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An Image Compression Algorithm
for a
High-Resolution Digital Still Camera

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Background

The development of the image-compression algorithm is part of the High-Resolution Still Camera Project under the direction of Don Yeates at Johnson Space Center[YEAT89]. The Electronic Still Camera (ESC) project will provide for the capture and transmission of high-quality image without the use of film. The image quality will be markedly superior to video, and will approach the quality of 35mm film. The camera will have the same general shape and handling as a 35mm camera.

The camera will be of great use on Space Station. The period between Shuttle visits to Space Station will be 90-180 days. If pictures were recorded on conventional film, people on ground would have to wait three to six months to see the images. Space Station crewmembers using the ESC will be able to send high-quality images to earth in near real-time. Space Station uses of the ESC will include crew health, in-flight maintenance, experiment monitoring, damage assessment and public relations.

To store an image, the ESC uses computer memory (RAM) in a removable cartridge instead of film in a film canister. To take a picture, the user clicks the shutter. Light entering the camera is converted into numbers and stored in the memory. To see a picture, the user removes the cartridge and inserts it into a computer. The picture can be viewed on a high-resolution monitor or it can be sent to earth to be analyzed and printed.

It takes an enormous amount of memory to store a single image. Each pixel (spot) of an image is represented by three 8-bit numbers, one each for red, green and blue. The final version of the ESC will record images that 2048 x 2048 pixels. Because each pixel needs three bytes of storage, one image requires 12Mbytes.

Because the ESC body needs to resemble a 35mm camera body, there is not room in the memory cartridge for much more than 12Mbytes. In other words, there is room for only one image on the cartridge. This is analogous to having a film canister that contains one exposure of film. This is unsatisfactory from a human factors point of view.

Image Compression

An image–compression algorithm stores an image using less memory. If each image needs less memory, then more images can be stored in a memory cartridge.

The image-compression process takes an image as input, and produces a compressed image that occupies less space. In the ESC, the compression will take place inside the camera and the compressed images are stored in the memory cartridge. After taking pictures, the user transfers the compressed images from the cartridge to a computer. The images are expanded to their original size and are called reconstructed images. The user can view the reconstructed images on the high–resolution monitor. (See Figure 1.)
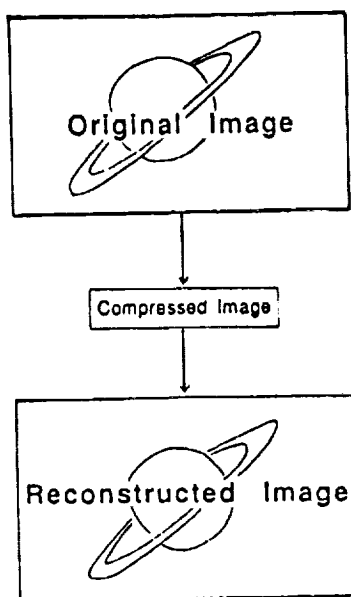

Figure 1: The compression process

Performance criteria for image–compression algorithms

Each image-compression algorithm is a tradeoff among the following criteria:

1. fidelity
2. efficiency
3. compression ratio

Fidelity refers to how well the reconstructed image resembles the original image. There are quantitative measures of fidelity, including signal–to–noise and mean–squared–error, but these do not always accurately measure fidelity, which is a subject measure. Two images with the same mean–squared–error can have radically different fidelities when viewed by the human eye.

Efficiency has three aspects — speed, space, and parallelism. Speed is a measure of the length of time the algorithm takes to finish the compression. Space is a measure of the amount of auxiliary storage the algorithm needs to compress an image. Parallelism is a measure of how well an algorithm can be decomposed into parts that can be executed simultaneously. A slower algorithm with a greater degree of parallelism can be more interesting that a faster algorithm with a low degree of parallelism.

Compression ratio is a ratio of the size of an original image to the size of the compressed image. This is a measure of how many images can be stored on the ESC memory cartridge.

The ESC requires the highest possible fidelity. The people receiving pictures from the camera will want images of the highest quality. Efficiency is second in importance. The compression must take place so the user will not have to wait a long time between shots. Further, the algorithm cannot use a large amount of auxiliary storage because memory is at a premium. Fidelity and efficiency are more important than an extremely high compression ratio.

Algorithms chosen for study

Image compression algorithms fall into two categories — lossless and loss-y[MOIK80]. Lossless algorithms lose no information when compressing an image. The reconstructed images are exact duplicates of the original images. When using a loss-y algorithm, some information is lost in the compression process. The reconstructed image will differ from the original. The differences may or may not be visible to the human eye.

For purposes of this study, I chose algorithms from each category:

Lossless

    run–length coding[LYNC85]

    frequency–based coding[ROSE76]

Loss-y

    block–truncation coding[DELP79]

    transform coding[HABI71]

I based the choices primarily on efficiency. Some algorithms, such as contour encoding[GONZ87], can be rather time–consuming. Others, like the Laplacian pyramid method[BURT83], require a large amount of auxiliary storage. Others sacrifice fidelity for a high compression ratio.

Of the lossless schemes, run–length encoding is the simplest and the fastest. The frequency–based schemes include Huffman, B- and S-codes. These are a little slower than run–length encoding, but provide a higher compression ratio.

