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New Perspectives on Image Compression

MICHAEL THIERSCHMANN, UWE MARTIN and REINHARD RÖSEL, Berlin

ABSTRACT

Effective data compression techniques are necessary to deal with the increasing amount of data produced by modern image processes. The quality and features of the currently established image compression techniques, including the JPEG-standard, are not sufficient for an increasingly large number of applications.

New image compression techniques based on wavelet-transformations offer a solution. These techniques allow the combination of lossless and lossy compression with extremely high compression rates and image quality. This paper discusses the principles of wavelet- and JPEG-compression and compares the new wavelet techniques with the JPEG-standard method. Additionally we present a software image compression package, LuraWave, which allows the use of wavelet image compression in a wide range of commercial applications.

1. INTRODUCTION

The increasing amount of data produced by modern image generating and processing systems is often limited by storage and transmission capacity. Effective data compression techniques are necessary to overcome this problem. The JPEG-standard is one such compression technique.

The JPEG-standard is a powerful image compression technique providing lossy image compression with a high visual quality. Nevertheless there are applications, which require a higher image quality than JPEG can provide. In very demanding applications the JPEG-technique has significant problems, for example increasing compression rates result in rapidly degrading image quality and annoying blocking artefacts. The completely different techniques used by JPEG to handle lossless and lossy compression may also pose problems for some applications.

New techniques based on wavelet transformations offer a solution, allowing lossless compression and very high compression rates with high image quality. The artefacts introduced at high compression rates are of a very different structure to those introduced by the JPEG-technique and can be influenced by a wide range of wavelet filters.

Even in the areas where JPEG performs optimally, wavelet compression delivers better image quality without requiring significantly more computational resources.

This paper discusses the principles of wavelet- and JPEG-compression and compares the new wavelet techniques with JPEG-standard method. This comparison is performed using statistical quality mesures and visual criteria. Additionally we present the commercial wavelet compression software LuraWave as an example of a practical implementation of wavelet image data compression.

2. IMAGE CLASSES

In choosing a suitable image compression technique one has to consider not only the type of compression required, for example lossless or lossy, but also characteristics of the images to be compressed.

We can divide images into two classes: images from a natural source, for example photographs and scans with a high colour resolution, we shall refer to as „natural images“; artificially generated images, for example line drawings and cartoon-like images, we shall refer to as „artifical images“.

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Images of these classes have distinct characteristics. Natural images tend to show a continuous distribution of colours and seldom contain abrupt changes of colour at object edges. In contrast artificial images often have a discontinuous color distribution and abrupt edges without transitions. Currently there is no compression technique which can handle both types of images, they both need specially adapted compression algorithms.

3. OVERVIEW OF IMAGE COMPRESSION TECHNIQUES

Currently used image compression techniques can be separated into two groups: *lossless* and *lossy* compression. Lossless compression allows the reconstruction of the original image data from the compressed image data. With lossy compression a higher compression rate is possible by allowing small differences between original and reconstructed images.
Compression rates for natural images with lossless compression are generally small, ranging from 1:1 for uncompressable data to 1:3. Typical values, using TIF-LZW encoding for example, are around 1:1.5.
Lossy compression achieves compression rates of 1:5 to 1:30 using standard techniques (e.g. JPEG) and up to 1:300 using newer techniques (e.g. wavelet LWF, WV; fractal compression FIF). Most lossy compression techniques are based on two-dimensional transforms, followed by quantization and encoding stages. The loss of information is introduced by the quantization stage which intentionally rejects less relevant parts of the image information (disregarding rounding errors in the transformation step).
Specially adapted techniques which achieve high compression rates exist for artificial images. These techniques are based on run length coding, sometimes followed by an entropy coder. Examples of this techniques are the Fax-encoding standard and the image formats PCX and RLE.
The confusingly large number of compression techniques prevents many potential users from directly applying image compression. A technique and an image format which covers a wide range of alternative compression requirements would be preferable. JPEG is one attempt at creating such a technique for natural images, assembling a number of compression techniques in a common standard. The following section describes its functionality.
While JPEG integrates a wide range of compression techniques, these methods can only be realized by introducing several very different working modes. In contrast wavelet compression allows the integration of various compression techniques into one algorithm.

