Delft University of Technology
Master's Thesis in Embedded Systems

Computational Imaging for Earth Surveillance

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Computational Imaging for Earth Surveillance

Master's Thesis in Embedded Systems

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28th May 2017

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Title

Computational Imaging for Earth Surveillance

MSc presentation

28th May 2017

Graduation Committee

TODO GRADUATION COMMITTEE	Delft University of Technology
TODO GRADUATION COMMITTEE	Delft University of Technology

Abstract

TODO ABSTRACT

Preface

TODO MOTIVATION FOR RESEARCH TOPIC

TODO ACKNOWLEDGEMENTS

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Delft, The Netherlands
28th May 2017

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Chapter 1

Introduction and Problem Statement

The history of cameras go back to 13th century when Aristotle first noticed how light passing through a small hole in a darkened room produced an image of the sun on the wall. Throughout the centuries, the basic design of cameras have been continuously changing with different versions of the 'camera obscura' with a single pinhole being developed by different civilisations. In a pinhole camera, light passes through the pinhole and forms an image on the sensor/image plane. As the size of the pinhole increased, the quality of image formed on the plane decreased and as the pinhole size became smaller, lesser light was allowed which resulted in decreased field of view. With the development of science and due to the limitations of the pinhole, lenses were introduced to increase the size of the aperture, the sharpness of the image and the light throughput. As humanity progressed with the rapid pace in technology, we were able to capture images and store them on a film. With the digital explosion in early 1990s, the thin films were replaced by Charged Couple Devices(CCD). Then came the cameras based on Complementary Metal Oxide Semiconductors(CMOS). CCD and CMOS sensors reduced the size of cameras considerably and it was possible to develop low cost cameras in a large number. However, cameras have retained the lens throughout the years. Cameras are used for various applications and one such application is the space exploration domain. Delfi Space is the small satellite program of TU Delft that is mainly meant for education and technology demonstration in very small sized satellites. Delfi-PQ programme is a sub-programme of the Delfi Space programme that aims at developing extremely small but highly capable PocketQube satellites. PocketQubes are an order of magnitude smaller than the well known CubeSat standard which formed the basis of previous Delfi satellite projects. The dimensions of a PocketQube satellite would be 50mm * 50mm * 178mm and their volume would be approximately eight times smaller than CubeSats.

One of the advanced payload that would be part of the Delfi-PQ would be an imager/camera that consumes extremely low power and would fit into the dimensions and power specified by the Delfi-PQ team.

In order to reduce the size of a camera, it would be necessary to remove the lens from the camera as the thinnest lens based mobile camera is 5mm thick. The primary focus of a lens would be to focus light from distant objects onto the CMOS sensor. Light from distant objects reach the sensor even without the lens except that the light is incoherent and the CMOS sensor would not be able to form the object properly without a lens. However, the lens could also be replaced by coded apertures. Coded Apertures have been used in the late 20th century to image X-Ray sources of light. Lensless coded aperture cameras can be as small as $100\mu m$ thick. By using lensless cameras, we could potentially reduce the form-facto multiple times to suit the requirements of Delfi-PQ. However, the thesis would focus on the broader applications of lensless camera in satellites and would also make an attempt at addressing the power and computational requirements of the Delfi-PQ.

The thesis would be addressing the following research questions:

- Would it be possible to design a lensless camera to capture astronomical objects in the visible range of light spectrum?
- What would be the minimum possible form-factor that would be achievable and the effects of different factors such as diffraction effects, mask-to-sensor distance and reconstruction algorithms?
- If possible, how would the lensless camera compare with the conventional lens based cameras used currently?
- Would it be possible to design a lensless camera that would fit the power and size constraints of the Delfi-PQ?

Chapter 2

Literature Survey and Trade-off Analysis

In this chapter, a state-of-the art study will be presented that could assist in design of the lensless imager with specifications mentioned in the previous chapter.

2.1 Trade-off Analysis

2.1.1 Camera Sensor

The camera sensor is the core of the Delfi-PQ Imager. The performance of a camera is mainly limited by the image sensor that it uses[1]. The camera sensor can be off two types namely, CCD(charge coupled device) or CMOS(Complimentary Metal Oxide Semiconductor). Both the types of CMOS sensors have their own advantages and disadvantages. TO understand the challenges that each type of sensor poses, we must understand how the sensors are designed.

The following factors have been chosen to make a trade-off between the different CMOS sensors:

1. Resolution : When rating a camera, the first thing that comes to the mind is the resolution of the camera. The resolution of a camera is directly dependent on the number of pixels in the image sensor of the camera.

2. Power Consumption : In the design of the PQ-Camera, the most important factor is the power consumption of the entire imager. The majority of the power consumption by the imager is dependent on the power consumption of the CMOS sensor.

