Camera Payload Report

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Description:

This document describes the considerations taken by the camera-group in the NCUBE–Project at NLH. The document will describe what goals the group was working towards and what requirements a satellite-camera have towards sensor chip, resolution, etc combined too these goals.

Table of contents

Introduction

The process of choosing the best payload for a cubesat follows through a section of decision-making:

1. What is the purpose of the actual payload? (In this case a camera)
2. What operations should the camera be able to perform, combined to the purposes in number 1? What should the camera do to reach the goals of the project?
3. What cameras satisfy the demanding in number 2? And what is the best camera solution?
4. Is the chosen camera in number 3 able to function together with the rest of the satellite?

At the end of every number in the list we may not reach the demands we had in the first place. We then have to go back and look for other solutions that may suit our purposes in a better way.
While repeating the numbers we may also come to the conclusion that the hole basic concept and goals of the mission have to be changed, else we won't move forward at all.
This report investigates the two first numbers in the section above. And the weight is laid on number two.

Ahead of the work with the camera payload, some considerations had already been taken regarding the purpose with a cameraunit in the cubesat. This report and the work with the cameraunit are based on these purposes (listed below).
Other aspects regarding the cameras interaction with the rest of the satellite are not discussed in this paper. The cameras need for a gyro in order to know where the satellite is pointing is not discussed either. These decisions are left out for others to decide.
Because of the authors background this report is written from satellite image analyst's point of view. The technical aspects around the satellite camera turned out to be a little more difficult and harder than first assumed. In order to supplement the contents of this report I refer to the sources I have listed at the end.

Goals

As mention above, the camera group have some goals they are working towards. These are:
1. Mapping of grazing land for reindeer and mapping of snow melting in Norway.
2. Area recourse mapping in Uganda, Tanzania and Nepal. And mapping of woodland areas in Russia.

These two goals above give us some criterions to work with for choosing the best camera solution for the project:

Spatial resolution

Mapping of grazing land for reindeer and area–recourse mapping have the same criterions when it comes to spatial resolution. In both cases the pixel size should be as small as possible. And in the other end it should not grow over 150x150 meter to give a satisfying spatial resolution. With toady's available chips a 100x100 km scene, easily should give a spatial resolution of 80 x 80 meter. And even down to 20 x 20 meter if we choose the best chips available today.
Mapping of snow melting do not have the same demand for spatial resolution as the forth-going example. Researches in this field have been done with images with spatial resolution up to 1 x 1 km. (NOAA AVHRR images). In other words it should be easy to reach this pixel size with today's sensor chips. Very cheap image sensors can useful for this purpose.
A huge scene-size gives a huge spatial resolution. But this criterion has to by compared with the criterion the satellite system gives to the camera. With limited space in the cubesat we may have to reduce the focal distance, which means a smaller scene size.
It should be noted that larger pixels needs shorter exposure time, since large pixels collects more light faster than small pixel. Large pixels also allow more movement during the exposure time. If we have restricted amount of power, as in the cubesat, these criterions favourites large pixel size.

Light considerations

Mapping of snow melting can be done with a monochromatic sensor chip. Colour images can be an advantage, but not necessary in the same way as in vegetation analysing. Monochromatic chips can deliver much higher resolution than colour chips. The amounts of data to be processed are also smaller. One problem though is to separate clouds from snow since they both appears as white spots in the image.

In order to analyse and separate different sources of vegetations, and separate vegetated areas from non-vegetated areas, we need to look at the electromagnetic spectrum and decide with part we are interested in.
The visible part of the spectra ranges from 400 nm to 700 nm. Most sensor chips and cameras available today sense light from this part of the spectrum. But in order to get proper information about vegetation it is a great advantage to get information from the near infrared part of the spectrum as well. Ranging from 700 nm to 900 nm. This is because of the spectral reflectance characteristics of vegetated areas on earth.
Ideally the camera in the satellite therefore should have two sensors. One that records waves from the visible part of the spectrum, and one that record waves from the near infrared part of the spectrum.
Today's environmental satellites record light form many different parts of the spectrum and save each of them into different bands. (So called multispectral sensors.) Depending on the processor and power in the cubesat we ideally want to do the same. But as we shall discuss further down in this report this can be rather difficult to implement in a cubesat.

The Camera Solution

Above we introduced some problems regarding the camera solution. Below we try to discuss the problems separated from each other.

Sensors

For this project we need a flat area image chip like CCD-chips (Charged Couple Device) or CMOS-chip (Complementary Metal Oxide Semiconductor).
Shortly explained the CCD- and CMOS- chips consist of a two dimensional array of very small photosensitive detectors also known as sensor elements.

