Comparative Analysis of Image Compression Algorithms for Deep Space Communications Systems

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Abstract. In deep communications systems bandwidth availability, storage and computational capacity play a crucial role and represent precious, as well as limited, communications resources. Starting from this consideration, high efficient image compression coding algorithms may represent a key solution to optimize the resources employment. In this paper two possible approaches have been considered: JPEG2000 and CCSDS Image Compression, which is specifically designed for satellite and deep space communications. In more details, two coders have been compared in terms of performance: *JasPer*, which is an implementation of the JPEG2000 standards, and the BPE, which is based on the CCSDS recommendations. The proposed comparison takes into account both the quality of the compressed images, by evaluating the Peak Signal to Noise Ratio, and the time needed to compress the images: the Compression Time. The latter parameters, which concerns the computational complexity of the compression algorithm, is very interesting for deep space systems because of their limited computational and energy resources.

Keywords: Deep Space Communications Systems, Image Compression, JPEG2000, CCSDS Compression, PSNR, Compression Time.

1 Introduction

In deep communications system bandwidth availability, storage and computational capacity play a crucial role and represent precious, as well as limited, communications resources. Starting from this consideration, high efficient image compression coding algorithms may represent a key solution to optimize the resources employment.

JPEG2000 is a wavelet-based image compression standard and coding system. It was created by the Joint Photographic Experts Group committee in the year 2000 with the intention of superseding their original discrete cosine transform-based JPEG standard. On the other hand, The Consultative Committee for Space Data Systems (CCSDS) data compression working group has adopted a recommendation for image data compression that proposes an algorithm based on a two dimensional discrete wavelet transform of the image, followed by progressive bit-plane coding of the transformed data. The algorithm can provide both lossless and lossy compression, and allows a user to directly control the compressed data volume or the fidelity with which the wavelet-transformed data can be reconstructed. CCSDS approach represents a low computational load compression

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and, as a consequence is suitable for both frame-based image data and scan-based sensor data, and has applications for near-earth and deep-space missions.

In this work, both JPEG2000 and CCSDS algorithms have been taken into account and compared in terms of performance. In more detail, two main performance parameters have been considered: Peak Signal to Noise Ratio (PSNR) and Compression Time.

The former (PSNR) is a measure used to evaluate the quality of a compressed image with respect the original. This quality index is defined as the ratio of the maximum power of a signal and the power of noise that can invalidate the fidelity of his compressed version. PSNR is usually expressed in terms of the logarithmic scale of decibels. It is worth noting that in this context the noise concept comes from the amount of information that is lost during the compression with respect the original image. PSNR is often used as an indicator of perceptual quality: higher PSNR often results for compressed image more pleasing to the human eye.

The latter parameter, the Compression Time, is the time needed by an algorithm to compress an image starting from the original one.

In general the simplicity, fastness, and small storage necessities of an algorithm make it easy to be realized in hardware and suitable for space borne application. With respect to JPEG2000, CCSDS approach is aimed at reducing the computational load of the compression algorithm by maintaining the overall quality of the compressed images.

Nevertheless, the proposed comparison shows that the performance are strictly dependent on the practical implementation of the algorithm and, in particular, it is shown that among the employed coders the JPEG2000 one have lower Compression Time with respect to CCSDS based coder.

The remainder of this paper is structured as follows. Section 2 shortly focuses on the considered Image Compression Approaches (JPEG2000 and CCSDS) and their possible implementation (*JasPer* and BPE coders). Section 3 illustrates the considered terms of the proposed performance comparison (PSNR and Compression Time). Performance comparison of the described approaches is presented in Section 4, whereas final remarks and conclusions are drawn in Section 5.

2 Image Compression Approaches: JPEG2000 and CCSDS

2.1 JPEG2000

JPEG2000 [1] is the well known new image compression standard for web and distribution on PDAs, phones, PCs, televisions, etc. It represents the evolution of the famous JPEG format and, even if equipped with highly innovative features, JPEG2000 is not intended, at least in the short term, to replace JPEG, but rather is expected a transition during which the new standard will integrate and expand the features offered by JPEG.

