IMPLEMENTATION OF DATA COMPRESSION S/W ON A SPACE QUALIFIED DSP BOARD

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ABSTRACT

Progress in digital imaging sensors such as high resolution CCDs allows space instruments to perform daily observations producing up to tens of gigabytes of data. In contrast with this technology boost, the increase of downlink capability remains insufficient. In the particular case of science missions with long spacecraft-ground distances, it is typically small (0.1 to 2 Mbps). The communication or data storage bottleneck is then a major factor limiting the coverage and/or resolution of science instruments. Considering the ratio between the data volume and the telemetry rate, on-board compression is mandatory.

Considering the high cost and the scarce nature of astronomy data, compression impacts have to be analysed. The work presented in this paper was to select a set of compression techniques compliant to astronomy mission objectives and to implement them on a flight representative DSP board taking into account its specific hardware architecture.

1. ON-BOARD COMPRESSION BASELINE

The requirements from an extensive set of missions have been compiled and can be summarised as:

- The data compression technique shall be generic and applicable to a large range of missions.
- Both lossless and lossy compression modes shall be provided in order to have an on-board system capable of adaptive response to user’s needs during the mission.

Since the space environment limits the usage of commercial component technology, we consider in this project a payload processing system based on a space qualified Digital Signal Processor, the “TSC21020F”. This led to a software compression module, which is embedded in the payload processing system software.

2. ON-BOARD COMPRESSION SPECIFICATION

The compression techniques for the intended space applications must take into account different types of requirements.

First at application level: the compression module should provide in case of the lossy option the following modes:

- The control of the output bit-rate to optimise, by a proper scaling, the usage of shared resources (storage capacity and telemetry bandwidth). Compression ratios ranging from 2 to 15 shall be considered.
- The minimisation of the error when memory resource limitation is less stringent.

Second at on-board system level: the algorithm computation time should be minimised.

3. COMPRESSION TECHNIQUE SELECTION

3.1. Candidate techniques

The JPEG algorithm has been used for on-board compression by pioneer missions. However, this technique has severe drawbacks for scientific data. Both frequency and blocking artefacts are added to the images. It is limited to pixels coded on 8 or 12 bits. Since its computation complexity is medium, it is used as a reference.

To enhance reconstructed image quality, various and numerous studies developed these recent years on data compression favoured the ones based
on Wavelet Transforms [5]. The complexity of these coders is roughly the same as that of the JPEG coder. Besides this, the interest for the Wavelet transform lies in its ability to decorrelate spatially the image information in different frequency subbands. The resulting multiresolution decomposition naturally leads to attractive possibilities like:

- Quick view of the original image at low resolution for browsing
- Progressive transmission

Wavelet-based image coders usually consist of 2 successive stages. The first one is based on the Wavelet Transform of the image. This transform can be computed through integer or floating-point Wavelet filter banks. The second one is the effective coding part. The variety of these coders resides in this part of the algorithm. This coding part can be categorised in two approaches:

1. The first approach quantizes and codes the different subbands separately from each other. Each subband quantizer is a midtreat uniform quantizer. The different quantizer step sizes are computed accordingly to a bit-allocation algorithm. The subband bit-allocation resource is a function of the subband average energy and the total compression ratio. Higher compression ratio is achieved by entropy encoding the quantized subbands. We developed an encoder based on this approach. This coder is called Wavelet Independent Subbands Encoder (WISE). Its bit-allocation scheme was published by Strange in [5] and the entropy coder is provided by Witten et al [6].

2. The second approach takes advantage of the dependencies still left among subbands with the same orientation. Shapiro has developed its initial version called Embedded ZeroTree (EZT) coder [1]. This technique induces sequels. Indeed, requiring 2 different symbols (IZ and ZT) for coding zero coefficients it leads to a suboptimal use of the bit budget.

The SPIHT [2], the ESTES [3] and the OZONE [4] encoders are refined versions of the EZT technique. The OZONE encoder based on an EZT scheme and integer coefficient Wavelet filter was tailored to fit an ASIC implementation. This coder is more suitable for high throughput rate and it is considered here for the sake of comparison. Constituting the core of Wavelet-based coders, the selected coders for evaluation are the SPIHT encoder, the ESTES encoder, the OZONE encoder, and the WISE encoder.

