Optimized Filtering and Compression System for an Earth Observation Satellite

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ABSTRACT
Most earth observation satellites in their daily image processing routine operate using the "store and forward" mechanism; this mode of operation is not efficient due to the huge amount of data that has to be stored on-board the satellite (but cannot due to memory constraints). The Cape Peninsula University of Technology (CPUT) 3U CubeSat named ZACUBE-02 will perform the filtering and compression processes of the images on-board. The focus of this research lies within the choice of the appropriate hardware that will be used to test the filtering and compression algorithm; the implementation of the hardware; the implementation of JPEG2000; and a detailed study on how to increase the compression ration without affecting the image quality as well as a suitable design and implementation. The chosen hardware will be used to implement the JPEG2000 using C programming language; the study on how to increase the compression ratio without affecting the image quality is proposed. By filtering and compressing images, the on-board storage memory constraints, the power constraints and the bandwidth constraints will be met resulting to the downlink transmission time being minimized. Filtering and compression of images find applications in photography, image/data storage and transmission where storage, bandwidth and power are restricted.

Keywords
Mechanism, satellite, CubeSat, JPEG2000, filtering, compression

1. INTRODUCTION
Low Earth Orbit (LEO) is referred as any altitude less than 2 000 Km above the Earth [1]. A satellite located at this altitude can easily capture images of the Earth using various imaging sensors. The development of large satellites such as the Planck satellite [2] and Landsat-D [3] is resource intensive and very expensive. To minimize development time and cost, Prof. Jordi Puig-Suari at California Polytechnic State University (Cal Poly), San Luis Obispo and Prof. Bob Twiggs at Stanford University's Space Systems Development Laboratory (SSDL) propose the CubeSat Project as a collaborative effort in 1999 [4]. These small satellites provide advantages such as low cost, low complexity, good imaging sensors as well as short development time.

The proposed CubeSat initiative is now regarded as the ideal platform for the transfer of satellite engineering skills. Africa has joined this opportunity to invest in space exploration through the development of CubeSats at Universities and research organizations. The South African Government in cooperation with the French Government established the French South African Institute of Technology (F'SATI) through the Cape Peninsula University of Technology (CPUT) and Tshwane University of Technology (TUT), with the aim to develop human capital for space science.

2. BACKGROUND
F'SATI, operating within the Faculty of Engineering at CPUT, introduced a CubeSat program in 2007. The main focus is to develop human capital for space science by providing an opportunity to graduate students from engineering and science backgrounds to be involved in the design and implementation of satellites. As a result of this program, the first 1U CubeSat (ZACUBE-01) is set to be launched in 2012 which will be Africa's first CubeSat in space. The design and implementation of the 3U CubeSat (ZACUBE-02) also commenced in 2011 and is set to be completed in 2012.

The primary mission of the 3U CubeSat (ZACUBE-02) is to capture images of the Earth. The 3U CubeSat (ZACUBE-02) will capture still images of the Earth from which potential information will be retrieved for a better understanding and monitoring of our planet.

The 3U CubeSat (ZACUBE-02) includes a 5 megapixels (high resolution) camera. According to [5], imaging sensors with large resolutions record file sizes that are typically larger than what can be transmitted by the majority of CubeSat transceivers in one overhead pass. Therefore, image filtering and compression are identified as crucial on-board facilities on the CubeSat. This need for increasing the automation on-board is predicted as one of the main trends for future satellite missions [6].

2.1 CubSat
A CubeSat is a satellite that has 10 cm of cubic volume and a mass of up to 1.33 kg for one unit (1 U), which can be extended up to three units (3 U) and is built in Aluminium 7075 or 6061.
A CubeSat is mostly used for space exploration and consist of the following subsystems [7]:

- *Payload:* the combination of hardware and software on the satellite that interacts with the target to accomplish the mission objectives.
- *Attitude Determination and Control System (ADCS):* used to point the satellite accurately and to stabilise it during image capturing.
- *Thermal:* plays a very important function on the satellite mission such as making sure that the satellite is protected against solar radiation in space. It also protects the

satellite's electronic components against very high and very low temperatures.