In summary, the salient features of JPEG 2000 are:

- □ It is a unique coding system that can deal effectively with images from different sources, with different needs compression.

- Allows both lossy compression (lossy), is that no loss compression (lossless).
- It produces images with better visual quality, especially at low bit-rate compared to those achievable with JPEG, thanks to the properties of the wavelet transform.
- Allows you to change and, possibly, to decode any image regions, working directly on data in compressed form.
- It can create scalable compressed images in terms of resolution both in the level of detail, leaving the implementer the freedom to choose how much information and what parts of the image can be used for decompression.
- Introduces the concept of *Region of Interest* (ROI) of an image.

Indeed, one of the novelties introduced in JPEG2000 is the opportunity to emphasize the importance of certain regions of the image, favoring the encoding of coefficients belonging to these areas. The use of ROI is particularly suitable for the encoding of images in which some parts are more important than their surroundings.

Moreover JPEG2000 can achieve high compression rates by maintaining acceptable image quality and there is the possibility of including, in a file that contains an image coded with JPEG2000, information on intellectual property and copyrights.

2.1.1 JPEG2000 Considered Implementation: JasPer

There are several distributions that allow to create JPEG2000 encoding, certainly the most important are the implementation *Kakadu* (downloadable from the web site http://www.kakadusoftware.com/) and the *JasPer* Project (download http://www.ece.uvic.ca/~mdadams/jasper/), which is interesting for its peculiarity of being open source and can therefore exploit all the functionality of JPEG2000. *Kakadu* needs instead of purchasing.

JasPer [2] is a software-based implementation of the codec specified in the JPEG2000 standard. The development of this software had two motivations: firstly, the implementers wanted to develop a JPEG2000 implementation using the standard as only reference. Secondly, by conducting interoperability testing with other JPEG2000 implementations, implementers might find ambiguities in the text of the standards, allowing them to be corrected.

In more detail, the design of the *JasPer* software was driven by several key concerns: fast execution speed, efficient memory usage, robustness, portability, modularity, maintainability, and extensibility. Since fixed-point operations are typically faster than their floating-point counterparts on most platforms, and some platforms lack hardware support for floating-point operations altogether, *JasPer* implementers elected to use only fixed-point operations in their software to match the objectives of high portability and fast execution speed.

The *JasPer* software is written in the C programming language. This language was chosen mainly due to the availability of C development environments for most of computing platforms.

The *JasPer* software consists of about 20,000 lines of code in total. This code is spread across several libraries. There are two executable programs, the first is the encoder, and the second is the decoder. The *JasPer* software can, moreover, handle image data in a number of popular formats (e.g., PGM/PPM, Windows BMP, and Sun Raster file).

2.2 CCSDS

The Consultative Committee for Space Data Systems (CCSDS) data compression working group has adopted a recommendation for image data compression. The algorithm adopted in the recommendation consists of a two-dimensional discrete wavelet transform of the image, followed by progressive bit-plane coding of the transformed data [4]. The algorithm can provide both lossless and lossy compression, and allows a user to directly control the compressed data volume or the fidelity with which the wavelet-transformed data can be reconstructed. The algorithm is suitable for both frame-based image data and scan-based sensor data, and has applications for near-Earth and deep-space missions. The standard is moreover accompanied by free software sources as briefly described in the sub-section below.

2.2.1 CCSDS Considered Implementation: BPE

Concerning the implementations of the CCSDS standard, there are only two: one developed by the University of Nebraska, "BPE" (http://hyperspectral.unl.edu) and one by the Universitat Autonoma de Barcelona, the "B Software" (http://www.gici.uab.cat/TER/). In this paper the first distribution, built in C + +, has been employed. Actually the TER, written in JAVA, has been used, but as a converter of raw images to pgm.

3 Terms of Comparison: PSNR and Compression Time

3.1 Peak Signal to Noise Ratio

Peak Signal-to-Noise Ratio (PSNR) is a measure used to evaluate the quality of a compressed image from the original [5]. This quality index is defined as the ratio of the maximum power of a signal and the power of noise that can invalidate the fidelity of its compressed representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic scale of decibels as will be done in the presented comparison.