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	Lossless	**Lossy**
Techniques	• Entropy Coder (e.g LZW, Huffman) • Run Length Coding	• Transformation DCT, DWT, Fractal Transformation • Quantizing “simple“ Qu. (Linear, Uniform, Characteristic) Bit-Plane-Quantization., Successive Approx.-Qu. • Encoding Entropy coder, Quadtree Coding
	Achievable Compression Rates	
Natural Images (Photos, Scans)	1:1,5 - 1:2	• 1:1,5 - 1:30 visual lossless • 1:10 - 1:300 lossy
Artifical Images (Drawings, Cartoons)	1:1,5 - 1:20	• 1:1,5 - 1:300
Image File Formats	• TIFF-LZW • Fax, BMP(RLE), PCX	• JPG • LWF, WV • FIF

Table 1: Overview of image compression techniques.

This shall be discussed in more detail when we describe the principles of wavelet compression.

4. THE JPEG-STANDARD (ITU T.81)

The popular current image compression techniques are implementations of the JPEG-standard (ITU T.81). The JPEG-standard covers a collection of compression techniques: it contains a lossless mode; two progressive modes; and a simple lossy technique, which encodes the image sequentially from the upper left to the lower right corner. Every mode can be split into different versions, so for instance one can chose between Huffman and arithmetic coding, though some useful combinations are partially missed, for example JPEG does not contain a progressive lossless mode of operation.
The large number of different coding techniques makes a complete implementation of the JPEG-standard extensive, while a minimal JPEG decoder has only to realize the sequential lossy mode of operation. So if one has to choose the best suited JPEG compression technique one has the problem of ensuring that the target system can decode the images.
The lossy JPEG compression initially divides the source image into squares of 8x8 pixels. As the squares are then separately encoded, the reconstructed image may contain discontinuities at the boundaries of the squares, resulting in one of the major JPEG disadvantages. In addition the analyzing functions of the DCT are applied independent of its granularity on small image areas of the same sizes. Better results could be achieved by applying smoothing low pass functions to larger areas and differentiating high pass functions to smaller areas.

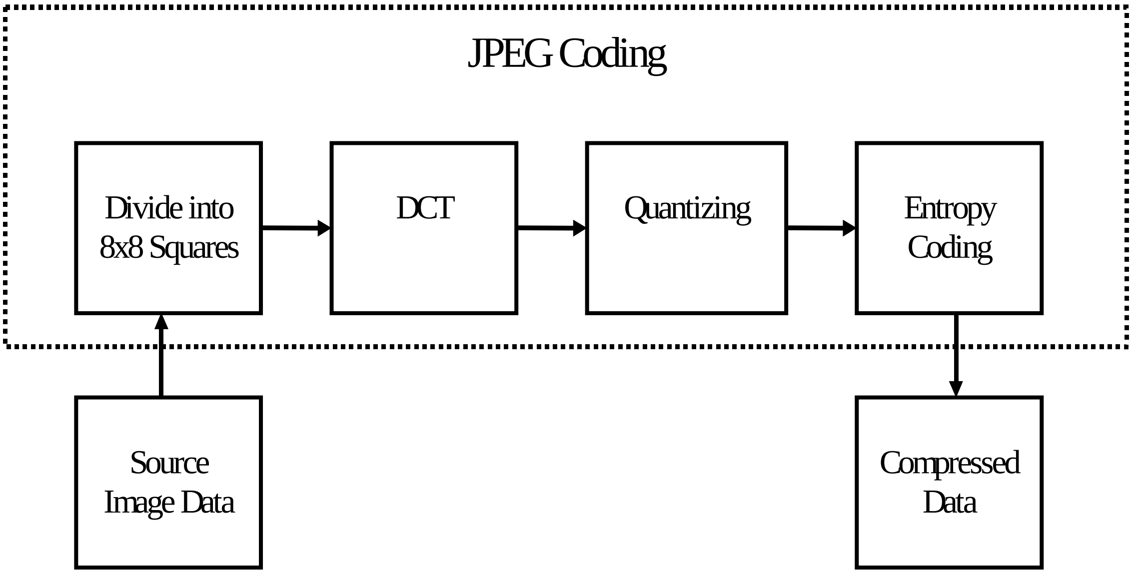

Figure 1: Simplified JPEG Coding Scheme for lossy compression.

These blocking artefacts of the JPEG technique are visible only in enlarged images, but cause problems in many image processing applications. Particular problems occur when analyzing algorithms are applied to JPEG compressed images or when the images are re-rastered for printing.
When a compressed image is re-compressed (e.g., with a higher compression rate or after some processing) these additional edges further degrade the quality of the image.

