Evaluation of a Progressive Lossless Compressor for the Transmission of Astronomical Images

M.F. López
Computer Architecture & Electronics Dpt.
University of Almería
04120 Almería, Spain
email: mflopez@ace.ual.es

V.G. Ruiz, J.J. Fernández, I. García
Computer Architecture & Electronics Dpt.
University of Almería
04120 Almería, Spain
email: vruiz@ual.es, inma@ace.ual.es

U. Thiele, R. Gredel
German-Spanish Astronomical Centre
Max Planck Institute for Astronomy
04004 Almería, Spain
email: thiele@caha.es, gredel@caha.es

ABSTRACT

In this work a lossless progressive image compression method called LPIC (Lossless Progressive Image Codec) is described and evaluated for the task of transmitting astronomical images. LPIC is based on a discrete wavelet transform and an efficient encoding method. The evaluation has been carried out by means of a set of figures of merit assessing the quality of the astronomical images which are reconstructed during its transmission. Results show that the quality of the images is very high since the very beginning of the transmission time. Therefore, LPIC is an excellent tool to allow the remote control of astronomical instruments without requiring channels with high bandwidth.

KEY WORDS

SPIHT, image transmission, DWT, astronomical application.

1 Introduction

Astronomical centres offer services for astronomical observation to researchers in astronomy. In most cases, astronomical instruments receive information and save it as images. The utilization of these services force the user to travel and stay at the astronomical centre. This situation involves considerable expenditure of money and time; and it can be avoided if the centre offers remote services in such a way that the user can make use of them at his/her place of work.

The Internet is a cheap and easily accessible media for remote control applications. The main problem of the Internet is that its capacity must be shared with a indeterminate number of users and, therefore, the bandwidth is quite variable. To partially solve this problem, image compression can be applied. The lossless compression ratio of astronomical images is rarely higher than 2:1. In this context, the progressive image coding of the images can be used to dramatically reduce the time necessary to obtain a good approximation of the original image. At the end of the process the image is received without loss of information.

A progressive image transmission technique allows the visualization of a full-sized image at any moment during the receiving time. This transmission method is more efficient than a non-progressive image transmission scheme, where every element of the transmitted data only contains information about a small piece of the image, and it is displayed by rows or by columns. Progressive image transmission is also a desirable feature because it provides the capability to interrupt a transmission when the quality of the image has reached an acceptable level or when the user decides that the received image is not interesting. Similarly, the user at the receiver site can make a decision based on a rough reproduction of the image and to interact with the remote device for obtaining a new image, or for recovering a higher quality (or even exact) replica of only a part of the image. This helps to save large amounts of bandwidth.

In this paper a Lossless Progressive Image Codec (LPIC) is proposed as the mechanism for speeding up image data transmissions, which facilitates the remote use of astronomical instruments [5, 4]. Its performance is calculated according to a set of figures of merit (FOMs) specifically designed to measure the quality of the reconstructed images at any time of the transmission process. Results show that LPIC is very efficient for the task of transmitting astronomical images.

This paper has been organized as follows: in Section 2 a description of LPIC is presented. In Section 3 the FOMs used for the evaluation are described and in Section 4 results are shown. It finishes with the conclusions of our work.

2 LPIC

Progressive image transmission systems are made up of two main blocks [3]. First, a transformation stage which plays an important role in decorrelating and compacting image data by using a spectral decomposition. Second, a progressive-fidelity encoding stage, which is applied to the transform coefficients to create a compact codestream in such a way that the image quality is gradually improved until a perfect reconstruction is obtained.

