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Quality measures for an optimized JPEG2000-like EUI compression

EUI Onboard Compression System

Samuel Gissot, E. Pylyser, J.-F. Hochedez,
Royal Observatory of Belgium, Circular 3, B-1180 Brussels, Belgium.

F.-O. Devaux, P. Correa, G. Rouvroy,
intoPIX s.a., Place de l'Université, 16b Louvain-la-Neuve, 1348, Belgium.

B. Inhester,
Max-Planck-Institut für Sonnensystemforschung, D-37191 Katlenburg-Lindau, Germany.

T. Kennedy,
Mullard Space Science Laboratory, University College London, Dorking, Surrey, RH5 6NT, UK.

F. Auchère.
Institut d'Astrophysique Spatiale, Université Paris-Sud, 91405 Orsay, France.

ABSTRACT

In future solar missions such as Solar Orbiter, telemetry limitations when confronted with scientific requirements impose to use efficient and high-quality data compression methods. In particular, the EUI instrument onboard Solar Orbiter consists of high resolution imagers (HRI) and one full Sun imager (FSI) that will monitor the chromosphere and low corona counterparts of large-scale solar eruptive events such as coronal mass ejections (CMEs) and will provide a crucial understanding of fine scale processes in the solar atmosphere.

The impact of the image compression system on the scientific interpretation of the data must be carefully assessed. This is of fundamental importance for the science objectives of EUI. In this poster, we present the constraint on the compression algorithm given the context of the Solar Orbiter mission. We then present the **JPEG2000 algorithm** to be optimized for EUI. Finally, we focus on the definition of a compression quality. Such study is essential to optimize a JPEG2000-like algorithm and its parameters. One important objective is to define a quality measure sensitive to the degradation of directional objects such as coronal loops.

EUI Onboard Compression System

The EUI instrument, shown in Figure 1, is composed of three channels. The baseline EUI instrument consists of 2 High Resolution Imagers (HRI) and 1 Full Sun Imager (FSI), each with its detector, and associated electronics (two High Resolution Imagers (HRI): one Lyman-α and one dual-EUV, and one Full Sun Imager (FSI), dual-EUV.). Figure 1 shows the compression FPGA located in the common electronics box and that will provide the compressed FSI and HRI imagers to the CPU. The onboard autonomy algorithms will be run by the CPU on the images produced by the compression FPGA.

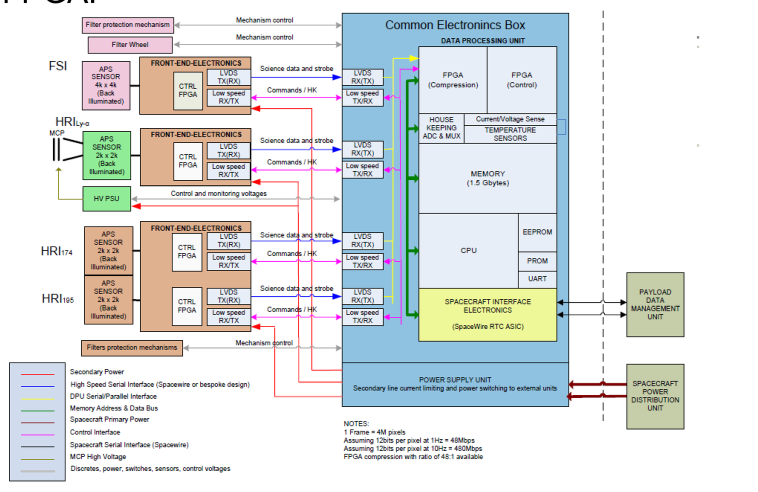


Figure 1 – EUI channels and electronic box configuration and Onboard system description