3.2. Compression techniques selection

To evaluate the encoding techniques described in section 3.1, we first developed a MATLAB toolbox simulating all the encoding algorithms presented in the previous section. This tool is called Wavecodec1.1. Figure 1 presents its graphical front panel. It realises a compression/decompression procedure with various options based on key parameters such as:

- Type of Wavelet filter bank
- Number of decomposition levels
- Coding schemes based on the previously selected encoders
- Compression ratio

It outputs for visual inspection the following information:

- Visual aspect of reconstructed images
- Classical metrics based on the Mean Square Error such as SNR and PSNR
- Mapping of the error
- Detection of real and faint objects
- Bit-error transmission effect on the reconstructed image

Reference astronomy images have been provided by the CDS (Centre de Données astronomiques de Strasbourg) considering calibrated data for astrometry and photometry. WaveCodec1.1 generated compressed/uncompressed images, corresponding to ratios equal to 5, 10 and 15. This tool also provided all the classical compression error metrics. More application-oriented tests have been performed by the CDS, such as:

- astrometry tests providing the error in the position of the celestial objects due to compression
- photometry measurements comparing the magnitude and the logarithm of the integrated density of detected objects in the original images and the ones of the reconstructed images.

At this point, results have shown that the Ozone encoder is not suitable for astronomy images. This encoder uses filters with integer coefficients. The resulting filtering introduces frequency distortions.

Considering the three remaining encoders such as the ESTES, the SPIHT, and the WISE, a crucial result for on-board data compression for scientific missions is:

- Lossless compression with a ratio up to 5 is insured.
• Lossy compression with ratio up to 15 can be considered as quasi-lossless. At this rate, all useful information within the celestial objects is preserved.

In spite of being the best at application level, ESTES coder has been discarded considering its higher complexity.

Thus, the selected algorithms for implementation are the SPIHT and WISE ones.

### 4. ENCODER IMPLEMENTATION ON THE PAYLOAD PROCESSING BOARD

The payload processing board (Figure 2.) has a Program Memory Bank of 128 KWords (48 bits), a Data memory Bank of 128 KWords (40 bits), a control and boot support circuitry (8KB PROM). Two Scalable Multichannel Communication Sub-System devices with their associated dual port memories provide 6 high-speed links of 100 Mbps each.

The companion memory board has a capacity up to 8 MWords (32 bits) but needs wait state during access.

To improve performance, core algorithm functions have been coded in assembly language. The board specific number crunching architecture favours scalar product instructions. Thus, we privilege the use of these instructions specifically for the Wavelet transform function and the SPIHT and WISE coding functions. The compression procedure is a data processing task within Virtuoso, a real-time operating system optimised for the DSP board.

This payload processing system allows the compression of images with sizes ranging from 64×64 pixels to 2K×2K pixels. The pixel resolution is ranging from 8 to 24 bits for integer values and 32 bits for floating point values. For a 1K×1K pixels image size, compression throughput rate ranges between 200 and 400 Ksamples/s depending on the image contents.

### 5. CONCLUSION

Considering lossy compression, the rate control and the distortion control are mutually exclusive modes. Compression techniques are either rate or distortion control oriented. The programmed solution we propose is based on the choice between the SPIHT encoder function and the WISE encoder function in the S/W compression module. This flexible solution fulfils the on-board compression specification presented in section 2.

For the SPIHT coder, the bitstream can be truncated to any desired rate. Thus, the control of the output bit-rate is possible. However, this algorithm is highly susceptible to transmission errors. A single bit error could potentially lead to decoder derailment. In the worst case, if the bit error occurs in the beginning of the bitstream, this leads to uncontrolled degradation of the image quality.

The WISE coder is more robust against error transmission. Since the arithmetic coder provides a certain degree of error protection [6], a bit error will affect only some coefficients in one subband. The WISE also offers a better distortion control through the bit-allocation algorithm. However, this coder does not control precisely the output bit-rate. A control loop control between the resulting bitstream length and the bit-allocation refinement can be used to confine the bit-budget.

This work provided a fruitful experience in the design and the evaluation of on-board compression for scientific missions. The related results have shown that on-board compression with ratio ranging from 2 to 15 are viable and feasible for space-based applications today. Scientific Payload processing systems can be designed to include on-board compression based on Wavelet coders without changing the significance of the final image product.

### REFERENCES


Figure 1: Wavecodec 1.1

Figure 2: Payload Processing System