It is worth noting that the noise is not related to the typical channel noise (e.g., thermal noise) or with the attenuation due to the distance between source and destination, or by other disturbs (e.g., electrical storm burst). The noise considered concerns, in the framework of this paper, the amount of information that is lost during the operation of lossy compression with respect to the original image.

PSNR is often used as an indicator of perceptual quality in the sense that a higher PSNR often results in a compressed image more pleasing to the human eye. Nevertheless, this measure must be analyzed with caution because it happens that compressed images with values of PSNR lower than others are more similar to the original one.

Independently of that consideration, it is possible to consider PSNR a fully reliable indicator in all cases in which it is used to compare results obtained from the same coder (or similar coders) [6].

From the analytical viewpoint, it is possible to define the PSNR from another well known estimator: the Mean Square Error (MSE) as reported in [6, 7]. It expresses the difference between the MSE of observed data and the values of estimated figures. Denoting by I the original image and the compressed image with K, both of dimension $m \times n$, the following quantity is defined as MSE between the two images:

$$MSE = \sum_{0}^{m-1} \sum_{0}^{n-1} \left\| I(i,j) - K(i,j) \right\|^2 \tag{1}$$

It represents the standard norm between correspondent pixels of the original image and compressed one. If the MSE is equal to 0 would mean that there is no difference between the two images.

Starting from equation (1), it is possible to compute the PSNR as follows:

$$PSNR = 20 \log_{10} \left(\frac{MAX\{I\}}{\sqrt{MSE}} \right) \tag{2}$$

Typically, 0.25 dB are considered a significant improvement of the image compression method, valuable from the viewpoint of human perception.

3.2 Compression Time

Another important aspect that has been taken into consideration in the evaluation of the compression algorithms is the compression time because, nevertheless the careful studies in the literature, some expected results may fails when the implementation aspects are taken into account. In more details, methods such as the CCSDS, studied to have low computational loads, may be unready to be employed due to their row implementation that need to be further developed.

In this paper, the standard JPEG2000 is assumed as reference from the performance viewpoint. It is however worth noting that JPEG2000 is valid for several environments and it is very complex and, for this reason, expensive from the computational viewpoint.

Therefore, as also described in previous section, it was born an image compression algorithm developed by the CCSDS studied to create a standard that focuses exclusively on the transmission of image through satellite and deep space transmission devices where the problem of energy consumption and, as a consequence, of computation load (and therefore of the compression time) becomes critical.

As will be shown later, however, the envisaged increased compression speed of the CCSDS approach, at the moment, does not exist, and indeed the JPEG2000 algorithm in many cases is faster.

4 Performance Comparison

4.1 Reference Scenario

Most of the tests were carried out using an image test taken directly from the site of CCSDS (http://cwe.ccsds.org/sls/docs/sls-dc/). That image (b3.raw) has a resolution of 1024 * 1024 pixels, and is encoded with 8 bits/pixel.

Below are reported several figures that analyze the performance of two approaches: JPEG2000 (*JasPer* coder) and CCSDS (BPE coder). The two considered approaches are absolutely identical in the processing of the original data in the Discrete Wavelength Transform domain but they differ in the coding of the transformed data. Firstly, coded images with the algorithm CCSDS will be examined. They have been processed with DWT 9/7 floating point and with four different rates (bit per pixel): 0.25 bpp, 0.5 bpp, 1 bpp and 2 bpp. Also different sizes of code blocks (8, 16, 32, 64) entering in to the coder itself have been tested. Analogously, the JPEG2000 algorithm, with the same processor, same rate and same size of code blocks has been evaluated.

As regards the calculation of PSNR, it should be noted that the *JasPer* open source package available is an executable that takes as input two images, in pgm format, and allows calculating various statistics, such as MSE and PSNR.

Differently, it is more complicated to determine the PSNR in the case of CCSDS algorithm, since that is not available a library that helps to calculate the statistics of the image. In this case, an ad-hoc algorithm to calculate precisely the PSNR has been developed. This program was written in Matlab, takes two input raw images and computes the MSE, thus giving the value of PSNR. Obviously the employed images are those before and after encoding CCSDS.