Title	Science Objective	Channel	Field of view	Exposure (sec)	Cadence (sec)	Compression	Total TM (Gbit)
S	Synoptic	FSI_{174} FSI_{304}	4 x 4 Rsun window centered on disc centre	10 1	600	50	0.1
	Reference Synoptic	FSI_{174} FSI_{304}	4 x 4 Rsun window centered on disc centre	10 1	1day	2.5	0.02
C	CH	HRI_{195} HRI_{174} $HRI_{Ly\alpha}$	Full FOV centered on CH with its boundary and/or plumes	180 60 1	180 60 30	15	0.3
Q	QS	HRI_{195} HRI_{174} $HRI_{Ly\alpha}$	Full FOV centered on QS	30 15 1	30 15 1	15	13.3
A	AR	HRI_{195} HRI_{174} $HRI_{Ly\alpha}$	Full FOV centered on AR	2 2 1	2 2 1	30	12.1
E	Eruptive event	HRI_{195} HRI_{174} $HRI_{Ly\alpha}$	Full FOV centered on event	0.2 0.2 0.2	0.2 0.2 0.2	30	90.6
G	Global eruptive event (e.g. an EIT wave)	FSI_{174} or FSI_{304}	Full FOV centered on event	10	10	30	0.6

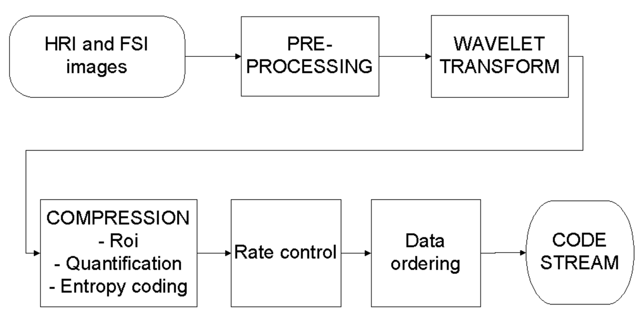
Figure 2 – Science observation programs.

Constraints on compression

The 4k x 4k sensor for FSI (low cadence and the2k x 2k sensors for HRIs (x3) at max. 10 HZ cadence, at a pixel depth of12 bits generate a data flow of 480 Mbps. The HRI, with 80 km px size at perihelion aims to study the fine structure and dynamical processes in the solar transition region (TR) and corona. The pixel size of existing instruments are EIT: 1800 km, TRACE: 350 km , and VAULT: 120 km. The main constraints to the compression system are the low telemetry link (mean telemetry 20 kb/s), associated to an assumed onboard storage capacity of 259 Gb per orbit. This imposes high compression ratios (up to 50), as foreseen in the science observation programs (see Figure 2). In addition to the compression of the images, given the limited data bandpass, an automatic filtering of the images may be necessary. The compression FPGA could contribute to the prioritization of the images by providing descriptors of the images such as thumbnail image and statistical moments. The scientific constraints that the compression algorithm must respect include preservation of coronal loops, and high performance on low-photon signals. To achieve this, it is crucial to define the best possible quality criterion of image quality; it has to be sensitive to the degradation of the coronal loops as well as to the elongated features in Ly-alpha images (prominences and cold loops). The algorithm must also be efficient on low-photon signal (and low signal-to-noise ratio)

The Compression Algorithm

Preprocessing:
✓ Recoding: the 12 bit images are recoded in 8-bit pixel depth using a square function mapping as in [4]: it simultaneously denoises Poisson intensity signal.
✓The JPEG2000 decorrelation used for color conversion can be used to remove cosmic ray hits, and possibly bad/hot pixels between images from two different detectors.



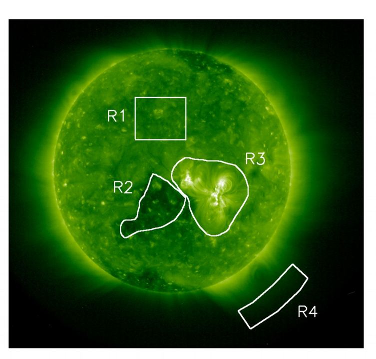
The algorithm proposed for the EUI compression system here is based on the standard JPEG2000, a now mature standard for still image compression and intra-frame encoding. The JPEG2000 algorithm has been chosen for its ability to outperform, at a lower level of implementation complexity, the existing lossy encoders (JPEG, MPEG video encoders, proprietary standards such as ICER). The compression algorithm has to provide compressed image of sufficient quality in the context of low-photon imaging since one expects to observe low-photon images in the HRI channels. A careful control of the image quality can be achieved using the rate control module that is part of the JPEG2000 standard.

