Computational Imaging for Earth Surveillance - Progress Meeting

Delft University of Technology

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Outline

Objective

- To design an imaging system for Delfi-PQ satellite satisfying the size and power constraints.
- The total system must consume a power of not more than 50mW. The system uses a low power 32-bit microcontroller(MSP432) for processing.
- The size constraints depend on the placement of the camera on the satellite. The total mass of the imager must not exceed 15g.

Note

The aperture can be on the side of the camera or protude through the top. The aperture size cannot exceed 36mm in both ways. The height of the optical part can be 6mm if placed sideways or 12.4mm if placed on the top.

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Lensless and Lensed Cameras

- There are two approaches to this problem- conventional lens based and new class of emerging lensless imaging.
- Lensed Cameras are generally bulky, and are suited for the visible light spectrum. The thinnest mobile camera is 5mm thick. The cost of the system goes up if imaging is to be done in other spectrums.
- Lensless cameras can be as small as few hundered microns thick. The trade-off is the computational complexity involved in lensless imaging.

Lensless and Lensed Cameras

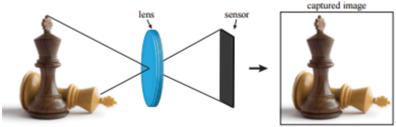

Figure: Lensed Imaging

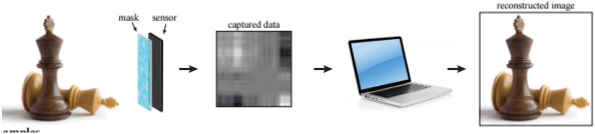

Figure: Lensless Imaging

Lensless Cameras

- The very first cameras were lensless pinhole cameras.
- Light passes through a pinhole and forms the image on th e sensor. Very small pinholes are required to produce sharp images. Size of pinhole limits light throughput.
- Lenses were introduced to increase the size of aperture, increase the sharpness of the image and light throughput.
- Coded aperture cameras extend the pinhole camera concept replacing the single aperture with a mask containing multiple apertures.

Lensless Camera

A lensless camera can be mathematically modelled as[1][2]:

- Sensor Measurement

$$y = \phi * x + e$$

- Mask
- Irradiance Vector
- Measurement Noise

After noise removal, the image can be recovered by using a function that is inverse of the mask. The response of the mask to its inverse is called System Point Spread function. An ideal SPSF would be a δ function[2].

Fresnel Zone Plates

- Introduced by Mertz and Young in the 1960s for a ”large aperture, high resolution camera with neither refracting or reflecting components”.

The FZP is defined such that the radius of the n^{th} zone is given as

$$r_n = r_1\sqrt{n}$$

and r_1 is the radius of the inner most circle.

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Fresnel Zone Plates

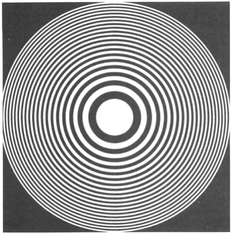

Figure: Twenty Ring Fresnel Zone Plate

- Zone Plates can be used in place of pinholes or lenses to form an image.

Uniformly Redundant Arrays

- Developed over the disadvantages associated with random arrays.
- Random arrays require infinite apertures to have an ideal SPSF.
- Fenimore and Cannon developed classes of functions into patterns which are called Uniformly Redundant Arrays with an almost ideal SPF[3].

Figure: A 60 * 60 random array

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Uniformly Redundant Arrays

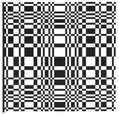

Figure: A 60 * 59 URA

- The URA has an ideal response and the open area is approximately 50 percent of that of the total aperture area.
- The collection efficiency of FZP and the ideal response of the random array is combined.

Doubly Toeplitz Masks

- The advantage of URA apply only for radiation wavelengths short enough that the diffraction effects are negligible. Reconstruction of images in visible light spectrum results in noisy low-contrast recovered images[4].
- Doubly Toeplitz masks were designed to solve this problem and reduce the effects of diffraction.
- The drawback is that the computational complexity increases in the image recovering process.

Figure: Doubly-Toeplitz Mask[4]

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FlatCam

- The most recent lensless camera architecture[1][5].
- Uses pseudo-random maximum length sequence masks which are similar to random arrays. Similar to doubly-toeplitz masks, it places two masks one after the other.
- Takes an average of 75ms to compute a 512 * 512 image on a standard laptop computer. 10 fps video capture feasible on a PC.

Lensed Cameras

- As mentioned before, they are thicker than lensless camera due to the lenses involved.
- New designs have come up that considerably reduce the size of the imaging system.

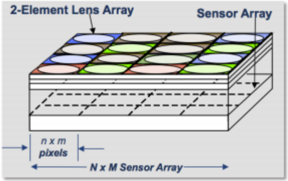

Figure: PiCam[6]

PiCam

- This approach uses multiple small lenses with color filters to capture multiple images
- Due to multiple CMOS sensors needed for this approach, the power consumption of the camera alone can exceed 500 mW.
- Apart from this computational reconstruction of the image is required.

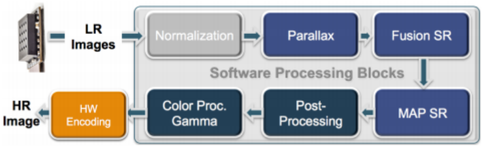

Figure: PiCam SW Pipeline

Conclusion

- Computational Complexity is directly propotional to the power consumed by the MCU for imaging the system.
- Another approach requires fabricating diffraction grating based CMOS sensors. However, they do not offer any specific advantage compared to the approaches mentioned above.
- A trade-off needs to be made between the spectrum that needs to be measured and the computational complexity.

Table: Comparison of Different Approaches

Approach	Computational Complexity	Spectrum
URA	Low	X-Ray, γ Ray
Doubly-Toeplitz	High	Visible, γ, X-Ray
FlatCam	High	Visible, γ, X-Ray
PiCam	High	Visible

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Next Work

- Computer based simulation of the approaches mentioned can be done in MATLAB.
- Acquiring of required CMOS sensors if visible light imaging needs to be done.

References I

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