The amount of light falling on each of these elements creates a small charge, which can be compared to the energy in the light (I.e. which part of the spectrum the light belongs to).
The difference between these two sensors types consists of how they handle this charge from now on.
The CCD-chip transfers each pixel's charge packet sequentially to a common output structure, which converts the charge to a voltage, buffers it and sends it off-chip.
In the CMOS-chip the charge-to-voltage conversion takes place in each pixel. (The structure of these chips can be read about in [1], [2], [4], [5])

Common for both chips is that further on the voltage creates an analog signal that is converted to a digital signal. (Typically 8-bit signal 0-255) This digitally signal can be saved in a memory card or directly read out.

Cameras build with these chips each have their own advantages and disadvantages that make them appropriate to different applications.
Active pixel CMOS cameras are a relatively new technology. Compared to traditional CCD cameras, they are simpler to manufacture (hence cheaper), has a low power usage, operates at a lower voltage, and may be produced to integrate several functions in the image sensor itself. Hence it is easier to integrate in different solutions.
On the other hand the CMOS – chip doesn't have the same capability to work proper in cold environments as the CCD-chip. The CCD–chip also have a better Signal to Noise ratio (SNR) than the CMOS, i.e. the chips capability to give correct output voltage and not to deliver to much incorrect noise. The CMOS–chip doesn't reach the size of the CCD-chips photosensitive area either. This means that most CCD-chips come with smaller and better resolution than most CMOS. But technology is moving towards the same capabilities for these sensors in the future.
More info about the choice of sensor chips can be viewed in the links [1], [2], [4], [5], listed as sources at the end of this paper.

Colour vs. Mono

The goals of this project are pretty clear. It is a huge advantage with a colour chip if we should be able to analyse vegetation.
For a Cubesat Project it can be problematic to get the colour images we want, because cheap colour chips don't give the spatial resolution we wish. And the

light conditions in the atmosphere are not perfect either. Other aspects depend on the satellites capability to transfer data down to earth. A colour image chip with several bands delivers more data than a monochromatic chip. At the same time colour sensor requires more work and more out of the satellite than a monochrome sensor does. But a colour image gives more data to work with than a monochrome image with the same resolution. It is much harder and almost impossible to analyse vegetation with a monochrome image, but snow-melting analyses can be done with both types of sensors.

Above we read that the sensor-chip finally gives us an 8-bit signal ranging from 0-255. We all know that this only displays grey levels from white to black. In order to get colour images instead of mono images we have to separate the light measurements in three different wavelengths: Red, Green and Blue. The information from these three measurements can be combined to simulate the colour we see with our eyes.

There are two basic methods of colour imaging using CCD or CMOS cameras. Single chip method and multiple chip method.

Single chip

In the single chip method each of the sensor elements have their own filter so that only red, green or blue (RGB) light reaches the given pixel. The greyscale value from 4 small sensor elements is used to form one colour dot. This filtering scheme allows us to capture colour images, but since four pixels must be combined to form one colour dot, the resolution of the image is less than a monochrome image. This is the solution that suits the cubesat project best. Only one chip demands little space and suits the cubesat in all ways

Multiple chip

When using multiple chips we spread the light beam with a colour-separating prism. I.e. the light beam is spread into three different beams, one for each colour. Each of this light beams is now measured by separated chips. For RGB measurements we then need three different chips. By this method the spatial resolution is improved and we are able to look at only one colour image separated from the other. The disadvantage is that it can be difficult to make such a camera to fit into a cubesat because of the limited space. It is also more expensive and has a complex design.

As mentioned in the introduction we ideally want look at the near infrared part of the electromagnetic spectrum as well as the visible part.
There are a number of different solutions of this problem as well. One of them is to include two chips in the camera and then use a device that scatters the light into two beams witch again hits two different chips. One beam witch contains long wavelengths (near infrared) and one with short wavelengths. (Visible light) By using this method we should be able to look at visible light in one image and near infrared light in another image. But is has the same problem as over, requires space and power.

Multiple bands and Wavelengths

So far this report has been concentrating on the sensors and chips. In order to get a result that satisfies the goals we had in the first place, it is important that we look at what wavelength we should record, in order to get the information we need for the project goals we have. This can best be viewed by comparing the bands the Landsat TM sensor offers and what information we can get from the different bands. I have chosen to focus on the 5 bands from 0.45-1.75 micrometer because these are the bands that fit our project goals.