5. DESCRIPTION OF WAVELET COMPRESSION

Wavelet compression applies a two-dimensional transformation to decorrelate the image information. Image compression with wavelet algorithms applies the following steps:

1. Image preparation
2. Transformation

3.a Quantization
3.b Encoding

The quantization and encoding steps are usually combined allowing *embedded coding*, which will be explained later.

<u>Image preparation:</u>
Wavelet transformation is applied recursively, dividing the original image matrix into 4 transformed matrices with the half number of rows and columns. To ensure this division by two in every stage, the original image is supplemented by rows and columns to ensure the width and height are a multiple of 2^{level}.
A division into image blocks, as used by JPEG and fractal compression, is not necessary. Nevertheless, it can be applied to gain more efficient memory usage if required. If division is applied, the transformation is performed overlapping the block edges, so these edges will not influence the transformed image. The image is always transformed as a unit.

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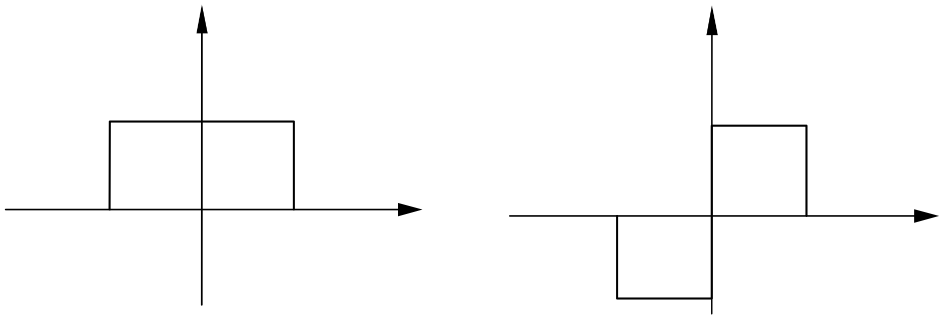
Transformation:

The discrete wavelet transformation (DWT) is very similar to the discrete cosine transformation (DCT), but it does not use the spatially unlimited sine and cosine functions for analyzing the image. The base functions of the DWT are scaling and wavelet functions. These functions combine orthogonality, which is the first condition for transforming and identical reconstructing signals, with „*compact support*“, i.e., they have a finite spatiality. This enables the analysis of signals without the windowing effects which result from the application of functions of infinite length to signals of finite length. For this reason images need not be split into blocks.
With the help of the most simple wavelet, the Haar-wavelet, we can explain the discrete wavelet transformation:



Haar scaling function -> lowpass Haar Wavelet -> highpass

One transformation coefficient is ...

mean value difference

... of two neighbouring pixels

Figure 2: The Haar Wavelet.

In this simple case analyzing the signal with the Haar wavelet and scaling functions calculates the mean and the difference of two neighbouring pixels. The results are downsampled and stored as lowpass and highpass images. The lowpass image is now further analyzed in the same way.
The final transformed image consists of a number of highpass images of different sizes and a single lowpass image. The left side of Figure 3 shows a simplified diagram of a two dimensional wavelet transformation. In the first step the original matrix is split into three highpass images (Dx01, Dy01, Dxy01) and a lowpass image (C01). The next step splits the lowpass of the first step (C01) into three new highpasses (Dx02, Dy02, Dxy02) and a new lowpass (C02). The highpasses of the first step are unaltered.
One can recursively transform the image in this way until only one pixel remains in the final lowpass image. The original image is hierarchical split. The highpass parts of the first transform level contain the finest image structures, those of the following stages contain coarser and coarser image structures.
The diagram to the right in Figure 3 shows a practical example. The original image is split with two transformation steps, as described above. The small picture in the upper left corner is the lowpass of the second step (C02). The other parts of the image are highpass images.