- *Tracking Telemetry and Command (TT&C):* it provides communication between the satellite and the ground station by transferring payload mission data and handling spacecraft housekeeping. The TT&C is used as the platform to pass operation commands to the satellite.
- *On-Board Computer (OBC):* the brain of the CubeSat, it gathers telemetry from subsystems, it performs general housekeeping, it controls other subsystems, it communicates with the ground station and it handles the execution of the flight plan.
- *Power system (Solar panel and batteries):* satellite power system uses solar energy system due to solar energy being the most favourable source of energy in space; the electric power produced by the solar panel is then dispatched to each subsystem.

After the design and implementation of the CubeSat, it has to go through vigorous tests to ensure its survival during the launch. The testing requirements are provided by the launch vehicle environment. In the case of the launch vehicle environment been unknown, the testing requirements can be derived from a document commonly used as a standard within the CubeSat environment. This document is referred to *General Environmental Verification Standard* (GEVS) for *Goddard Space Flight Center* (GSFC) Flight Programs and Projects GSFC-STD-7000 [8]. The GSFC-STD-7000 is very useful as reference when it comes to defining the launch environment although does not guarantee accurate details of all launch vehicle testing environments. Before the launch, all CubeSats should be tested [4].

2.1.1. CPUT 1U CubeSat (ZACUBE-01)

The CPUT 1U CubSat (ZACUBE-01) illustrated in Figure 1 (Adapted from F'SATI, 2011) has a camera resolution of 640 x 480 (0.3 megapixels). Images of the Earth captured at these resolutions can easily be transmitted to the ground station without the need to be filtered and compressed because of their low resolutions.

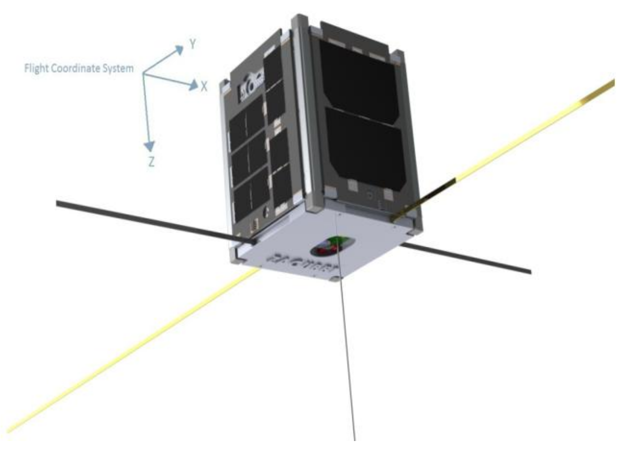

Figure 1: CPUT 1U CubeSat (ZACUBE-01)

Figure 2 illustrates the camera block diagram used for the CPUT 1U CubeSat (ZACUBE-01).

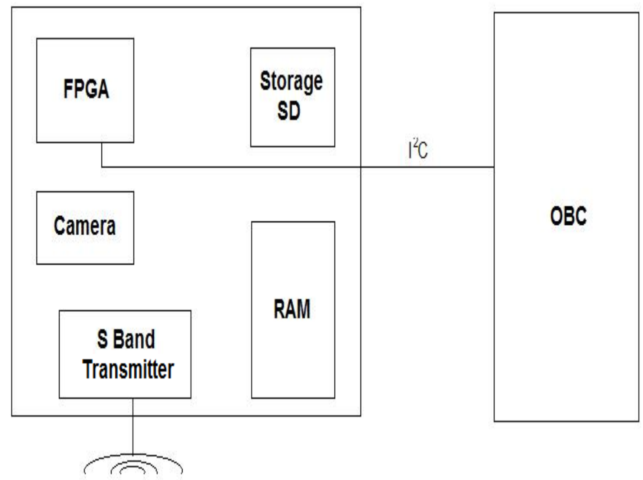

Figure 2: CPUT 1U CubeSat (ZACUBE-01) Camera block diagram

The image is captured by the camera, buffered in the RAM, and then stored in the Storage Secure Digital (SSD). When communication between the CubeSat and the ground station occurs, the OBC sends instructions to the Field Programmable Gate Arrays (FPGA) through the I^2C cable, the FPGA then alerts the S Band transmitter for image downlink. With the 0.3 megapixels camera on-board the 1U CubeSat (ZACUBE-01), images taken will be easily transmitted to the ground station without the need of filtering and compression.