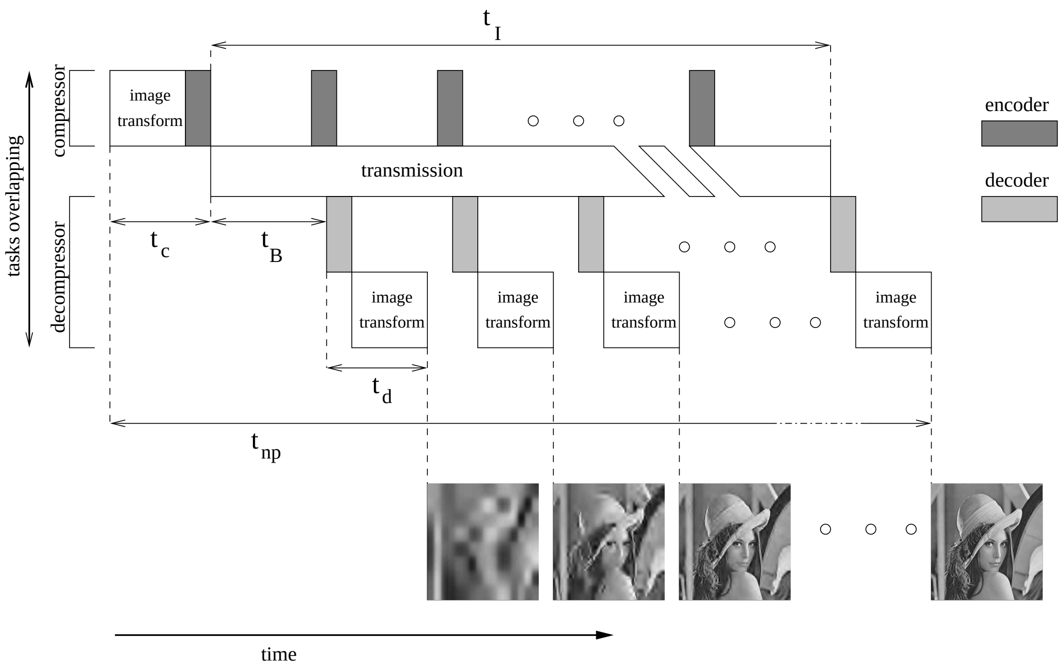

Figure 1. Progressive transmission of an image using LPIC.

Figure 1 is a time based model of the progressive image transmission process. In this model it was supposed that: (a) compression, decompression and visualization processes can be overlapped with image transmission; (b) the time spent to generate a code-stream of N bits is shorter than the time spent to transmit N bits. Note that the encoding/decoding processes are performed during the transmission.

A non-progressive image compressor would visualize the full-sized image only after $t_{np} = t_c + t_I + t_d$, where t_c is the compressor latency, t_I is the time for the full compressed image to reach the receiver, and t_d is the decompressor latency. On the other hand, in progressive image transmission a preliminary version of the full-sized image can be visualized at the receiver after $t_p = t_c + t_B + t_d$ seconds, where t_B is the time spent to transmit the sending buffer. An exact replica of the original image is visualized at the receiver after t_{np} seconds. However, during this time a sequence of $\frac{I}{B}$ full sized images is shown (I is the size of the compressed image and B the size of the buffer). The similarity of the images in that sequence with respect to the original image increases throughout the sequence. In practice, for real systems $t_c \simeq t_d << t_B = \frac{B}{I} \cdot t_I << t_I$ is met, but even slower compressors ($t_c \simeq t_d \simeq t_B$) would yield the same results because compression and decompression processes are overlapped with the data transmission procedure.

LPIC is a progressive image transmission system which relies on a specific discrete wavelet transform (13/7-T) and an efficient codec (SPIHT, which stands for Set Partitioning In Hierarchical Trees). Next subsections introduce these elements.

2.1 Discrete Wavelet Transforms

Transformation is a key stage in a wide spectrum of image compression techniques. Image transforming provides a spectral representation of the information of the image so that, in general, most of the information is contained in relatively few coefficients.

Wavelet transforms have recently arisen as a powerful mathematical tool in many image processing applications, and specifically in image compression [1]. One of the main distinctive features of the wavelet transform is its ability to provide a multiresolution spectral decomposition of the image in terms of a certain kernel function. This means that a wavelet decomposition allows us to build variable resolution reconstructions where the most important objects of the image can be represented with higher resolution.

LPIC uses the integer discrete wavelet transform known as the 13/7-T transform [2]. The 13/7-T transform of a discrete signal $s[k]$, with an even number of samples $k = 0, \ldots, N-1$ is defined as the pair of sequences [2]

$$\begin{aligned} h[n] &= s[2n+1] - \lfloor \tfrac{9}{16}(s[2n] + s[2n+2]) - \\ &\quad \tfrac{1}{16}(s[2n-2] + s[2n+4]) + \tfrac{1}{2} \rfloor \\ l[n] &= s[2n] + \lfloor \tfrac{9}{32}(h[n-1] + h[n]) - \\ &\quad \tfrac{1}{32}(h[n-2] + h[n+1]) + \tfrac{1}{2} \rfloor \\ &\text{with } n = 0, \ldots, N/2-1, \end{aligned} \tag{1}$$

where $\lfloor . \rfloor$ represents downward truncation. The inverse transform [2] restores the original data exactly.