Concerning the compression time, the comparison has been performed in the following way: the *time* command has been exploited. In practice, the time spent in the execution of the compression from the first to the last line of code has been computed. Obviously that computation is influenced the type of hardware configuration and the processes running on your computer when launching the executable. For this reason the tests performed were made from the same machine on the same day, and with the same hardware configuration. Moreover, for each test, there have been seven measures. The result suggested in the graphs is the result of an arithmetic average on these measures.

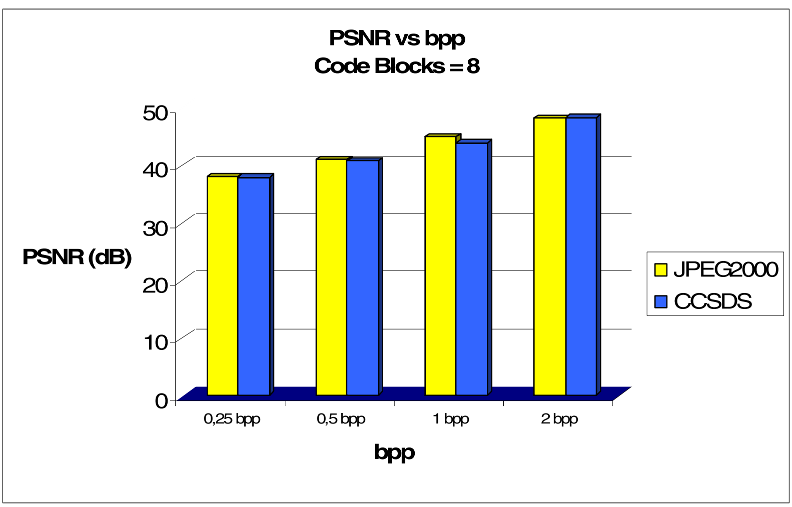

Fig. 1. PSNR vs. bpp (Code Blocks = 8)

4.2 PSNR Comparison

In the following figures, the PSNR obtained by employing the described image compression algorithms has been reported in the several situations, in terms of bpp and Code Blocks, mentioned above.

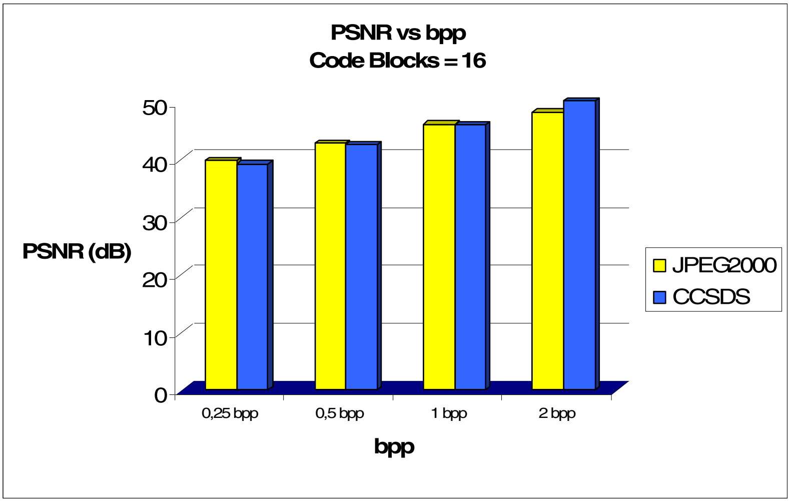

Fig. 2. PSNR vs. bpp (Code Blocks = 16)