Table 1: [6]

Band	**Wavelength (Micrometer)**	**Name**	**Characteristics**
1	0.45-0.52	Blue	Supports analyses of land use, soil, and vegetation characteristics
2	0.52-0.60	Green	Used mainly for mapping vegetation. (Healthy vegetation reflects green light)
3	0.63-0.69	Red	Very important band for vegetation discrimination
4	0.76-0.90	Near-IR	Indicates the vegetations health, and the amount of biomass in the scene. Emphasizes land/water contrast
5	1.55-1.75	Middle-IR	Important band for separating between clouds, snow and ice in a scene/image. Also useful when looking at amount of water in vegetation. (Health analysis)

[6] →Table 1: [3] *Landsat-5 TM spectral Bands*

We see that the most important bands for vegetation are bands 3 and 4. But this doesn't exclude the other bands in vegetation analyses. When analysing satellite images we have to look at different bands simultaneously in order to obtain the best analyse result. An example of this is that vegetation absorbs much of the incident light for photosynthetic purposes. Vegetated areas will therefore appear dark in band 1-3. But because the same vegetation reflects over half the incident near infrared light, it will appear as bright areas in band 4.

For hydrologic resource we see that the wavelengths from band 5 are very useful. If we want to look at snow melting and separate snow from clouds this is a very important band.

So analyse of satellite images often depend on several images from several bands to obtain good results.

In our project multispectral analysis limits itself to one chip solution. In a simple colour chip camera solution we won't be able to look at multiple bands except for the visible part of the spectrum. If the choice falls on a monochromatic chip we should consider each wavelength separately in order to record light from the parts of the spectrum we wish to analyse.

Camera design

What criterions should we have to the camera we choose for this project? Different demands around image size, pixel- and radiometric- resolution depend on the choice of chips, camera and lenses. Calculations of focal length and the connection between image size, focal length and height can be viewed below.

Lenses

There is a strong connection between the choice of sensor chip and choice of lens. The diameter of the lens and the focal length determine the amount of light getting through to the chosen chip. Therefore in order to obtain the correct illumination of the chip we have to calculate the lens diameter. In our case the lens diameter should be around 30mm. In some situation it is not critical to get the lens diameter entirely correct because the sensitivity of the chip can be adjusted to suit the right environments.

Focal Length

Under follows a number of easy calculations that can be done in order to decide the connection between image size, focal length and height. We have to decide:

Distance to object:

Height of the satellite above earth surface is ca 600 km.

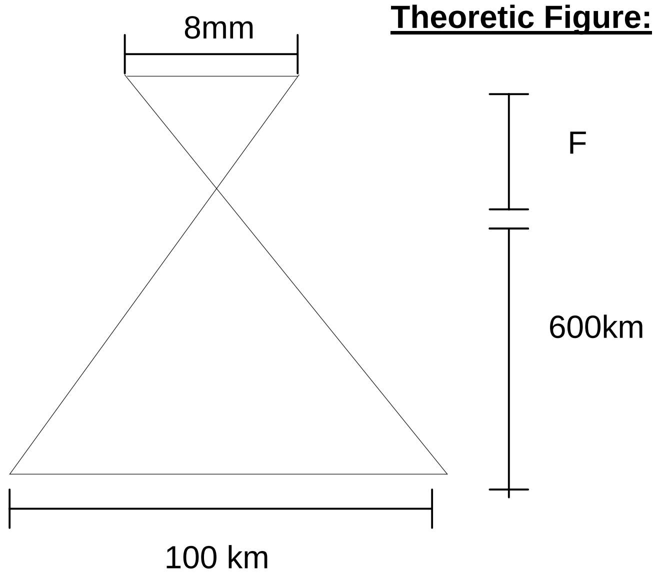
Size of one scene:

Lets say 100 x 100 km

Size of the senor area on the chip.

Not bigger than ca 8 mm

Theoretic Figure:



F= focal length

(8 mm /100 km) * 600 km = F

F = 48mm

If the 8 mm sensor area covers 1300 x 1300 pixels:

Spatial resolution:
100 km /1300 = 77 meters

These are not final calculations but an example how it can be done. Choosing a different focal length or scene size only change the area to be photographed. If we choose the scene size 200 km we get a focal length of 24mm. The other way if we choose a scene size of 50 km we get a bigger focal length = 96mm. As we see this moves towards the maximum length in the satellite.

