A transputer based system for real-time processing of CCD astronomical images

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Abstract

A complete transputer based, real-time system has been developed to manage the whole chain of operations from acquisition of CCD images to quick-look, both in on-site observations and in remote observations.

The system is able to read a CCD image, display it on a local monitor and/or lossy-compress the data sending it to a remote station for quick-look.

Display and compression are performed by a transputer network. The former operation is managed by a graphic transputer module, whilst the compression, based on a fast DCT algorithm, is managed by a network of transputers organized on a geometric or farming parallel architecture. The system is open to further developments to perform on-line image calibration and interactive image analysis (histograms, ...).

1 Introduction

CCD images require a large amount of bytes, thus much time and mass memory are needed for elaboration, transmission and archiviation of the data in remote quick-look operations. It is possible to reduce the dimensions of data using compression techniques: through them the number of bits used to encode information is reduced. These techniques require a conspicuous amount of computing power, but, on the other hand, only simple arithmetic operations are required. Accordingly a powerful and expensive workstation may be replaced by other, cheaper, solutions, such as a transputers' array.

Transputers (from "*trans*istor com*puters*") are a class of VLSI chips developed by INMOS (Bristol) and first marketed around 1983. They are fundamentally low cost microcomputers, i.e. chips with processor, FPU and memory, with channels (links) to enable rapid comunication (up to 20 Mbits/s) with other transputers.

With a set of six transputers, a real-time system has been developed at OAT to manage the whole chain of operations from acquisition of CCD images to quick-look, either in the case of on-site observations or in remote observations. The scheme of the system is shown in fig. 1 [**?**].

2 Software developed

On-site display is managed by a graphic transputer which reads CCD memory and shows the CCD image on the monitor. Functions for quick image calibration can easily be inserted to clear instrumental distorsions from images.

Quick-look's function is to provide the astronomer with the possibility of understanding if an image is satisfactory or not (if the field is correct, if there is manifest over or underexposition and so on). This requires the transmission of only the relevant data. Thus lossy compression has been used.

In lossy compression degradations are allowed in the reconstructed image in exchange for a reduced bit rate as compared to lossless compression. The general framework for a lossy scheme includes three components: image decomposition or transformation, quantization and symbol encoding [?].

The image decomposition is performed to reduce the dynamic range of the signal. By quantizing the data, the number of possible output symbols is reduced. The type and degree of quantization has a large impact on the bit rate and quality of a lossy scheme. Quantized data is then encoded with lossless techniques as a means of reducing redundant information.

Decomposition can be obtained by processing images directly in the spatial domain (interpolators, predictors, Block Truncation Coding, etc.) or transforming them into a different domain, that of spatial frequencies typically, and then selecting transformed data (transform coding). At present transform coding techniques are considered the most efficient for the reduction of the dynamic signal range, the elimination of redundancy and the minimization of errors in the reconstructed image, even if they require more complex algorithms.

Discrete Cosine Transform (DCT) is the mathematical transform that is being used increasingly in image transform coding, because it allows high quality reconstructed images and has a fast algorithm. DCT is applied to an nxn block of the image. The transformed nxn image coefficients in the spatial frequencies domain are compacted around the top-left coefficient, which represents the average brightness of the spatial block [?] [?] [?].

The Chen, Smith and Fralick [?] fast algorithm is used in the work developed at OAT . The original image is partitioned into NxN pixel blocks (with $N = 2^m$) and each block is independently transformed by DCT. Quantization is then obtained by multiplication of transformed data by a mask that cuts all the higher spatial frequencies. This produces many zeroes. To take advantage of these zeroes, the 2-D array of the DCT coefficients is formatted into a 1-D vector using a zigzag reordering. This rearranges the coefficients in approximately decreasing order of their average energy (as well as in order of increasing spatial frequency) with the aim of creating large runs of zero values. All final zeroes are then cut and also the sequencies of 1 and -1 produced by DCT are encoded by writing the quantity of these values in every sequence. This work is done on each image block. All final vectors are then arranged one behind the other to form a single sequence. This must be further compressed with lossless techniques. Three public domain lossless compression algorithms were tested: `pack` (Huffman coding), `compact` (adaptive Huffman coding) and `compress` (Lempel-Ziv coding). The results of compression efficiency test are shown in fig. 2.

`Compress` and `pack` are faster, on an average `compact` is five times slower, but `compress` is more efficient. Consequently the latter was chosen.

The complete compression/decompression programs, written in C language, were tested by a workstation HP9000/425 on a set of two images. The first - NGC 6362 - is an image of an open cluster object with several details and thus a great entropy. The second is a galaxy - NGC 4639 - an extended, much more uniform object. Tests were performed applying DCT on 4x4, 8x8, 16x16, 32x32 pixel image blocks. The results are shown in tab. 1.

The application of DCT on 8x8 pixel image blocks seems to be the best compromise among time, compression efficiency and quality of the reconstructed image. Thus this format was chosen for the implementation of the program on transputers.

Compression/decompression programs were then translated into occam, the transputer language. Two parallel architectures were tested: farming on 6 transputers and pure geometrical architecture on 4 transputers. In each architecture a transputer - the "*master*" - reads the image

Image	NGC 6362				NGC 4639			
Original image dim. (bytes)	524288				524288			
Image block dim. (pixels)	4x4	8x8	16x16	32x32	4x4	8x8	16x16	32x32
Compr. image dim. (bytes)	31371	22716	17618	10344	11268	5434	2706	1682
Compression ratio	16.7	23.1	29.8	50.7	46.6	115.6	193.8	311.7
Time (secs)	7.16	5.34	5.64	6.90	5.30	5.02	5.34	6.06
rms error (counts)	5.47	5.79	8.25	16.56	1.19	1.26	1.40	1.84
peak error (counts)	89	87	111	120	32	35	48	91

Table 1: Compression DCT tests

Image	NGC 6362	NGC 4639
Farming architecture (6 transputers)	9.11 secs.	7.74 secs.
Pure geometric parallelism (4 transputers)	8.59 secs.	7.25 secs.

Table 2: Compression times with different parallel architecures

and sends parts of it to the other transputers - the "*slaves*". These elaborate and return them to the master, which provides final lossless compression on quantized data. In the farming architecture master transputer sends an NxN image block to every transputer, till all the blocks are encoded. In pure geometric parallelism the entire image is divided by the number m of the transputers in the network, and each of these receives $1/m^{th}$ of the image. In this architecture, 4 transputers were used because a transputer has only 4 links, thus the master transputer - which must use one link to connect with the host - can be directly connected with no more than other three transputers. The use of a higher number of transputers requires mixed farming-geometrical architectures.

The results of the tests on parallel architectures shown in tab. 2 demonstrate how a higher number of communications among processes in the farming architecture produces a deterioration in time performance.

3 Conclusions

Compression ratios of the order of ten have been obtained on images with great entropy. A higher order of compression rate has been obtained for uniform images. The system is open to further developments:

1) higher compression rates can be achieved using refinder quantization methods and new adaptive DCT algorithms;

2) faster algorithms can be obtained optimizing parallel architectures, in this way reducing communications among processes;

3) CCD management can be improved to allow interactive operations like histograms, image analysis, etc.

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Figure 1: Scheme of the system: operations in the local observatory and in the remote site

Figure 2: Compression efficiency test