2.1.2. CPUT 3U CubeSat (ZACUBE-02)

The CPUT 3U CubeSat (ZACUBE-02) is depicted in Figure 3(Adapted from F'SATI, 2011). It has a 5 megapixels camera on-board that will be used to capture images of Earth. Images captured by this camera will be at high resolution and can't be entirely transmitted to the ground station in one pass of the satellite over the ground station.

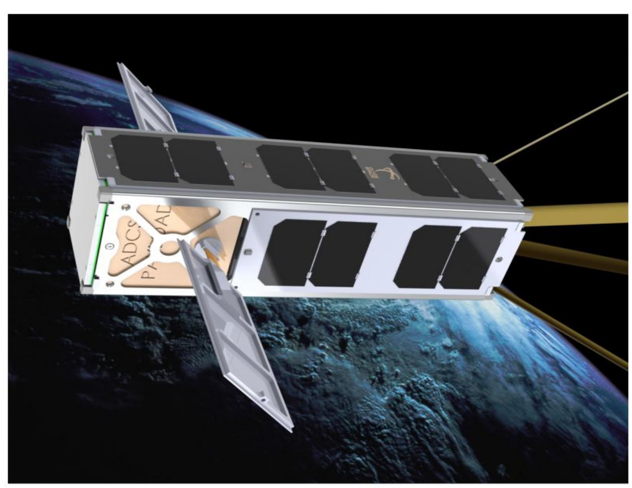

Figure 3: CPUT 3U CubeSat (ZACUBE-02)

2.2. CPUT Ground Station

CPUT has its own ground station used to track satellites utilizing amateur radio frequencies. When the CPUT 3U CubeSat passes through the horizon, the filtered and compressed images on-board will be received at the ground station. The CPUT ground station is illustrated in Figure 4.

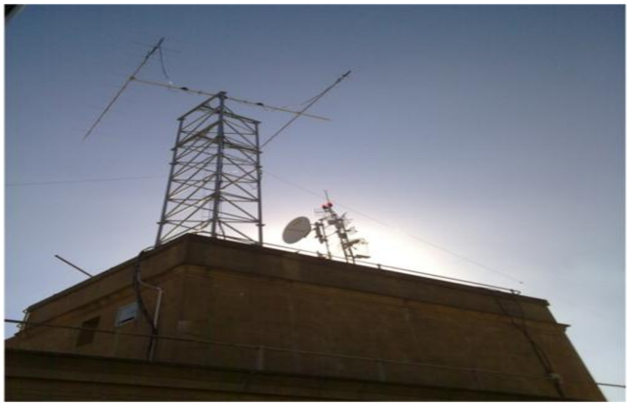

Figure 4: CPUT Ground station

2.3. Image processing

In this research project, the still images captured by the camera on-board the 3U CubeSat (ZACUBE-02) will be used as an input signal to the chosen hardware. The input image will be filtered and compressed on the chosen hardware resulting in an output signal. The output image will then be stored temporary while waiting for the CubeSat to communicate with the ground station. This process is then referred to as image processing [9].

2.3.1. Image filtering

Image filtering is a technique used to classify whether the compressed image will be lossy or lossless. Image filtering is very important for image processing in the sense that it ensures the filtering technique to be implemented according to the CubeSat (ZACUBE-02) mission requirements. Image filtering is classified as:

- 9/7 wavelet filter: irreversible wavelets transform; this technique is used for lossy compression.
- 5/3 wavelet filter: reversible wavelets transform; this technique is used for lossless compression.