The two dimensional (2D) transform is computed by applying the transformation (1) sequentially to the rows and columns of the image. As a consequence, the image is decomposed into quadrants, corresponding to four subsequent subbands. The wavelet multiresolution spectrum has the property of a spatial self-similarity among the coefficients at different levels and frequency subbands of the hierarchical decomposition.

2.2 Encoding and Transmission of the Coefficients. SPIHT

The underlying idea for progressive image transmission is to transmit the most important information first. The importance of a piece of information is usually evaluated in terms of a distortion measurement of the reconstructed image. In wavelet-based progressive image transmission, the information to be transmitted is the set of spectral coefficients provided by the wavelet transform. The mean-squared error (MSE) is typically used as the distortion measurement.

Transmitting the wavelet coefficients according to a decreasing order of magnitude yields the minimum MSE for the reconstructed image [7]. Nevertheless, the use of a bit-plane ordering transmission strategy has a similar behavior in terms of reconstruction distortion and only need to partially sort the coefficients. In this work, SPIHT (Set Partitioning In Hierarchical Trees) [6] has been used as the method for the compression and transmission of the wavelet coefficients. SPIHT is an efficient compression algorithm that takes advantage of the spatial self-similarity relationship that exists among the subbands in the wavelet space to efficiently compress and transmit them bit-plane by bit-plane.

3 FOMS

A figure of merit (FOM) is a measurement of the quality of a reconstructed image from a specific point of view; it allows us to compare the original image with the reconstructed one at the receiver in terms of an easily quantifiable similarity. The FOMs of our work are defined so that a perfect reconstruction yields a zero FOM value.

In this specific work, we intend to design and use FOMs that somehow reflect the efficiency of the image transmission method in reproducing the original image, with special emphasis in its astronomical objects. The FOMs are:

Source maximum FOM. The source (or object) maximum of an astronomical object is the pixel with highest value of the object. In astronomy the value of a pixel is called the number of counts (or counts) of a pixel. This FOM measures the relative difference between the counts of the source maximum in original and reconstructed images.

Object centroid FOM. The centre of an object can be calculated by the first-order 2-D mathematic moments. This FOM measures the error in pixels between the centre of the object in original and reconstructed images.

Full Width at Half Maximum FOM. The technical term Full-Width Half-Maximum, or FWHM, is used to describe a measurement of the width of an astronomical object. It can be calculated by the second-order 2-D mathematic moments. This FOM measures the relative error in pixels between the FWHM of the object in original and reconstructed images.

Sky estimation FOM. To properly work with astronomical images, it is necessary to know their sky background. The sky of an astronomical image can be calculated with the average of the counts of some pixels chosen appropriately. This FOM measures the relative error in counts between the estimated sky in original and reconstructed images.

Table 1. Astronomical images used to test LPIC and lossless compression ratios (lossless-bpp).

Image	bpp	cols×rows	lossless-bpp
TVG	16	764×574	8.62
STAR	16	764×574	8.62
B0100	16	1083×1024	4.84
WIDEFIELD	16	1148×1024	7.64
MOSCA	16	1501×1501	6.14
D0030	16	2172×2701	7.51
ESTRELLAS	32	1024×1024	14.06
GALAXIA	32	1024×1024	14.18
OCASS	32	1024×1024	10.35

4 Results

This section shows the performance of LPIC applied to a set of typical astronomical images kindly donated by the German-Spanish Astronomical Centre at Calar Alto (see Table 1). TVG and STAR are low quality images used to guide the telescopes. B0100, WIDEFIELD, MOSCA and D0030 belongs to the visible spectra while ESTRELLAS, GALAXIA and OCASS are infrared images. All the images were obtained using the telescope of 3.5 metres placed at the Calar Alto astronomical centre.

The quality of the images progressively produced by LPIC has been quantified using the FOMs proposed in Section 3, as well as its lossless compression performance (see Table 1). The evaluation has been performed using the approximated image that the receiver has at any time of the transmission. Figures 2, 3, 4 and 5 show the difference between this image and the original one displaying FOMs values as a function of the number of bits/pixel (bpp) received.

