brain processing. Given this initial motivation, for the first time CAOS imaging results are reported to demonstrate visible band color imaging. In addition, CAOS imaging is deployed to observe at 8.33 p.m. on January 31, 2018, the super blue moon in Cork city, Ireland.

2. CAOS Smart Camera Design and Experiments

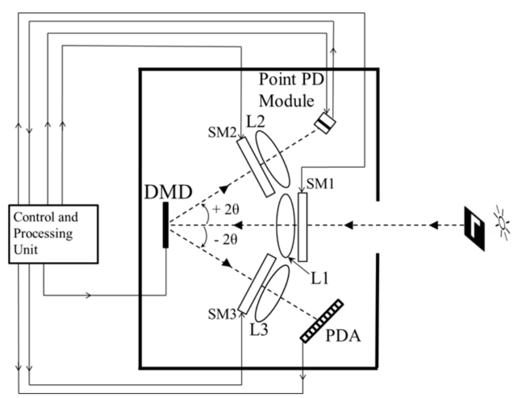

Fig. 1. CAOS smart camera design for sensing and tracking diverse spatial and spectral targets.

Fig.1 shows the CAOS smart camera design whose full operational detail is described in our earlier work [2]. The components used are: L1, L2, L3 imaging lenses; Digital Micromirror Device (DMD), SM1/SM2/SM3: optional smart modules, PDA: Photo-Detector Array sensor and point Photo-Detector (PD). Each SM can contain variable attenuators, programmable and/or fixed wavelength filters, polarizers, and variable apertures. PDA sensors can include silicon CMOS/CCDs, HgCdTe FPAs and InGaAs QWIPs. Imaged target light is first directed by the DMD to fall on the PDA sensor to acquire scene intelligence information. This data is used to control the DMD in its time-frequency modulation CAOS mode that is engaged to view the desired target with extreme dynamic range and full spectrum flexibility. As first mentioned earlier [2], using prior scene and target data sets, the CAOS camera processor can also use machine learning to enable efficient and faster sifting and tracking of the sought after targets.

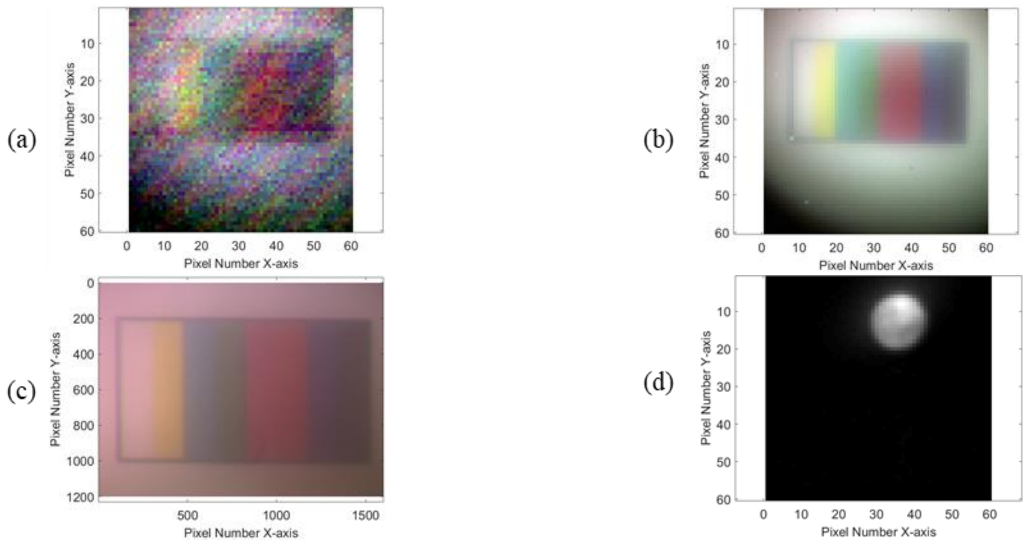

Fig.2. (a) TDMA-mode CAOS image of the observed colour target showing a high noise level. (b) Low noise CDMA-mode CAOS image of the colour target acquired by the CAOS camera. (c) Colour target used in testing that is captured by a commercial camera. (d) CDMA-mode CAOS monochrome image of the super blue moon observed in Cork, Ireland.

The CAOS smart camera built uses a Vialux V-7001 DMD with a 13.68 μm micromirror side, a Thorlabs variable gain PDA100A point PD, a IDS UI-1250LE-M-GL monochrome E2V PDA Silicon CMOS sensor with a 5.3 μm pixel pitch and 1600 × 1200 pixels, a NI 6211 DAQ to digitize and record the point PD output voltage, a 5 cm Focal Length (FL) imaging lens L2, a 6 cm FL imaging lens L1 and a 2.54 cm FL 1:1 imaging lens L3. A SMPTE colour bar test target is used. Such a target is used to calibrate imaging systems per NTSC television standards for chrominance and luminance. L1 is placed at a distance of 24 cm and 8 cm from the target and DMD, respectively. DMD to L2 distance is 13.3 cm and L2 to point PD distance is 8.0 cm. The point PD gain is set to 50 dB. Used is a DAQ sampling rate of 100 Kbps with a ±5.0 V voltage limit. Thorlabs FD1B Blue (B), FD1G Green (G), and FD1R Red (R) colour filters are placed between L2/L3 and the target and applied in succession to record R, G, B images from the CAOS smart camera. A 180 lumens white light LED flash light illuminates the target. Fig.2(a) shows the colour image produced using the TDMA-mode of CAOS imaging where one agile pixel on the DMD is scanned in the image space via a time sequence with 3600 time intervals, each 1 ms duration, to collect pin-hole sampled 60×60 pixels image data. Next Fig.2(b) shows a much improved 3600 pixels colour image produced using R, G, B images captured using the CDMA-mode of the CAOS camera where 4096 bit 3600 Walsh time sequence codes are used with a 1 kbps bit rate and a 10×10 micromirrors CAOS pixel size. As expected, given the much lower light levels at the point PD per bit interval, the noise in the recovered TDMA image is much higher when compared to the CDMA-mode of CAOS imaging. Fig.2(c) shows the colour image produced using R, G, B images captured with the monochrome PDA sensor with a 0.25 ms integration time. In all cases, MATLAB is used to reconstruct the colour image using the R, G, B images. To test CAOS imaging using a natural target, L1 is changed to a 3 inch diameter 20 cm FL lens that points to the sky with a Field of View (FOV) of 21.57°. L1 placed 20 cm away from the DMD. L2 to DMD distance is 11.2 cm and L2 to PD distance is 9 cm. Fig.2(d) shows that the CDMA-mode CAOS camera captured image of the super blue moon observed in Cork, Ireland. Here no colour filters are used and the point PD gain is 40 dB with a 1.56 μs rise time. The dynamic range measured for this blue moon image is 29.9 dB.

3. Conclusion

In summary, the demonstrated colour imaging capabilities of the full spectrum CAOS smart camera can create impact in scenarios requiring target pattern recognition and/or tracking within extreme dynamic range scenes such as in colour photography, food inspection, medical testing, defence, and automotive and industrial machine vision.

4. References

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