

Image Data Compression

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COMPRESSION is important because it decreases the time and cost required for image transmission, and it decreases storage requirements. As radiology groups and institutions have moved to implement picture archiving and communication system (PACS) and teleradiology systems, compression has taken on increased importance. Compression algorithms can be either lossless (reversible) or lossy (irreversible). For radiologic images, lossless algorithms yield compression ratios in the range of 1.5:1 to 3:1.¹ However, to have a substantial practical impact, much higher compression ratios (eg, 10:1 or higher) are desirable. Higher degrees of compression are only possible using lossy or irreversible techniques, and therefore lossy compression has been the subject of considerable investigation.

Algorithms for lossless compression include run length encoding, Huffman encoding, arithmetic coding, and Lempel-Ziv and variants. The simplest example is run length encoding, which is used to succinctly express a series or "run" of 0s or 1s using a code word and the number of 0s or 1s that follow. Other techniques use other schemes to uniquely represent an image data set such that no information is lost in the process.²

Various types of lossy encoding algorithms have been investigated including the Joint Photographic Experts Group (JPEG) standard, JPEG variants, the full frame discrete cosine transform (DCT), vector quantization, wavelets, fractals, and others. The critical question is whether lossy data compression is clinically acceptable. It can be argued that radiologists sacrifice information in routine practice, eg when static images are recorded to document a sonographic or fluoroscopic examination. Indeed, any use of teleradiology and PACS results in data loss because even the highest resolution (2560 × 2048) displays have modulation transfer functions substantially lower than conventional radiographs.³ Digitizing radiographs is a subsampling process that is inherently lossy in nature but which has been judged to be appropriate for clinical use.

There is growing evidence that lossy compression can be applied without significantly affecting the diagnostic content of images.^{4,7} For example, two receiver operating characteristic (ROC) studies^{4,5} using different compression techniques (full-frame DCT, modified JPEG) have shown that

compression ratios of at least 20:1 can be used without a significant effect on the diagnostic interpretation of chest radiographs. There is growing consensus in the radiologic community that some forms of lossy compression are acceptable.

MATHEMATICAL TRANSFORMATIONS AND COMPRESSION

Many lossy compression techniques are based on mathematical transformations. Mathematical transformations decompose the spatial information in an image into a series of basis functions, that represent the features of the image, and associated weighting factors. Imaging specialists will be familiar with the Fast Fourier Transform (FFT) because of its use in magnetic resonance imaging (MRI) where image signal is represented as the sum of sines and cosines. The most efficient transformations concentrate the features of an image into the smallest possible number of mathematical terms. Compression is further achieved by a step referred to as quantization, in which coefficients (or weighting factors) are rounded off or approximated by zero. The quantization step should be designed to minimize any effect on image quality. The final step in transform-based compression is lossless coding of the final data set to eliminate residual redundancy. Decompressing the image first involves reversing the lossless step. The quantization step cannot be reversed, information that is "rounded off" is lost in the process. The inverse mathematical transformation is then applied to reconstitute the image.⁸

JPEG: ADVANTAGES AND DISADVANTAGES

JPEG is a transform-based compression technique, and it is the most commonly used compression algorithm in radiology. The underlying mathematical transform is the DCT that represents spatial information in a manner somewhat analogous to the FFT. JPEG is widely used in other applications including compression of a variety of types of images on the World Wide Web. Advan-

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tages of JPEG include the fact that it is widely available, inexpensive, relatively fast, implemented in hardware and in software, and it is an International Standards Organization standard. It is also the only algorithm supported by the Digital Imaging and COmmunications in Medicine (DICOM) standard. Its inclusion in DICOM should not be misconstrued as an endorsement of JPEG as the compression technique of choice. JPEG is included so that DICOM addresses the important issue of compression using a popular and standardized technique. The DICOM working group on compression is considering other algorithms such as wavelets for inclusion.

There are a number of techniques that may outperform JPEG in the compression of radiologic images including the full-frame DCT technique⁹ and wavelets.¹⁰ JPEG suffers from block-shaped artifacts at increasing compression ratios.¹¹ These artifacts result from the fundamental approach of the algorithm which is to divide the image into many smaller 8×8 pixel blocks that are processed independently. The human visual system is keenly sensitive to the detection of edges, and artificial edges are introduced by this block-oriented approach. Full frame techniques, that is compression algorithms that process the image in its entirety, do not suffer from this type of artifact. As a result, higher compression ratios can be achieved before image degradation becomes perceptible.

WAVELETS

The mathematics of wavelets were discovered in 1987. Wavelets use a new set of basis functions with some unique features, compared to the FFT or DCT, that are advantageous for compression. First, the basis functions discretely encode spatial as well as frequency information. The result is that image detail is efficiently preserved. Wavelets have outperformed JPEG in direct comparisons and do not suffer from the type of block-shaped artifacts described above.¹⁰ Artifacts from wavelets are more broadly distributed over the image and tend to have a smoothing effect. As a result, higher levels of compression are possible. The tutorial includes numerous examples of wavelet-based image compression.

DIFFERENT COMPRESSION FOR DIFFERENT IMAGE TYPES

Compression will have to be optimized based on the type of image being processed. For example,

experience with wavelet compression suggests that skeletal radiographs may be more sensitive to compression than chest radiographs.⁶ Cross-sectional images such as computed tomography (CT) and magnetic resonance (MR) do not compress as well as conventional radiographs.^{1,9} CT and MR images have smaller matrix sizes and more noise, resulting in less inherent redundancy. Recent techniques have focused on the use of three-dimensional compression for CT and MR.^{12,13} This takes into account the slice to slice correlation as the body is sectioned into consecutive images, and can be used to achieve higher levels of compression. Examples are shown in the tutorial.

REGULATORY ISSUES

The standard for teleradiology developed by the American College of Radiology makes allowance for the use of compression, indicating that compressed images should be clearly labeled for the interpreting radiologist. The College does not indicate what type of compression should be used or at what ratio.¹⁴ The US Food and Drug Administration (FDA) considers compression technology as part of teleradiology systems and PACS in applications for premarket notifications (510 (k)). The FDA states that devices "which utilize lossy compression shall be provided with instructions which explain the effects of lossy compression, and include examples of the effects of information loss on image quality."¹⁵ Images that have been subjected to lossy compression must be labeled accordingly, including the approximate compression ratio used. These policies alert the user to the types of artifacts or image degradation that may occur at various compression ratios. The physician ultimately takes responsibility for interpreting images subjected to image compression and must be aware of its use and potential effects.

SUMMARY

The tutorial will expand on all of the topics outlined above and will provide additional information on other compression techniques. The practical implications of data compression and the important considerations in choosing a compression scheme will also be discussed. Development of new compression algorithms remains an active area of investigation and will continue to increase the degree of compression possible.

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