In the light of the results obtained we can assert that even at the very beginning of the transmission, errors are minimal and sometimes negligible. In most cases, the error in the computation of the centroid of the objects is lower than 0.2 pixels at 1.0 bpp. Therefore, we can conclude that the time necessary to find the exact location of the objects could be reduced by a factor of 16 or 32 times depending on the type of image (see Table 1).

The FWHM is a little more sensitive. In general we need to receive 3.0 bpp to reduce the relative error below 0.01 and 2.5 bpp to obtain a relative error lower than 0.1. This behavior is due to characteristics of the algorithm used to segment the astronomical object that provides the pixels to compute the FWHM.

The relative error in the measurement of the counts

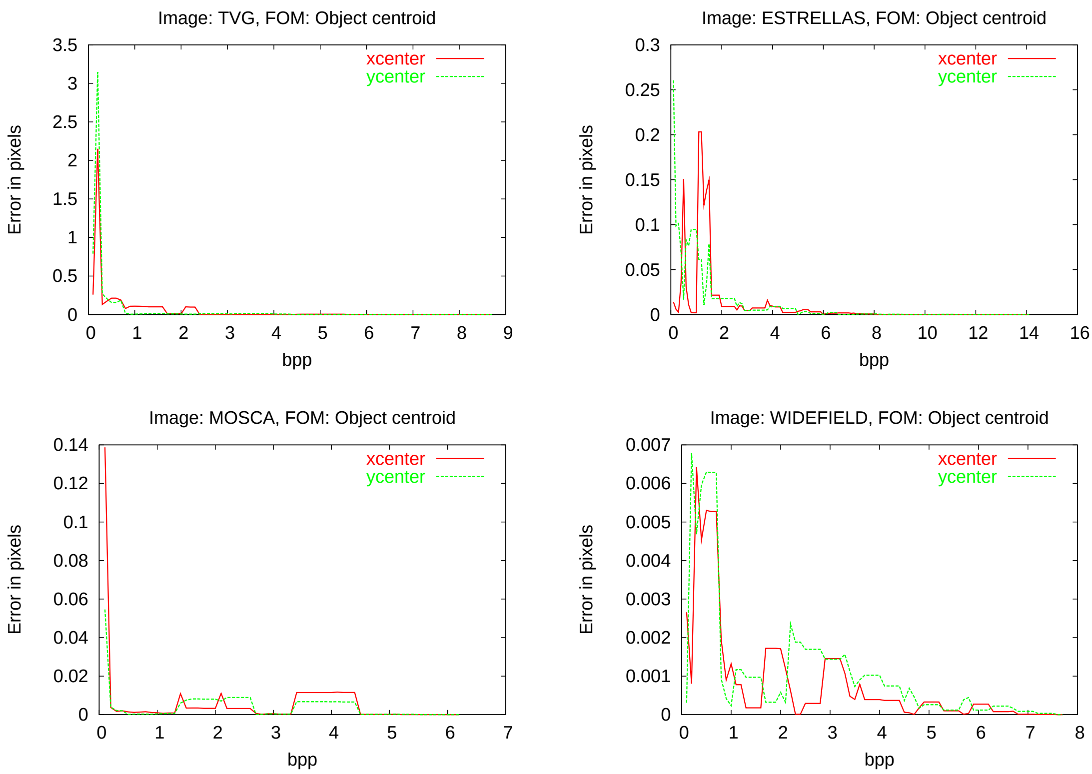

Figure 2. Centroid FOM for an object from the images TVG, ESTRELLAS, MOSCA and WIDEFIELD.

