**“Justification of the use of CCSDS 122.0-B-2 Compression Standard in Space Missions over other Compression Methods through the assessment of Image Quality”**

CS39440 Major Project

Author: Charlie Curtis ([chc73@aber.ac.uk](mailto:chc73@aber.ac.uk))

Supervisor:

3rd March 2022

Version 1.0 (Draft)

This report is submitted as partial fulfilment of a BSc degree in

Computer Science (G400)

Department of Computer Science

Aberystwyth University

Aberystwyth

Ceredigion

SY23 3DB

Wales, UK

Declaration of originality

I confirm that:

* This submission is my own work, except where clearly indicated.
* I understand that there are severe penalties for Unacceptable Academic Practice, which can lead to loss of marks or even the withholding of a degree.
* I have read the regulations on Unacceptable Academic Practice from the University’s Academic Registry (AR) and the relevant sections of the current Student Handbook of the Department of Computer Science.
* In submitting this work, I understand and agree to abide by the University’s regulations governing these issues.

Name …………………………………………

Date ……………………………………………

Consent to share this work

By including my name below, I hereby agree to this project's report and technical work being made available to other students and academic staff of the Aberystwyth Computer Science Department.

Name …………………………………………

Date ……………………………………………

Acknowledgements

I am grateful to…

I’d like to thank…

Abstract

Include an abstract for your project. This should be approximately 300 words.

The abstract is an overview of the work you have done. Highlight the purpose of the work and the key outcomes of the work.

Contents

Table of Contents

[2 Background, Analysis & Process 1](#_Toc101519139)

[2.1 Background 1](#_Toc101519140)

[2.2 Analysis 1](#_Toc101519141)

[2.3 Process 2](#_Toc101519142)

[3 Use of Algorithms 3](#_Toc101519143)

[3.1 Bit Plane Encoder (BPE) 3](#_Toc101519144)

[3.2 JPEG 2000 (J2K) 3](#_Toc101519145)

[3.3 Mean Squared Error (MSE) 3](#_Toc101519146)

[4 References 4](#_Toc101519147)

# **Background, Analysis & Process**

## **Background**

The European Space Agency (ESA) will soon launch the second part of their ExoMars mission. Rosalind Franklin is the rover that shall travel to the surface of Mars with the goal of attempting to establish if there is or ever has been life on Mars.

One of the rovers many instruments is PanCam, a camera system tasked with capturing how the planet looks and preparing these images to be sent back to Earth. Part of this preparation is the compression of the images to reduce their storage space and allow for a more streamlined and hopefully less error prone transfer back to Earth. The ESA has chosen to use the CCSDS 122.0-B-2 compression standard, the purpose of this report is to establish a justification for this, and reasons why other compression methods such as JPEG 2000 (J2K) are not used. This is done through the encoding of sample images taken from the Aberystwyth University PanCam Emulator (AUPE), through both compression algorithms, after which the results are compared against each other.

A sensible approach to begin seemed to be to conduct some preliminary research into image compression. This included not only image compression algorithms used in a variety of disciplines including medicine, graphic design, and military applications, but also, the theory behind image compression, i.e., lossy versus lossless compression, techniques used in image compression, including - but not limited to; quantization, discrete cosine transform (DCT), fractal compression – and performance comparisons of some compression algorithms.

The goal of this was to try and establish what sort of numerical operations these algorithms were performing, and through this, trying to build an understanding of how the quality assessment algorithms - that would be used as part of the overall analysis of the compression algorithms - might begin to calculate numerical quality in a general sense. This was very useful for understanding metrics such as Mean Square Error (MSE), Root Mean Square Error (RMSE), and Peak Signal to Noise Ratio (PSNR).

During this preliminary research, a grouping system of image quality assessment (IQA) methods was identified. Methods are grouped into Full Reference (FR), Reduced Reference (RR), and No Reference (NR) IQA methods. They refer to if a ‘perfect’ quality - original image is used as a reference as part of the algorithm to compare to the compressed version. For this project, FR seemed the most appropriate since there *are* original images to be accessed and so if the more comprehensive algorithms can be exercised as part of testing of PanCam and as part of this project, the greater assurance we can have as to our understanding of the level of compression and quality of the images being sent back by Rosalind Franklin.

One motivation for this project was having the opportunity to produce something that could potentially have real world implications towards the operational effectiveness of the European Space Agencies (ESA) Rosalind Franklin rover. Moreover, developing a tailored script (written in Python) that’s sole purpose is to facilitate the gathering, processing, and analysis of the numerical aspects of IQA algorithms.

## **Analysis**

The projects focus is on IQA algorithms. To that end, regardless of the direction of the project, these algorithms would have to play a significant role in any conclusions or findings. This led to the belief that a comparative study was the best approach, since the result that objective IQA algorithms provide are numerical values, for the quality of images. This leaves great scope for statistical analysis.