Of the loss-y schemes, the block–truncation encoding method is superior in terms of speed and parallelism. It also needs little auxiliary space. The block–truncation scheme uses a moment-preserving quantizer. An image is divided into n x n pixel blocks. Each pixel in a block is quantized to one of two levels x and y such that the block's sample mean and variance are preserved. To perform the compression, a new n x n bitplane is created. A binary 1 in the bitplane indicates that the corresponding pixel in the original block was above the sample mean, and a binary 0 indicates that corresponding pixel was below the sample mean. To preserve the sample mean and variance, all the pixels above average are quantized to

$$x = \mu - \sigma\sqrt{q/p}$$

All pixels below average are quantized to

$$y = \mu + \sigma\sqrt{p/q}$$

where μ is the sample mean, σ the standard deviation, and q and p are the number of pixels above and below the sample mean, respectively. A compressed block consists of the n x n bitplane, and the values of x and y.

The transform methods need more space and run more slowly. This study examined the Fourier and cosine transforms. For the transform method, the image was divided into 8 x 8 tile of pixels. The tile of pixels was converted from RGB to YIQ. The transform was performed only the Y–component, because most of the image's bandwidth is located there [EIDS86].

Compression was achieved by retaining the dc coefficient and the l highest–energy ac coefficients in the block. The retained coefficients $c_{i,j}$ were truncated to to an average of m bits. An 8 x 8 bitplane records the position of the retained coefficients. A binary 1 in the bitplane at location (i, j) indicates that the corresponding coefficient $c_{i,j}$ was retained.

There are several other ways to achived compression using transforms, but they involve making a temporary file containing the entire transformed image. The extra space required to store the file makes these methods impractical for this application, but their higher compression ratios are very attractive. For example, one method determines and retains the highest–energy coefficients $c_{i,j}(k)$ over all blocks k. Since the same coefficients are retained in each block, there is no need to include an 8 x 8 bitplane in each block, and the resulting compression ratio is higher.

The I– and Q–components are handled differently. For each block, the average I–component value is computed and stored. The Q–component is handled similarly.

The following information is stored in a compressed block
1. 8 x 8 bitplane
2. sample mean of the retained coefficients
3. standard deviation of the retained coefficients
4. the retained coefficients
5. the average I–value
6. the average Q–value

A range of compression ratios can be achieved by varying the number of retained coefficients, and the number of bits used to quantize the coefficients.

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Comparision Method

Because all chosen algorithms have acceptable efficiency, comparisions among the algorithms were based on fidelity and compression ratio. Four images were chosen for the study. These included a face shot, a view of the Shuttle payload bay, a shot of the remote manipulator arm with the earth in the background, and a picture of an experiment located on the Shuttle middeck. These images are representative of the images that will be needed by the Space Station applications.

For the lossless compression algorithms, whose fidelity is perfect, the images were compressed and the compression ration recorded. The test of the loss-y algorithms was more involved. For a given compression ratio, each image was compresse, using the block–truncation method, the Fourier transform method, and the cosine transform method. The images reconstructed from the two methods were compared side–by–side.

Results

The lossless algorithms were superior in fidelity, but their compression ratios were very low. The ratios of the four images ranges from 1.7:1 to 2.1:1. The compression ratios were adversely affected by noise introduced by the device used to scan the images. However, even if the images were noise-free, the compression ratio produced by a lossless algorithm is not constant. The compression ratio of any lossless algorithm is bounded above by the entropy in the picture. Entropy is a measure of information content. If an image has high entropy (if the image complexity is high), the compression ratio will be lower than if the image had lower entropy.

The block-truncation method was disappointing. To get a reconstructed image of acceptable fidelity, the method produced a compression ratio of 1.8.

The transform methods produced reconstructed images that had few artifacts, and the compression ratio was 5.3. As the compression ratio was increased to 8.5, the fidelity did not deteriorate significantly. The cosine transform seemed to produce a reconstructed image with slightly higher fidelity.

Future Work

The compression ratio would increase significantly if each compression block did not contain the 8 x 8 bitplane that gives the location of the retained coefficients. Elimination of the bitplane would mean that the pattern of the coefficient retention would be fixed. This requires a study of the distribution of the high-energy coefficients within a block. Another possibility is to have a few fixed patterns of coefficient retention. Each block would contain a number indicating which pattern of coefficient retention was used in that block.

There is a way to take advantage of of compression algorithms that require generating an entire transformed image to gather global statistics before proceeding to compress the image. The image could be transformed twice. On the first transformation, the statistics could be gathered, but the coefficients would not be stored. The compression would require transforming the image a second time. This is a slower process, but with the introduction of DCT chips, it may be feasible.

With these improvements, the transform method should be able to produce high fidelity reconstructed images with a compression ratio of 10:1.

Conclusions

The ESC could have two compression modes: on and off. Normally, the compression would be turned on, and a user of the ESC could store ten images on a memory cartridge. If, however, a researcher wants every bit of an original image, the user of the ESC could turn off the compression, and store the one image on a memory cartridge. Even though the lossless algorithms produce reconstructed images with flawless fidelity, the compression ratios are too unpredictable for use in the ESC. The transform method will compress the images with reasonable efficiency, produce images of high fidelity, and guarantee an acceptable compression ratio.

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