Noise and Light Exposure

If to little light passes trough the lens we will not get useful images. This is because of the Signal to Noise ratio (SNR) I have mentioned before. To little light gives a little to no charge in the sensor elements and the output value depends more on the noise than on the real signal. It is therefore better that the chip is exposed with too much light than to little light.
Because of this we have to calculate the amount of light exposure the camera will get in space approximately 600 km above earth surface. Calculations from Aalborg Unv. [3] estimates the light intensity 600 km above earth surface to 16425 lux. The normal indoor lux varies from 300-600.
Hence it is critical to estimate the right value for light exposure. If we allow way too much light onto the chip, the chip will be over-exposed and the resulting image will appear as a white surface. (Blooming)

Distortion

The quality of the lens also plays an important roll in the design of the satellite camera. A high quality lens should be implemented together with a high quality chip; that is a chip with high resolution and many sensor elements. A lens of bad quality and with high distortion will give a high degree of errors in the image. Implementing a lens of such a quality together with a high quality chip would be a waste of money. So before implementing a lens with a chip, the lens quality should be tested in order to decide the quality of the lens.

Other aspects

A camera that goes into space has to tolerate low temperature. It would be a waste of power if had to warm up the satellite before taking the pictures of earth. It should also be able to tolerate a quite good shake while orbiting the earth. No use in a camera that break apart the moment it is launched.
The satellite should also be able to know if it is pointing towards the stars or the sun in order to take pictures of the earth. If the satellite won't be able to do this, it is no use in having a camera as payload. Except if it is going to be used as a star telescope.
The camera should be a low weight application, which has low power consumption.

Different Cameras

There are very few cameras in the world build for the purpose of going into space with a cubesat and to take pictures. So the primary goal for this project was to search up and find camera components that we can be able to put together.

The report from AAU-Cubesat [3] has been helpful in the selection process of sensors. The goals of their project may be different from ours but I think their choice of sensors suited our mission as well.

The product sheets and product specifications for each component can be downloaded from the company's website.

Cameras

The camera below is a camera NASA has been using. The camera needs adjustments to suit our mission.

- The PC67XC/2. A complete CCD camera solution from the company supercircuits. [10]

Cameras to be modified

These cameras can be modified in order to suit our project.

- The Logitech Fotoman Plus is a 8-bit greyscale digital camera [6], Used in a satellite project.
- Philips WebCams, ToUcam-product series. [14]

The Web-Cams from Philips, are in my list because I know some of them are been used in amateur astronomy. In our case it is the chip and the structure of the cameras we might want to look and take advantage of, not the camera itself. The lens in these cameras can't be used in our project.

Sensors

The sensors under are only sensors and need a whole framework to be implemented in a camera. (Designing of a new camera) Not at all a cheap process, but Aalborg University have a firm called Devitech to help them with this process.

- PB-MV40. This is a HighSpeed CMOS photochip from the company photobit. [13]
- PB-MV13. This High Speed CMOS photochip is also from photobit. [13]
- MCM20027. Kodak manufactures this chip. [12]
- KAF-6302CE. Full-Frame CCD Color Image Sensor. Also Kodak.[11-1]
- KAF-5100CE is a pixel colour image CCD sensor. Kodak. [11-1]
- KAF- 4202 Monochrome CCD Image Sensor, Kodak [11-2]

Lenses

Aalborg University chooses between two different lenses to be implemented in the designed camera.

- Acromat lens [3]
- Triplet [3]

I have not managed to get further information about these specifics lenses. But the choice depends on the quality of the lens and how they mach the purpose of the projects. More information can be viewed above in the Camera Design section.

Conclusion

It is hard to come with a solution without proper knowledge in camera design. Signals from the Camera Payload group in NTNU in the latest days have moved in the direction of a certain camera solution. I therefore won't recommend one specific solution in front of others. This paper should be regarded as supplementary information for the group on NTNU.

Discussion

The goals ahead of this project have a good chance to be reached. We should be able to design a camera and make it work. The purpose of the project isn't to get the worlds best result, but show the world that we can obtain good result and build a camera with limited resources.

Many people may have great expectations regarding the camera, included my self in the beginning. But the size and other limitations of the satellite effectively stop huge expectations regarding the amount of data we should be able to get from the camera.

Many of the possibilities in this paper can be considered as pretty optimistic. A great deal of it should be regarded as informative text, written to discuss our options.

It is not easy to decide that one solution is better than the other. So far, many aspects around the camera design remain unsolved and the camera designers should be apart of the decision making as well.

It is clear that a cubesat camera should be designed from scratch or at least built on an existing application. In the last case strongly modified to fit our requirements of course.

My greatest sources of information about possible camera solutions have been the other Cubesat projects. Many of their goals suit our project as well, and in some cases they are nearly similar. Therefore it could be interesting and a grate source of information if we could be able to work together and exchange experiences in the work with our own project.

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