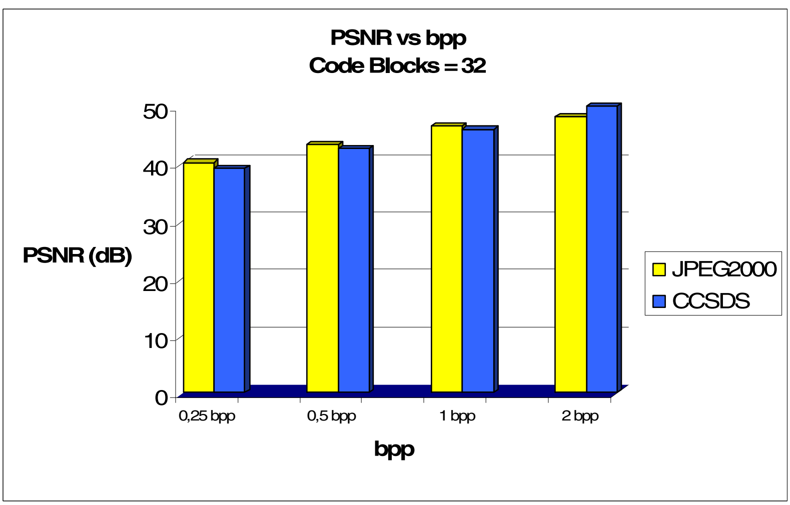

Fig. 3. PSNR vs. bpp (Code Blocks = 32)

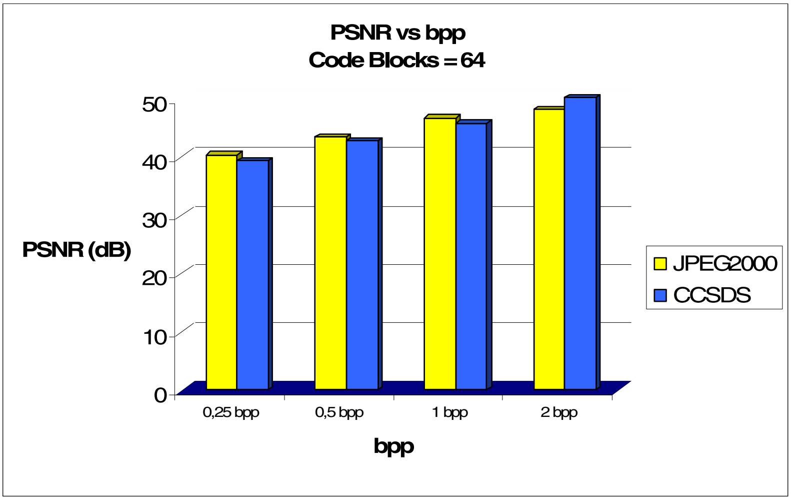

Fig. 4. PSNR vs. bpp (Code Blocks = 64)

The analysis shows that the variation of the size of code blocks does not affect particularly the value of PSNR significantly. It remains fairly constant, except for cases where the code blocks have size equal to 8 (please note that size 8 means equal to 8 * 8, then a total of 64 blocks input to the coder) that is lower that about 2 dB.

Concerning the rate, as expected, increasing the compression, and thus reducing the rate, the quality decreases more significantly. It also indicates how the choice of encoding blocks of size 8 is always the worst from the performance point of view.

The JPEG2000 has a gain of at least 1 dB compared to the CCSDS in all scenarios, except for case in which the image is compressed with 2 bpp. In such cases, in fact, the CCSDS performs better, and this improvement increases with the size of the blocks. In the case of "high quality", where the test image has been encoded at 2 bpp with Code Blocks = 64, the difference is estimated at 2.34 dB.

In general, from the test performed in this paper the superior quality of JPEG2000 has been observed.

4.3 Compression Time Comparison

In the following figures, the Compression Time obtained by employing the described image compression algorithms has been reported in the several situations also considered previously, in terms of bpp and Code Blocks.

These graphs are very interesting. The Figures, from 4 to 8, show that the compression time of JPEG200 decreases significantly with the increasing of the size of the blocks. As a consequence, in addition to increasing the quality, it also increases the efficiency. Differently, for the algorithm CCSDS, the block size does not have any impact on the compression time.