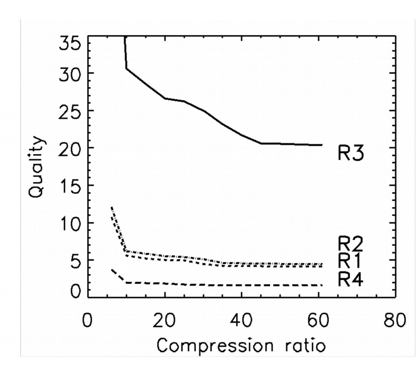
The main features of the JPEG2000 algorithm are:

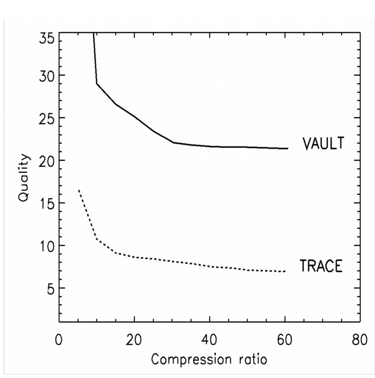
1.Lossy and lossless compression: this is accomplished by the compression module. The parameters of the compression module will be adapted to the properties of the HRI and FSI images,
2.Scalability (progressive transmission by quality, resolution, component, or spatial locality)
3.possibility of ROI specific compression rates by prioritizing an image area,
4.Region of interest coding by progression,
5.Low complexity in encoding compared to inter-frame video coding schemes,
6.Low compression time, *i.e.* the time of processing one frame is less than the minimal expected time between two frames,
7.Production of low resolution thumbnail images.

Outputs:
✓Image thumbnails are produced by the low-pass filters during wavelet transform as low-images
✓Basic processing such as statistical moments computed on wavelet coefficients subbands.

First test on EUVI Image







In our first tests, Q is defined as the SNR of the distorted image. It is a normalized criterion that can be used to compare the effect of compression from region to region, and for various compression rates. Up to a compression ratio of 40, the quality of high variance regions (Active Region R3) appears to depend linearly on the compression ratio. Beyond this value of 40, the loss of quality due to compression is at the moment difficult to link to physics investigations.

$$SNR^2(x,y) = \frac{\mathrm{var}(I_O)}{MSE}$$

Quality Metrics of Compression

In order to measure the level of quality of compression of an image, the most used metrics is the mean squared error (MSE) which measures the intensity difference of compressed and original image. A derivative of the MSE is the peak signal-to-noise ratio (PSNR). They are simple to calculate and are mathematically convenient in the context of optimization, but the tests on EUV images (see EUVI example) are not satisfying. The classical approach is to adapt the MSE measure to specific applications is to use visual estimation of the quality by human observers: the errors are then penalized depending on subjective quality. Here we propose to use a measure of structural similarity (***SSIM***) that compares local patterns of pixel intensities that have been normalized for intensity and contrast as proposed by Wang et al [1-3]. The SSIM quality metrics defines the level of distortion as a combination of the mean intensity distortion, the loss of correlation, and the contrast distortion. The component ***c*** measures the correlation coefficient between compressed and uncompressed data, and is equal to 1 (best value) if they are linearly related. The other relative distortion effects are measured by the comparison between mean intensity (***l***), which is equal to 1 if the local means are equal, while the quantity ***s*** measures the similarity between the local contrasts. We here give the mathematical definitions of the SSIM quality metrics.

SSIM (Structural Similarity Index)

$$SSIM(x,y) = \underbrace{l(x,y)^{\alpha}}_{\text{Luminance similarity}} . \underbrace{c(x,y)^{\beta}}_{\text{Contrast similarity}} . \underbrace{s(x,y)^{\gamma}}_{\text{Structural similarity}} . \underbrace{g(x,y)^{\delta}}_{\text{Directional Similarity ??}}$$

$$Q(x,y) = \mathrm{median}(SSIM)$$

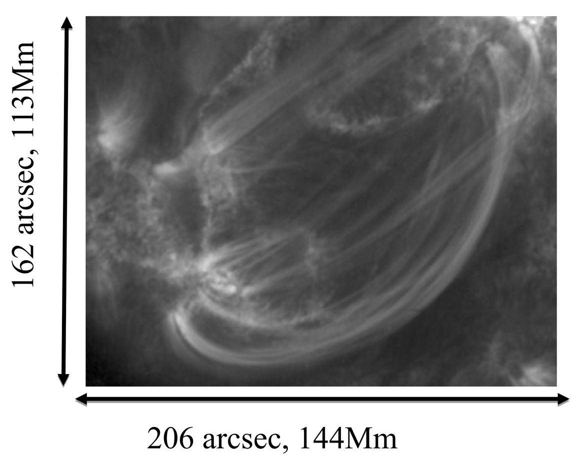
(Over full image)