3. Availability : Even though there are innumerable number of CMOS sensors in the world, availability of CMOS sensors is quite low when it

comes to small-scale. Many CMOS manufacturers require large scale orders.

4. Quantum Efficiency(QE) : Quantum Efficiency is the measure of efficiency of the camera sensor to convert incoming photons into electrons. The ratio of electrons generated during the digitization process to photons is called quantum efficiency.

5. Pixel Size : Pixel size is the size of each pixel unit in the CMOS camera. It is also an important factor considering that the signal produced by the CMOS sensor depends on the pixel size as well.

$$Signal = LightDensity * (PixelSize)^2 * QE$$

6. Electronic Interface : The electronic interface that can be used to retreive data from the CMOS sensor also plays an important role. Since the project uses a low-power microcontroller that has limited communication capabilities, it would be wise to chose an interface that is supported by the microcontroller. Recently available chips use LVDS/MIPI interface to send data. These interfaces are not supported by the microcontroller that is being used as an on-board computer.

7. Dynamic Range : Dynamic Range and SNR are used interchangeably in CMOS sensors. The only difference is that dynamic range considers only the temporal dark noise while SNR includes the root mean square of the shot noise as well.

8. Shutter Type : Camera sensors use different types of shutters namely, global shutter and rolling shutter. Global shutter reduces the distortions due to fast moving artefacts while increasing the dark current. Rolling shutter has more distortions in the case of imaging moving artefacts, but also has lesser dark noise compared to global shutter.

9. Voltage Level : Voltage level also has to be taken into account while choosing the sensor because if the CMOS sensor needs a voltage level higher than that of the main satellite bus voltage, then additional circuitry has to be introduced to step up the voltage level which in turn increases the overall system power.

10. Operating Temperature : Operating temperature is an important factor to take into account when choosing an imaging sensor. Since the camera is going to operate in space, it is better if the CMOS sensor has a higher operating range of temperature.

11. Overall Size and Weight : As the imager has to fit within specific dimensions, the overall size and weight of the CMOS sensor also needs to be taken into account.

12. Frame Rate: Even though, it is not required to have a camera sensor that is capable of high frame rates, it is an added advantage and higher frame rate camera could help in imaging larger areas of the earth if required.

13. Price: While there are no specific cost constraints in the project, price has also been taken into account.

Table 2.1: Comparison of Different Image Sensor Candidates

Factors \ Candidates	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
Optical Parameters										
Resolution										
QE										
Pixel Size										
Shutter type										
Frame Rate										
Electrical and other parameters										
Power Consumption										
Availability										
Electronic Interface										
DR and SNR										
Voltage										
Operating Temperature										
Overall Size and Weight										
Price										
Points										

2.1.2 Compression Algorithms

2.1.3 Reconstruction Algorithms

Chapter 3

System Modelling and Design

INTRODUCTION TEXT TO THIS CHAPTER IN WHICH ALL SECTIONS ARE DESCRIBED ROUGHLY (1 SENTENCE EACH).

This chapter describes the ... In Section 5.1, examples are given of how to use tables and figures in MSc theses.

3.1 SECTION TITLE

Every caption of a table (or figure) should start with a capital letter, and should end with a period. References to tables are given with a capital letter for table, as in "(see Table 5.1)" or "in Table 5.1, ...".

left aligned	centred	right aligned
12	34	56

Table 3.1: Complete sentence describing the tabular data.

References to figures are given with a capital letter for figure, as in "(see Figure 5.1)" or "in Figure 5.1, ...".

[?] [?]

Figure 3.1: Complete sentence describing the figure thoroughly.

Chapter 4

Implementation

INTRODUCTION TEXT TO THIS CHAPTER IN WHICH ALL SECTIONS ARE DESCRIBED ROUGHLY (1 SENTENCE EACH).

This chapter describes the ... In Section 5.1, examples are given of how to use tables and figures in MSc theses.

4.1 SECTION TITLE

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left aligned	centred	right aligned
12	34	56

Table 4.1: Complete sentence describing the tabular data.

References to figures are given with a capital letter for figure, as in "(see Figure 5.1)" or "in Figure 5.1, ...".

[?] [?]

Figure 4.1: Complete sentence describing the figure thoroughly.

Chapter 5

Experimentation and Validation

INTRODUCTION TEXT TO THIS CHAPTER IN WHICH ALL SECTIONS ARE DESCRIBED ROUGHLY (1 SENTENCE EACH).

This chapter describes the ... In Section 5.1, examples are given of how to use tables and figures in MSc theses.

5.1 SECTION TITLE

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[?] [?]

Figure 5.1: Complete sentence describing the figure thoroughly.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

TODO CONCLUSIONS

6.2 Future Work

TODO FUTURE WORK

Bibliography

[1] A. El Gamal and H. Eltoukhy. Cmos image sensors. *IEEE Circuits and Devices Magazine*, 21(3):6–20, May 2005.