The 5/3 wavelet filtering technique will dictate the image filtering to be implemented on-board the 3U CubeSat (ZACUBE-02) according to its mission requirements

2.3.2. Image compression

Image compression is vital for image processing especially when the storage memory and the transmission bandwidth are limited. Image compression may be lossy or lossless. According to one of the 3U CubeSat (ZACUBE-02) mission requirements, images of the Earth captured have to be identical after being compressed, therefore the image compressed will be lossless. Image compression on-board the 3U CubeSat (ZACUBE-02) will be implemented using JPEG2000 lossless algorithm standard. This choice is made according to the 3U CubeSat's (ZACUBE-02) constraints (image quality, storage memory, bandwidth and power).

3. PROBLEM STATEMENT

Most CubeSats employ a high resolution camera on-board and it is inevitable that the images captured by the camera are larger than what can be sent to the ground station in a single pass over the ground station. The CPUT 3U CubeSat (ZACUBE-02) will host a 5 megapixels camera resolution and the on-board storage memory will be unable to store images captured at these resolutions. The purpose of ZACUBE-02 is to capture images of the Earth and relay these images to the ground station with the limited resources at hand. The focus of this research lies within the choice of the appropriate hardware that will be used to test the filtering and compression algorithm, the implementation of the hardware, the implementation of JPEG2000, and a detailed study on how to increase the compression ration without affecting the image quality as well as a suitable design and implementation.

4. RESEARCH OBJECTIVES

The main objective of this study is to design and propose an optimized filtering and compression system of Images for an Earth Observation Satellite. In order to reach this objective a number of sub-objectives are identified:

- Study the available compression standards and adequately choose a standard suitable for the CubeSat environment.
- Study methods on how to improve the compression ratio of the JPEG2000 lossless standard.
- Identify hardware specifications and choosing appropriate hardware for Digital Signal Processing (DSP).
- Implementation and testing of identified hardware components.
- Implementation of compression standards**.**
- Detailed study to optimize the compression ratio without affecting the image quality.
- Design and proposal of optimized compression method.
- Implementation and evaluation of proposed design.

5. SOLUTION APPROACH

5.1. Hardware

The image filtering and compression algorithm on-board the 3U CubeSat (ZACUBE-02) requires an industrial hardware that meets the vibration test requirements and the CubeSat's constraints such as low power consumption, low cost, small dimensions (less than 10cm), suitable temperature range for LEO.

The solution approach consists to:

1. Compare different hardware and choose one according to the 3U CubeSat (ZACUBE-02) constraints as illustrated in Table 1.

From Table 1, GUMSTIX is the best suitable hardware for the CubeSat regarding the CubeSat's constraints. The GUMSTIX hardware for image filtering and compression will be interfaced with the camera board module. GUMSTIX hardware has many modules such as Gumstix Overo Air COM, Gumstix Overo Earth COM, Gumstix Overo FE COM, Gumstix Overo Fire COM, Gumstix Overo Tide COM and Gumstix Overo Water

Table 1: Hardware features

		Hardware			
		TILERA	GUMSTIX	TRITON	CONGATEC
Features	Power	15 – 22W @ 700MHz all cores active	Less than 1W	Less than 1W	5 W @ 5V
	Price	$435 for each Tile64	$ 229.00	£455.00	$ 1088.00
	Dimensions	482.6 x482.6 mm²	17mm x 58mm x 4.2mm	67.6 x 36.6 x 7.3 mm	70x70mm²
	Temperatures	0-70°C Commercial	Built with components rated -40°C < T < 85°C	-40°C to 85°C	Operating: 0°C to 60°C Storage: -20°C to 80°C

COM [10]. Gumstix Overo Water has a DSP chip, therefore will be used for implementation and is illustrated in Figure 5 [10].

2. Implement the chosen hardware using C programming language.
3. Implement JPEG2000.
4. Study how to increase the compression ratio without affecting the image quality.

The high resolutions image captured by ZACUBE-02 will be filtered and compressed on-board using the Gumstix hardware to overcome the limited storage memory. Figure 6 illustrates the block diagram of the CPUT 3U CubeSat (ZACUBE-02) image processing.