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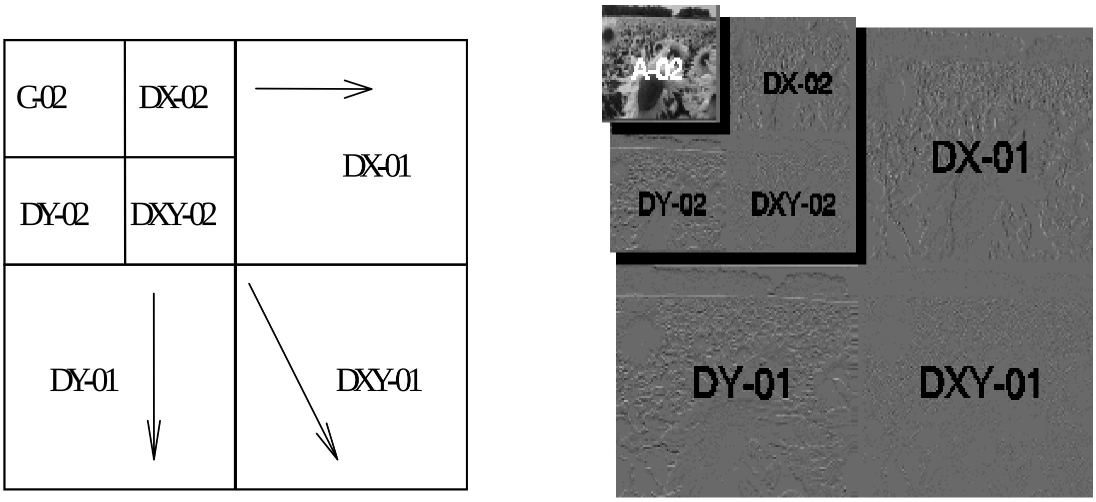

Figure 3: Diagram and Example of a 2-Level, 2-Dimensional Wavelet-Transformation.

The transform is normally applied with more function pairs than the Haar wavelet and scaling, e.g., Daubechies wavelet or biorthogonal spline wavelets.
The DWT can be calculated using either integer or floating point arithmetic. Floating point calculations allow a larger number of possible wavelet filters and the potential of high quality lossy compression. On the other hand, it has the disadvantage of rounding errors which need to be eliminated for lossless compression, resulting in higher expenses and calculation time. If one wants to compress images losslessly, the transform must be completely reversable, no rounding errors are allowed. This can be achieved applying a special integer transformation.

Quantizing and coding:
Quantization and encoding have to select the data being transmitted and to put them into a suitable order in the data stream. They can be implemented as separate stages, as in JPEG, with the quantization stage rejecting some of the less relevant information and passing on the rest to encoder stage for encoding.
By combining quantization and encoding into a single stage one gains the ability to exactly control the compression quality (image quality vs. compression rate). The size of the encoded data stream can be predefined exactly. Here quantization of the transformed coefficients occurs during encoding.
The initial quantization is coarse with only the largest coefficients considered and encoded. The quantization intervals are then split and new smaller coefficients, which were not considered in the first cycle, become significant. The values of the coefficients selected in the first cycle are specified more exactly by the new information. The cycles continue until the data stream has reached its predefined length or until all information is encoded and the image is compressed losslessly. Applied to binary numbers and intervals, which are halfed in every cycle, the individual bit planes of the binary representation of the coefficients are encoded separately. This process is called bitplane coding. The resulting data stream is embedded, that is, the image information is ordered with respect to its importance in reconstructing the image. This allows the reconstruction of a complete image from the initial part of a data stream, though of course with a reduction in quality when compared to the image which can be reconstructed from the whole stream. This feature has many potential advantages for applications in a wide range of fields, e.g., Internet and World Wide Web.
So wavelets can be used to form the basis of a compression technique which combines lossy and lossless compression. From lossless compressed image data one can obtain a higher compression rate simply by cutting the data stream. In addition the reconstructed images are of a higher quality than JPEG compressed images.

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6. EXAMPLES AND COMPARISONS

The following gives some examples for compression results using JPEG and wavelet compression.

„Goldhill“

Original

1:1

8 bit/pixel

JPEG Wavelet (LWF)

1:25

0.32 bit/pixel

1:50

0.16 bit/pixel

Figure 4: Visual comparison JPEG-Wavelet for the image "GOLDHILL".

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„Tiger“

Original
1:1
8 bit/pixel

JPEG | Wavelet (LWF)

1:25
0.32 bit/pixel

1:50
0.16 bit/pixel

Figure 5: Visual comparison JPEG-Wavelet for the image "TIGER" (coloured).