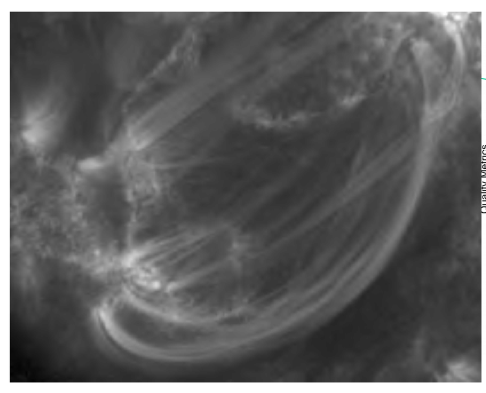
$$l(x,y) = \frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1}$$

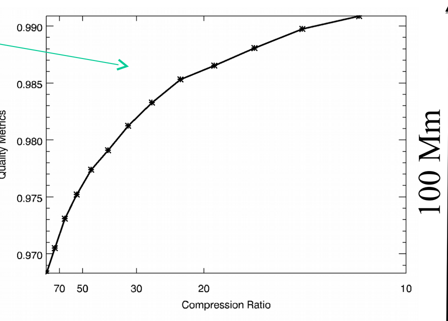
$$c(x,y) = \frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2}$$

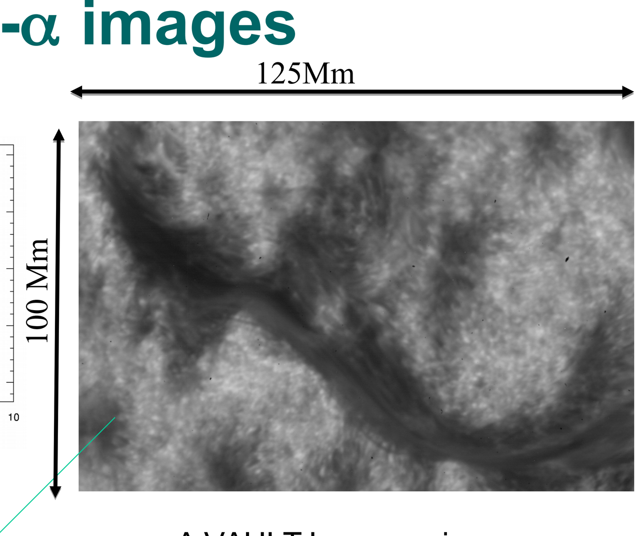
$$s(x,y) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3}$$