With this in mind, the logical progression was to compare the already selected compression algorithm with another - that was not selected to be a part of PanCam - to try and establish the reasons that the aforementioned algorithm was chosen over the other. This led to the construction of the overall research question for this project:

**Given the quality of compressed images, what reasons are there for the use of the CCSDS 122.0-B-2 compression standard on PanCam, and why are other image compression algorithms not used in the context of interplanetary communication?**

This in turn lead to more specific questions regarding the technicalities of the project and its process, such as; Which IQA algorithms would be best suited to a project of this nature? What sort of analysis and statistical metrics should be applied to any collected data? What would be the best method to approach this question?

The chosen research question also has the advantage of leaving the door open for further research or variations of this project, for instance, delving further into the question of which IQA algorithms are most suitable as metrics for assessing image quality in the context of space mission or conducting the same or similar research with other possibly more advanced image compression algorithms other than J2K.

## **Process**

This project is a comparison using objective measures. Mathematical processes conducted by the computer and then interpreted by the user. Due to this fact, the data collected was always going to Quantitative data. A positivism-based [1] research project, collecting primary data for processing and to develop conclusions from.

An inductive process, aiming to answer the overall research question first proposed at the beginning of the project. [2] Given that the compression algorithm has already been decided upon for the rover, and that trying to produce a conclusive set of results would be beyond the scope of this project, the project took an approach indicative of an exploratory project, trying to establish the reasons for the selection of compression algorithm.

These are very blanket terms that best describe a process that was dynamic and constantly changing based on complications encountered at various stages and the capricious availability of pre-existing libraries and/or implementations of IQA algorithms.

Additionally, regarding the production of a technical submission. The project was research focused and so, a technical submission was not going to be of the same nature or standard of complexity as the likes of a project involving the development of some bespoke software, because of this, following an Agile Development approach was challenging. Nonetheless, a SCRUM approach was loosely adopted and maintained over the lifecycle of the project, with a ‘sprint’ being a weeklong process, and the planning for said sprint being conducted at the end of the previous sprint.

Finally, in the forthcoming sections the report will address the following subjects to aid in building an understanding of the process, and algorithms involved.

In the next section, a discussion of the algorithms used for both the compression of the images, as well as those used for the assessment of image quality, to establish how they work, and therefore why these particular algorithms have been chosen for the process. Upon conclusion of this discussion a description of the method that was adopted, not only for the collection of the data the project relies upon, but also a description of the process for the analysis of this data that is necessary for the development of a based, well-founded conclusion. This will be followed by the presentation of the results and then a discussion of these results, what they mean, and what can be learnt from them. The report is to be finalised, with a critical analysis of the process and administration surrounding the project as a whole - from beginning - to end.

# **Use of Algorithms**

This section will explore the various algorithms that are used as part of this project including algorithms for both the compression of sample images; namely the CCSDS standard and JPEG 2000, as well as those used in the image quality assessment process – Mean Squared Error, Peak Signal to Noise Ratio, and the Structural Similarity Index. The compression algorithms are as follows:

## **Bit Plane Encoder (BPE)**

BPE is a command line implementation of the CCSDS 122.0-B-1 algorithm. The algorithm is based on wavelet transform and bit plane scanning. [3]

Bit plane encoding operations involve the conversion of image pixel values into their binary form, and then slicing. The process by which the binary values are separated by the most a least significant bits and then different bit planes constructed. Subsequently, the original image is reconstructed using the greatest value planes. This creates an image that has been lossy compressed using a significantly reduced amount of data as the refinement bits in the lower value planes are removed. [4] One of the main factors for this is use of binary representation of pixel values, because with current hardware standards this is particularly convenient. [5]

Wavelet transform is an adaptation of the Fourier Transform, that considers a wavelet of frequency, in this case, pixel intensity. The function operates in a localised region of the image known as a ‘window’ and based on the pixel intensity and window function (function used to select the area of the image for encoding) essentially quantizes the pixel values. [6][7]

On PanCam – this CCSDS algorithm is used by default at a ratio of 1, which achieves an x8 compression, and for quick look images at a ratio of 0.1; x80 compression.

## **JPEG 2000 (J2K)**

J2K is a compound compression algorithm curated from a series of image compression procedures and similarly, is based on wavelet transforms. [8] J2K is an accessible, scalable, and popular compression algorithm which is why it was selected as part of this project. Moreover, when trying to discern reasons for CCSDS 122.0-B-1, comparing it to a relatively more standard compression algorithm seemed like a good step, as it helps to develop a picture of the magnitude of difference between an inter-disciplinary ‘basic’ method, and a bespoke solution for the demanding environment that is space and missions in space.

For this project – OpenJPEG was employed. [9] This is again, a command line implementation, alike to BPE, with parameters to change the compression ratio up to x9000 compression.

Given the parameters for compression outlined by the team behind PanCam, for this project. OpenJPEG was used with compression rates of x8 and x80, this is to bring it in line with what is to be used on Rosalind Franklin, and so produce an analysis and discussion/conclusions that are valid.