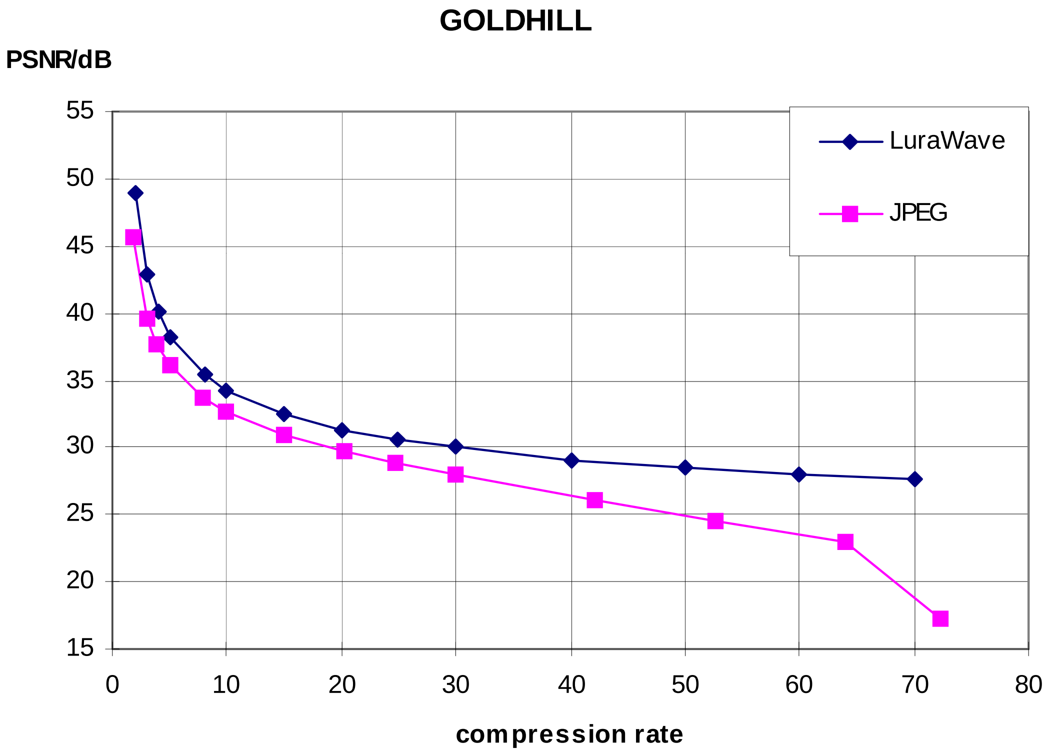

Figure 6: Statistical comparison JPEG-Wavelet for the image "GOLDHILL".