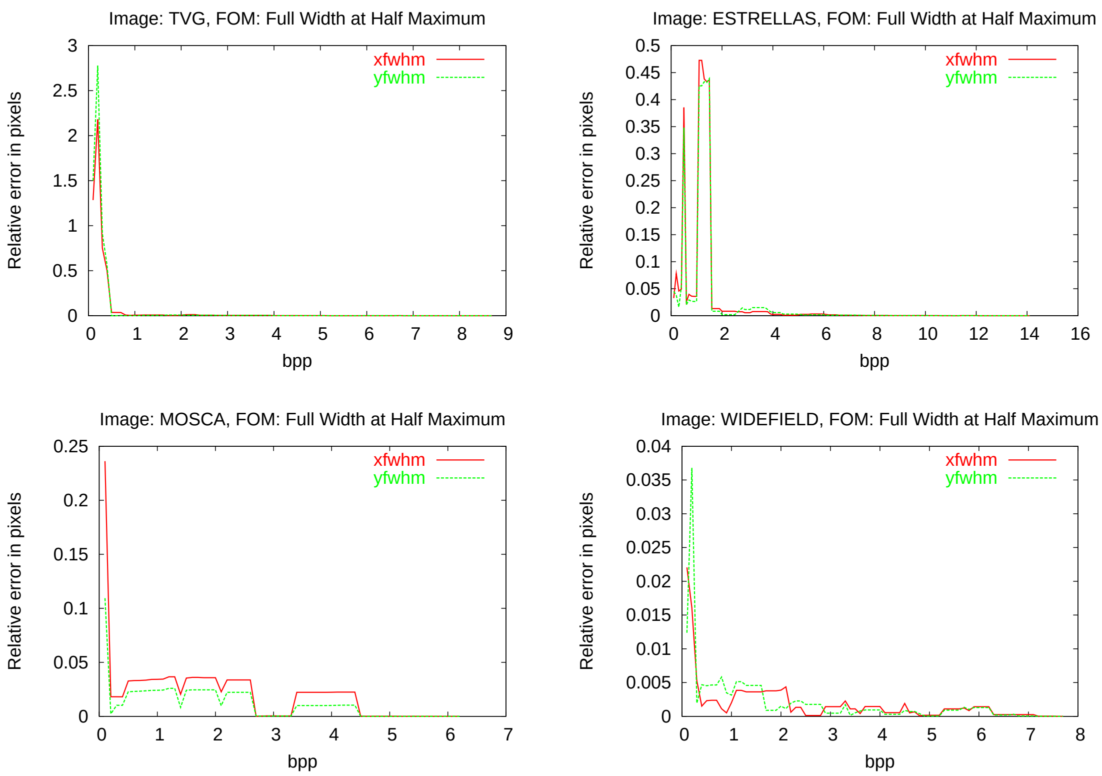

Figure 3. Full Width at Half Maximum FOM for an object from the images TVG, ESTRELLAS, MOSCA and WIDEFIELD.

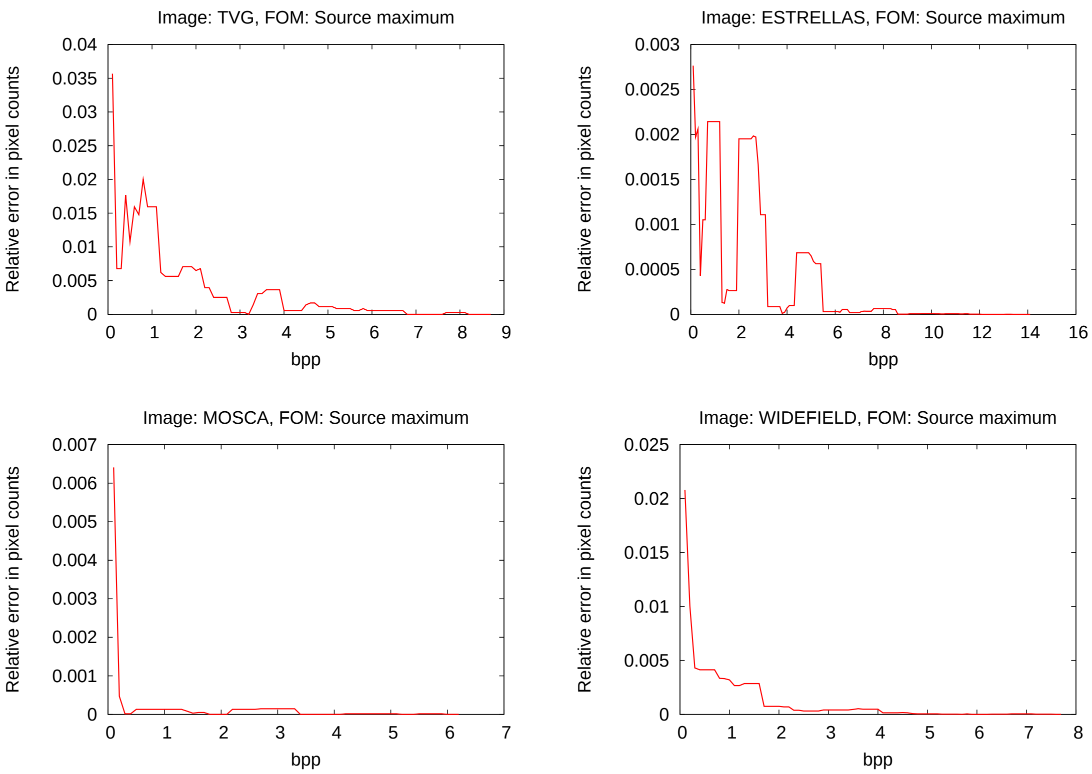

Figure 4. Source maximum FOM for an object from the images TVG, ESTRELLAS, MOSCA and WIDEFIELD.