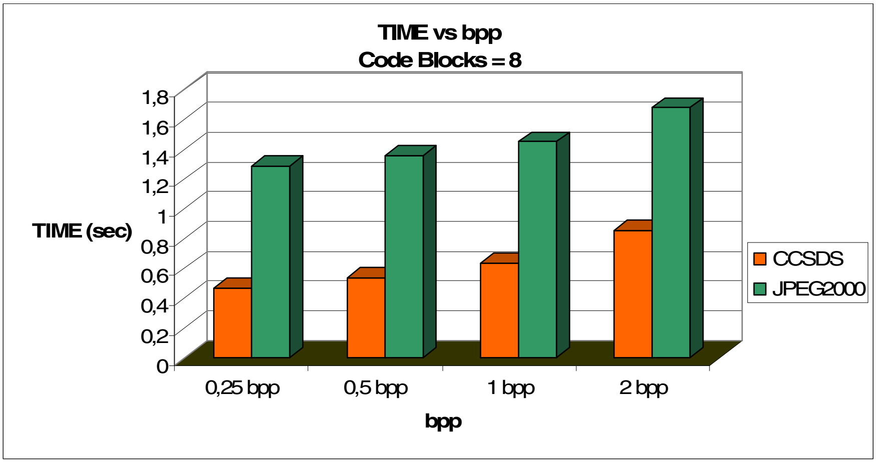

Fig. 5. Time vs. bpp (Code Blocks = 8)

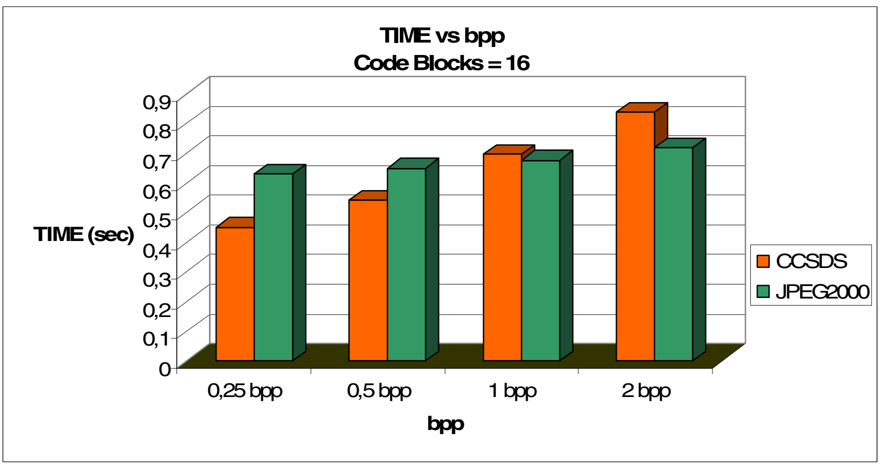

Fig. 6. Time vs. bpp (Code Blocks = 16)

Except for the case of Figure 5, in which the CCSDS behaves much better than the JPEG2000 (the compression time equal to half of the reference standard), it is possible to observe the compression times are similar. Moreover, it is possible to observe a different trend compared to what was expected when the block size is equal to 32 and 64: in such cases, the JPEG2000 algorithm is more efficient than the CCSDS.

This result was originally unexpected at the time of the analysis, since the CCSDS was designed, by its express declaration, with the intent to be more efficient than JPEG2000.

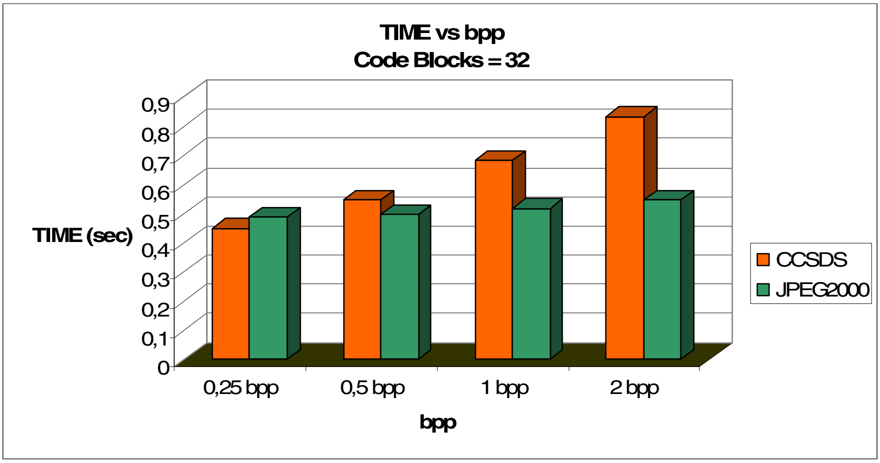

Fig. 7. Time vs. bpp (Code Blocks = 32)