## **Mean Squared Error (MSE)**

Mean Squared Error is the first of three Image Quality Assessment metrics that were used in this project. MSE measures the difference between a predicted set of data, and an actual, measured set. It is the second moment of error [10]. In this scenario, the predicted is the original ‘perfect’ quality image, and the actual is the compressed version, this makes MSE a full reference objective method. MSE is defined by:

Where is the original image, and

the distorted image.

MSE has a clear physical meaning and can be applied in multiple ways to linear algebra, this makes it one the most used metrics in image quality assessment [11].

Because it is a measure of error, values closer to 0 mean a greater quality, and thus, less information loss during compression.

## **Peak Signal to Noise Ratio (PSNR)**

Peak Signal to Noise Ratio is the ratio between the maximum possible signal value (pixel value) and the power of distorting noise where the signal is the perfect reference image, and the noise the error yielded by compression [10].

PSNR can be defined by:

Where is the maximum possible signal value; In the case of an 8-bit (unsigned) image this would be . The sample images however used in this project are all 16-bit, and as such .

## **Structural Similarity Index (SSIM)**

SSIM is a perception-based method [10]. The only of the three IQA algorithms to be based on the Human Visual System (HVS). Algorithms that replicate the HVS consider different aspects of the image rather than the image as a whole, aspects such as brightness, contrast, and texture [12].

SSIM specifically – considers luminance, contrast, and structure [10][11]. SSIM can be defined as [13]:

Where:

is the average of

is the average of

is the variance of

is the variance of

Where:

is pixel range (for 16-bit this is 65535)

= 0.01 and = 0.03 (these are default values)

This overall equation may be further broken down into component formulas for luminance, contrast, and structure. SSIM operates by assessing an area of each.

# **References**

1. Clark, A.M. (1998), The qualitative-quantitative debate: moving from positivism and confrontation to post-positivism and reconciliation. Journal of Advanced Nursing, 27: 1242-1249. <https://doi.org/10.1046/j.1365-2648.1998.00651.x>
2. Business Research Methodologies <https://research-methodology.net/research-methods/> - accessed 20/04/2022
3. Bit plane encoder

<http://hyperspectral.unl.edu/> - accessed 22/04/2022

1. Bit-Plane Slicing

<https://theailearner.com/2019/01/25/bit-plane-slicing/> - accessed 22/04/2022

1. F. Auli-Llinas and M. W. Marcellin, "Scanning Order Strategies for Bit plane Image Coding," in IEEE Transactions on Image Processing, vol. 21, no. 4, pp. 1920-1933, April 2012,doi:10.1109/TIP.2011.2176953.
2. Description of the process of wavelet transforms - <https://www.youtube.com/watch?v=kuuUaqAjeoA> – accessed 22/04/202
3. A Tutorial of the Wavelet Transform – Chun-Lin, Liu; 2010 <https://www.researchgate.net/profile/Vladimir-Kulchitsky/post/Is-there-any-difference-in-the-tiling-of-the-time-frequency-plane-by-the-orthogonal-and-biorthogonal-wavelet-basis-functions/attachment/59d629c179197b807798844a/AS%3A337039875690496%401457367976408/download/WaveletTutorial.pdf> - accessed 22/04/2022
4. JPEG2000 compression - <https://jpeg.org/jpeg2000/> - accessed 22/04/2022
5. OpenJPEG GitHub repository- [https://github.com/uclouvain/openjpeg/tree/v2.4.0](https://github.com/uclouvain/openjpeg/tree/v2.4.0 - accessed 22/04/2022) - accessed 22/04/2022
6. Umme Sara, Morium Akter, Mohammed Shorif Uddin, “Image Quality Assessment through FSIM, SSIM, MSE and PSNR—A Comparative Study” (2019) **DOI:** [10.4236/jcc.2019.73002](https://doi.org/10.4236/jcc.2019.73002)
7. Zhou Wang, Alan C. Bovik, “Modern Image Quality Assessment Synthesis Lectures on Image, Video, and Multimedia Processing” - (2006), Morgan & Claypool <https://doi.org/10.2200/S00010ED1V01Y200508IVM003>
8. Yusra A. Y. Al-Najjar, Dr. Der Chen Soong “Comparison of Image Quality Assessment: PSNR, HVS, SSIM, UIQI” International Journal of Scientific & Engineering Research, Volume 3, Issue 8, August-2012 1  
   ISSN 2229-5518 https://www.ijser.org/researchpaper/Comparison-of-Image-Quality-Assessment-PSNR-HVS-SSIM-UIQI.pdf
9. Wang, Z.; Simoncelli, E.P.; Bovik, A.C. (2003-11-01). Multiscale structural similarity for image quality assessment. Conference Record of the Thirty-Seventh Asilomar Conference on Signals, Systems and Computers, 2004. Vol. 2. pp. 1398–1402 Vol.2. [doi](https://en.wikipedia.org/wiki/Doi_(identifier)):[10.1109/ACSSC.2003.1292216](https://doi.org/10.1109%2FACSSC.2003.1292216). [ISBN](https://en.wikipedia.org/wiki/ISBN_(identifier)) [978-0-7803-8104-9](https://en.wikipedia.org/wiki/Special:BookSources/978-0-7803-8104-9).