Results on *TRACE* 17.1 nnm and VAULT Lyman-α images





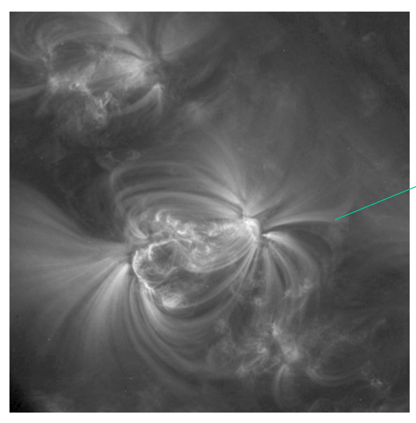


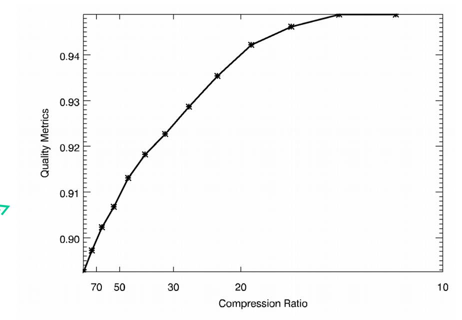


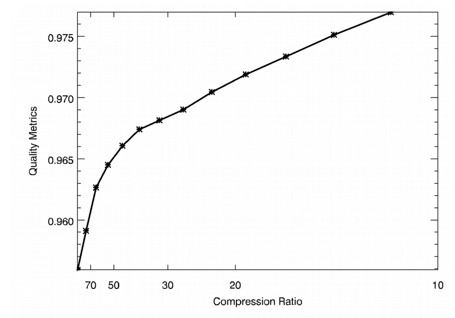
Compressed image: CR=53

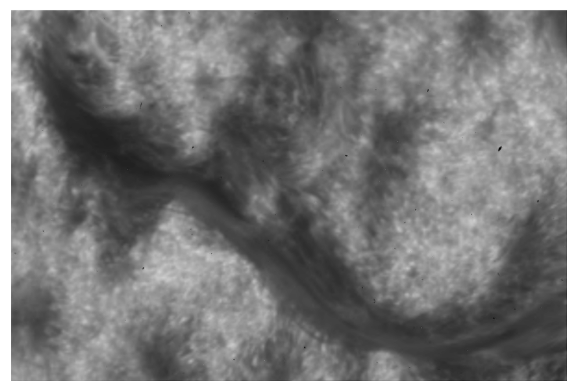
TRACE image, 12/04/2000

A VAULT Lyman-α image





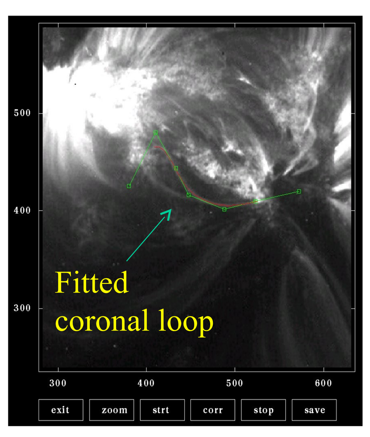


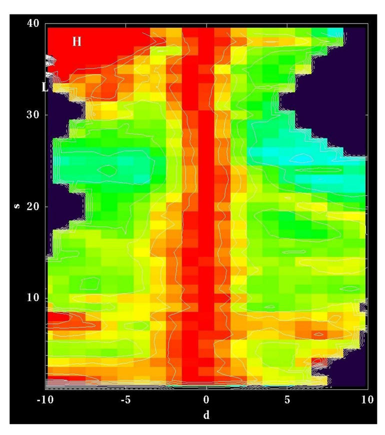


The line represents the SSIM quality metrics. Depending on the type of image, The local SSIM quantity is estimated on neighboorhoods of 7x7 pixels.

Compressed image: CR=53

Loop distortion measures





A coronal loop is fitted using B-spline. The profiles of the loop of the compressed and uncompressed images are compared in a graph representing the intensity of the pixels in the loop neighbourhood, as a function of the normal distance of the pixel to the fitted spline and the arc length along the spline; their discrepancy between both the compressed and uncompressed loop structure is evaluated using normalized variance. This could be used as a possible definition of the g component of the SSIM.

Conclusions

➢**Combined with recoding, JPEG2000 seems to offer promising results of high-quality compression.**
➢**The quality metrics will be used to optimize the JPEG2000-like algorithm that will be tested during the EOCS project.**
➢ **In JPEG2000, the rate control is the process by which the code-stream is coded so that a target bit rate can be reached. The rate-control module adjusts the coding precision of each small group of pixels (the code-blocks). The strategy of truncation of the code blocks is to minimize the distortion while reaching the target bit-rate : for that, it is possible to define a quality metrics more efficient than the MSE.**
➢**The SSIM seems to be a reliable quality metrics in order to asses the efficiency of the compression algorithm. We will adapt it to the particularities of the EUV images of the solar atmosphere, e.g. by taking into account the distortion of directionality. We hope it could help us to adapt JPEG2000 to EUV images of the solar atmosphere.**

References

[1] Wang, Z. & Bovik, A.
A Universal Image Quality Index
Signal Processing Letters, IEEE
[2] Wang, Z.; Bovik, A. C.; Sheikh, H. R. & Simoncelli, E. P.
Image quality assessment: from error visibility to structural similarity
Image Processing, IEEE Transactions on
[3] Wang, Z.; Simoncelli, E. P. & Bovik, A. C.
Multiscale structural similarity for image quality assessment
Conference Record of the Thirty-Seventh Asilomar Conference on Signals, Systems and Computers
[4] Nicula, B.; Berghmans, D. & Hochedez, J.-F. Poisson Recoding Of Solar Images For Enhanced Compression
Solar Physics , Vol. 228 , pp. 253-264 , 2005