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Thinking Camera – Powered by the CAOS Camera Platform

Nabeel A. Riza [1,*]

[1]School of Engineering, University College Cork, Cork, Ireland

Abstract. Introduced is the system level design of a *Thinking Camera* powered by the CAOS camera platform. The proposed camera provides features such as extreme linear dynamic range and full spectrum operations with selectable space-time-frequency CAOS pixel modes using active and passive light. The imager has triple output ports design and is controlled via application-specific classical image processing, machine learning techniques, and human/user feedback. Imaging capabilities cover multi-dimensional mappings allowing diverse full spectrum (350 nm to 2700 nm) applications from industrial metrology to quantitative medical imaging to artefact preserving colour photography.

1 Introduction

Advances in electronic, optical, opto-electronic, opto-fluidic, & MEMS devices coupled with developments in high speed and energy efficient electronic processors have brought about a revolution in compact and handheld sensors impacting both the industrial and commercial worlds. Mass production of these devices and processors along with advances in packaging technologies has brought price points down to consider the realization of a modular design *thinking camera* for multi-function operations empowered by both classical image processing methods as well as modern machine learning algorithms to optimize high efficiency camera controls for a specific application. Hence the unique power of the thinking camera lies both in the raw physics-based image data extraction powers of the modular optical hardware as well as the mathematical basis of the smart camera controls provided by the high speed implementable algorithms optimized per application using training samples. It is important to stress the limitations caused by the intrinsic properties of light and the device-physics of both the light-to-electronic signal conversion as well as the electrical signal flow and processing electronics, all operating with noise levels. Hence an adequate Signal-to-Noise Ratio (SNR) of optimally designed and extracted raw image pixel signal data is required before Digital Signal Processing (DSP) image processing and machine learning can be useful for extraction of robust image data. Recently, such a novel image pixel signal conditioning and extraction technique-based camera has been proposed and demonstrated that works on the principles of an RF wireless mobile phone network where image pixels are treated as time-frequency coded mobile phone-like handsets. This camera is called the Coded Access Optical Sensor (CAOS) camera [1] and forms the foundational modular platform to design the proposed thinking camera system. The CAOS smart camera is currently designed using cost-effective technologies that includes silicon CMOS/CCD image sensors, point detectors, TI Digital Light Processing (DLP) technology Digital Micro-Mirror Device (DMD) chips, lenses, mirrors, etc.

2 Thinking Camera Design

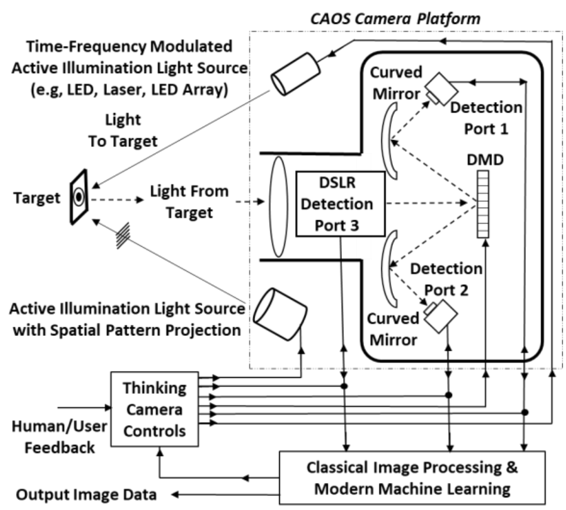

Figure 1 *Thinking Camera* Design empowered by the CAOS Camera Platform.