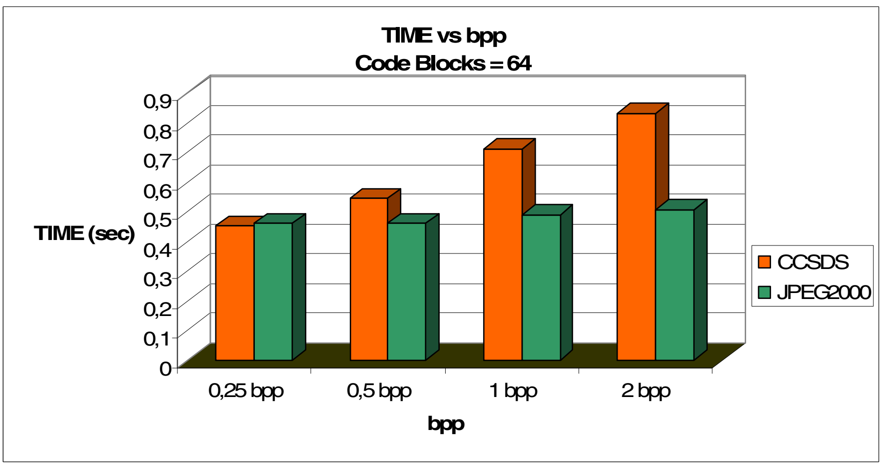

Fig. 8. Time vs. bpp (Code Blocks = 64)

The key point is the considered implementation: the problem that affect the CCSDS' compression time does not concern the algorithm, but its implementation. In fact, the *JasPer* software has been optimized over time while the CCSDS coder is still under development.

5 Conclusions

This work focused on the comparison between two possible image compression approaches. The first algorithm, briefly described and evaluated, is based on the

JPEG2000 standard. The second algorithm is based on the CCSDS recommendation for image compression for satellite and deep space communication systems.

Nevertheless the nature of the latter algorithm, though to be simple and to have a limited computational complexity, the current implementation of it, the BPE coder considered in this paper, has good PSNR performance but does not guarantee a really reduced image compression time. On the other hand, the JPEG2000 coders, in particular the JasPer, being optimized guarantees good PSNR performance and also better compression time with respects the CCSDS coder.

In practice, from the results reported in this work, the CCSDS image compression coders need to be further enhanced before their practical employment in satellite and deep space transmission systems.

References

1. Taubman, D.S., Marcellin, M.W.: JPEG 2000: Image Compression Fundamentals, Standards and Practice. Kluwer International Series in Engineering and Computer Science (2000)
2. Adams, M.D., Kossentini, F.: JasPer: A Software-Based JPEG-2000 Codec Implementation. In: Proc. IEEE International Conference on Image Processing, Vancouver, BC, Canada, October 2000, vol. 2, pp. 53–56 (2000)
3. International Standard ISO/IEC 15444-1, JPEG2000 Core Coding System (December 2000)
4. Yeh, P., Armbruster, P., Kiely, A., Masschelein, B., Moury, G., Schaefer, C., Thiebaut, C.: The New CCSDS Image Compression Recommendation. In: Proc. IEEE Aerospace Conference, Big Sky, Montana, March 5-12 (2005)
5. Web site, `http://en.wikipedia.org/wiki/Peak_signal-to-noise_ratio`
6. Huynh-Thu, Q., Ghanbari, M.: Scope of validity of PSNR in image/video quality assessment. IEEE Electronics Letters 44(13), 800–801
7. Thomos, N., Boulgouris, N.V., Strintzis, M.G.: Optimized Transmission of JPEG2000 Streams Over Wireless Channels. IEEE Transactions on Image Processing 15(1), 54–67