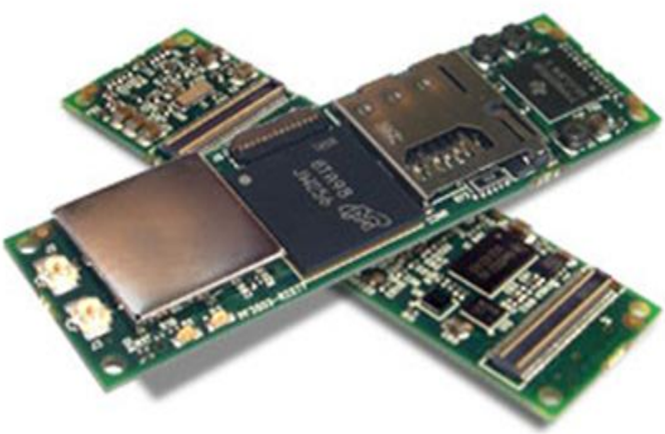

Figure 5: Gumstix hardware

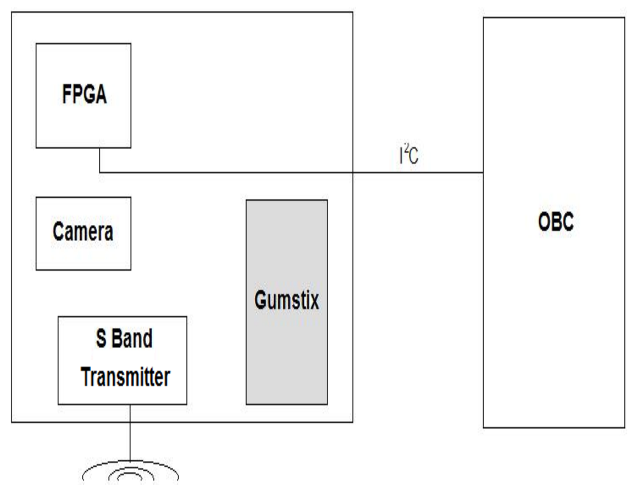

Figure 6: CPUT 3U CubeSat (ZACUBE-02) image processing block diagram

The image of the Earth is captured by the 5 megapixels (high resolution) camera; the image is buffered, filtered, compressed and stored by the Gumstix hardware while waiting for communication between the ground station and the CubeSat. When communication occurs, the OBC will instruct the FPGA via the I^2C cable then the FPGA will alert the S Band transmitter for image downlink.

5.2. Delineation

This research project will only focus on the CubeSat on-board image filtering and compression. The image captured by the camera will be buffered then filtered and compressed before being stored in the temporary memory. The OBC responsibility for image downlink will not be part of this research project.

6. SIGNIFICANCE OF RESEARCH

Image processing is best known as extracting information from a given image for analysis. The analysis of images has great scientific contribution in medical imaging, space exploration, Earth monitoring. Image filtering and compression are major image processing techniques that are often implemented. The 3U CubeSat (ZACUBE-02) will host a camera of 5 megapixels on-board and at these resolutions (high); the file sizes will be large such that the CubeSat can't transmit the image in one pass over the ground station. At high resolution, the file sizes will be a big challenge for the CubeSat therefore, the filtering and compression of images on-board is necessary.

7. CONCLUSION

Space related image processing is a crucial source of information about the space environment, our planet and other planets. Since the CubeSat has emerged, the image processing applications have increased significantly and have given real opportunity for the understanding of the space environment and the planets. This research project consists to design and propose an optimized filtering and compression system of images for an Earth Observation Satellite using the theory of JPEG 2000 image compression standard. The future idea will be to develop a genuine filtering and compression algorithm for an earth observation satellite.

8. ACKNOWLEDGMENTS

Our thanks to the French South African Institute of Technology (F'SATI) organization who has given us the privilege and the funding to be part of the space related activities in the world.

9. REFERENCES

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