The CAOS camera 3-port platform used to design the Figure 1 *Thinking Camera* is highly programmable. This extreme programmability also presents a camera system controls challenge, thus requiring a “thinking” camera design for an efficient camera controls solution. For a selected application, specific imaging features of varying weights are desired that can be computed using an application specific image data set produced from both real and synthesized images. Given these weighted features (e.g., with a grey scale zero to 1 weighting where a 1 weight implies feature is extremely important and a zero weight indicating that a feature is not at all

* Corresponding author: n.riza@ucc.ie

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important), an optimization process based on classic image processing as well as modern machine learning techniques is deployed to select the best deployed camera mode/modes. The optimization system is trained using a known data set of camera features and modes. In addition, given the mode/modes produced by the optimization process, next a best set of control parameters is required for efficient camera operation. These control mechanisms can be computed using a second optimization process using classical and machine learning techniques and human feedback. Hence pre-processing is implemented for the camera using different application scenario test data given the next described Thinking camera imaging features, modes, and control mechanisms. Specifically, the CAOS camera platform [2-5] can provide powerful *Thinking Camera* **imaging features** such as:

- 177 dB Extreme Dynamic Range (XDR)
- Wide Spectral (350 nm to 2700 nm) Access
- Linear Camera Response Function (CRF) over Full XDR
- Low Contrast Inter-Pixel Recovery within XDR
- Narrow Hyperspectral Access
- 1-D (x), 2-D (x,y), 3-D(x,y,z), 4-D(x,y,z,t), 5-D space-time-wavelength image data mapping modes via coded space-time signalling
- Fast Pixel/s Imaging Speed
- High Adjacent Pixel Isolation
- Bright Light Imaging

CAOS pixel irradiance data harvesting is done using DMD chip pixel-level programming control by implementing various CAOS modes [6]. These CAOS modes using active and/or passive light control are similar in design to the time-frequency modes deployed in the RF wireless multiple access mobile phone network. These CAOS modes are called TDMA, CDMA, FDMA, FM-CDMA, FM-TDMA, CDMA-TDMA, FM-CDMA-TDMA, FDMA-TDMA, FDMA-CDMA, and FDMA-CDMA-TDMA [11]. In addition, there are hybrid camera modes such as CAOS-CMOS mode combining point detector and multi-pixel detector space-time modulation operations. In short, the CAOS camera platform provides powerful *Thinking Camera* **imaging modes** such as:

- Passive Illumination Mode
- Active Illumination modes with Power, Spatial (e.g., Fringe Pattern) and Time/Frequency Controls & Optical Interferometric Imaging
- 10 Time-Frequency Pixel/s CAOS-modes
- Hybrid CAOS-CMOS/CCD/Lidar Pixel Modes
- Super Resolution (Sub-Micromirror)

The CAOS platform control signals connect to the specific hardware components that include DMDs, point detectors, multi-pixel image sensors, DSLR mirror/tilt prism/grating/slit opto-mechanics, and active light sources, etc. To summarize, the CAOS camera platform provides powerful *Thinking Camera* **control mechanisms** such as:

- Pixels of Interest (POI) Location Control
- Region of Interest (ROI) Location Control
- POI & ROI Control in Large Space-Bandwidth-Product, e.g., $1cm^2$ area with 10^6 points
- Front Lens-free Imaging Control
- Harvested Pixels Shape Control (circular pinhole, rectangular slit, ellipse, etc)
- Pixel, POI, ROI Acquisition Time Controls
- Moderate Bandwidth Point Photo-Detection Electronic Gain/Bandwidth Control
- Digital Signal Processing (DSP) gain controls
- Multi-pixel full frame image sensor Frame Rate and Gain Controls
- Simultaneous Multi-Port Image Fusion and Noise Cancellation Control
- Pixel Spatial Light Rejection Controls for a Chosen Light Detection Port
- Coherent (with Reference) or Incoherent (Direct) Optical Photo-Detection and Electronic Incoherent/Coherent Signal Detection Controls
- DSLR Mirror for Scanning Grating/Slit Image Sensor & CAOS Hyperspectral Imaging Controls
- DSLR Tilt Prism Option for spatial image dither super-resolution imaging Controls

3. Conclusion

Proposed is the fundamental design and operation of a *Thinking Camera*-based on the CAOS camera platform. This highly programmable camera provides powerful imaging capabilities and requires a 3-faceted "*thinking*" approach to optimize efficient and smart camera operations for specific applications. It relies on classical as well as modern machine learning techniques using processing parameters of desired imaging features, camera modes, and control mechanisms. It also incorporates as needed, human/user feedback for camera controls. Future work includes full design and demonstration of the proposed *Thinking Camera*.

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