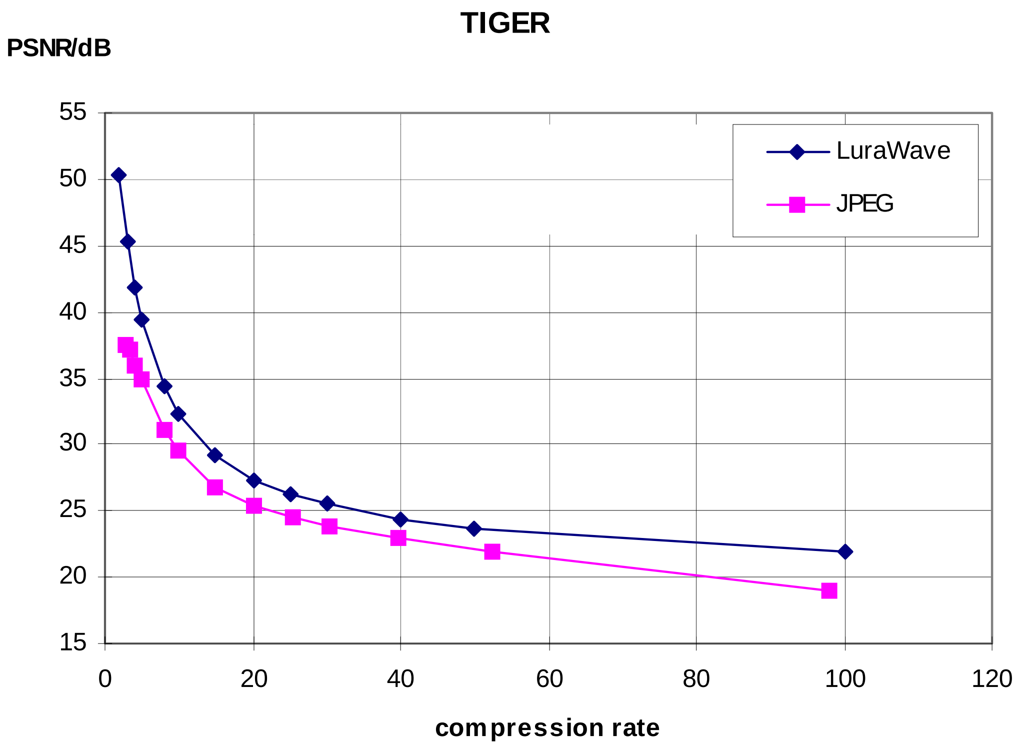

Figure 7: Statistical comparison JPEG-Wavelet for the image "TIGER".

7. FUNCTIONAL ADVANTAGES OF WAVELET COMPRESSION

This section presents the functional advantages of wavelet compression and some possibilities for its application.
Wavelet compression **combines lossless and very high quality lossy compression** in one algorithm. Using only a small fraction of lossless compressed data one can always generate images with every higher compression rate. Applications which have to supply images with different resolutions and qualities have a very high administrational overhead using the old compression techniques, having to generate, to store and to update every image more than once. Using wavelet compression from an embedded compressed image, generated with the highest required quality, every smaller resolution can be generated. This **substantially decreases the administrational and storage costs** for such applications.
Another advantage of wavelet compression is the **absence of blocking artefacts**, typical in JPEG compressed images. Images highly compressed using wavelet techniques have their artefacts, too, but they are of a completely different structure and have a direct relation to the image content. They are often less problematic for analyzing applications than the arbitrarily introduced square edges of JPEG compression.
Wavelet compression has **short and nearly symmetric compression and decompression times**. The complexity and the calculation times for wavelet compression are comparable to those for JPEG compression, despite the greater functionality of wavelet compression, and well below that required for fractal compression.

8. PRESENTATION OF THE LURAWAVE PACKAGE

LuRaTech, in cooperation with the University of Potsdam, began the development of the wavelet compression system LuraWave for the German Space Agency DARA.
Now in version 2.0, Lurawave is available in a variety of forms, integrating the wavelet compression functionality into a range of existing standard software: Netscape PlugIn (Macintosh, MS-Windows), PhotoShop-Plugin (Macintosh, MS-Windows), Command Line-Tools (UNIX, MS-Windows), MS-Windows-OCX-Control, LuraWave for Windows, LuraWave-Quicktime PlugIn (Macintosh, MS-Windows), LuraWave-C-SDK (MS-Windows).
Computer networks are one of the main application areas for image compression. In particular the use of the Internet, with the World Wide Web, for commercial applications is quickly growing. The Internet bandwith available is often insufficient for the transmission of large images, requiring the images to be compressed to save transmission time and costs.
The administration cost of managing image databases can be reduced by wavelet compression. Current providers of image databases have to store their images at three or more resolutions: a quicklook for browsing, medium resolution for evaluation and high resolutions for sale and printing. These images of varying resolution can be generated from a single file using LuraWave.
LuraWave also provides the ability to protect an image with a password up from a predefinable image quality. This enables access to the full image resolution to be limited to authorized users only, allowing others to see a lower resolution version of the same image from the same file on the server. The provider of an Internet page can specifiy the amount of data which is initially used to show an image. The user can be given the option to load more data to improve the image quality if required. These examples show how the new wavelet compression technique can introduce a new flexibility into the interaction between provider and user of a Web page.
Of course these advantages are not limited to the Internet, they equally apply to Intranet and local database applications too. In addition, user specific applications can be enhanced with LuraWave compression functionality using LuraWave OCX or C-SDK.

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9. SUMMARY

JPEG is a powerful image compression technique comprised of a collection of compression algorithms and modes of operation. Nevertheless there are many applications which require higher image quality than JPEG can provide. In practice many implementations of the JPEG-standard use only the simplest mode of operation, with many of the other modes rarely used. The advantage of standardization is not realized for these modes.

Currently, in terms of compression quality, there exist better techniques than JPEG for image compression. Wavelet compression is a new and very efficient image compression technqiue, providing higher functionality and image quality than JPEG. Lossless and lossy compression of natural images can be achieved with the same algorithm. The software package LuraWave supplies the functionality of wavelet compression to a wide range of commercial applications.

10. REFERENCES

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