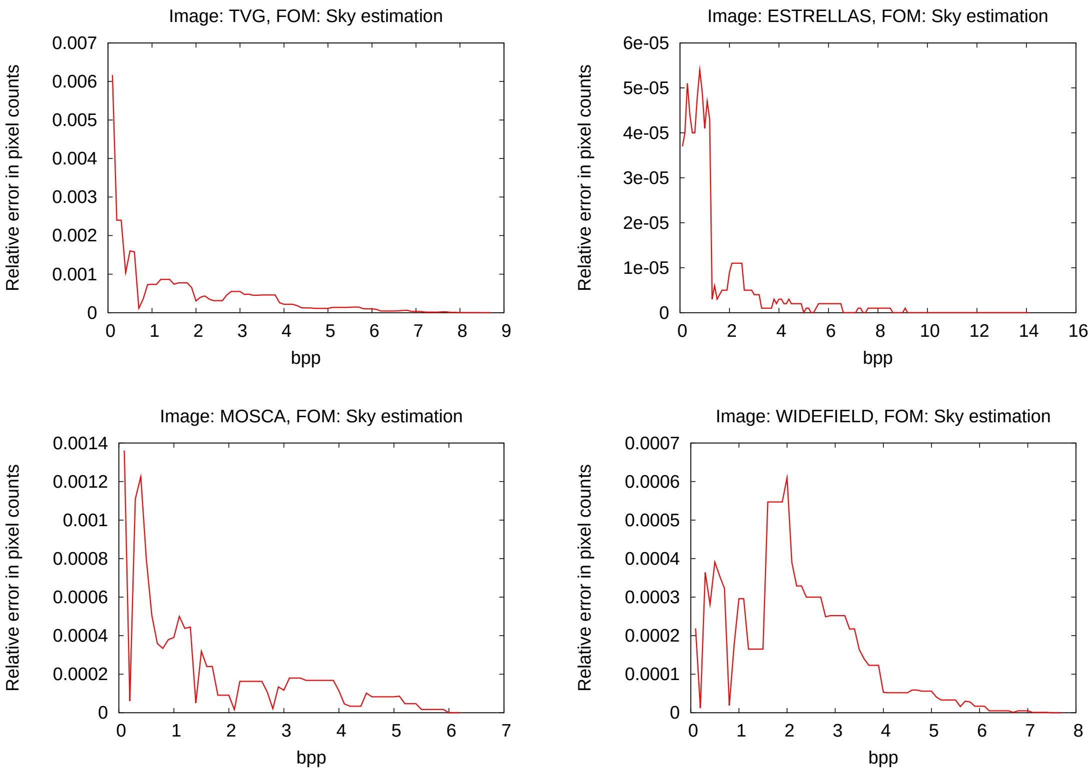

Figure 5. Sky estimation FOM for the images TVG, ESTRELLAS, MOSCA and WIDEFIELD.

of the source maximum of the astronomical objects is, on average, lower that 0.01 when 0.8 bpp have been received. This result, together with the fact that the relative error in the counts of the sky estimation is always insignificant, allow us to think that astronomical objects with a magnitude 100 times lower than the brightest objects in the image can be distinguished at this compression ratio.

5 Conclusion

Our results show that LPIC can be used to minimize the time necessary for interacting with a remote telescope, as well as to minimize the total transmission times of the generated images. Results show that LPIC is an efficient lossless progressive image scheme, that can be applied in astronomy to transmit images which are captured during astronomical observations. Typical astronomical FOMs such as the centroid and the counts of the pixels can be measured at the beginning of the receiving process with a minimal penalty. These advantages can save large amounts of bandwidth in the channels used to remotely control the instruments and allow astronomers to minimize the time necessary to operate with them.

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