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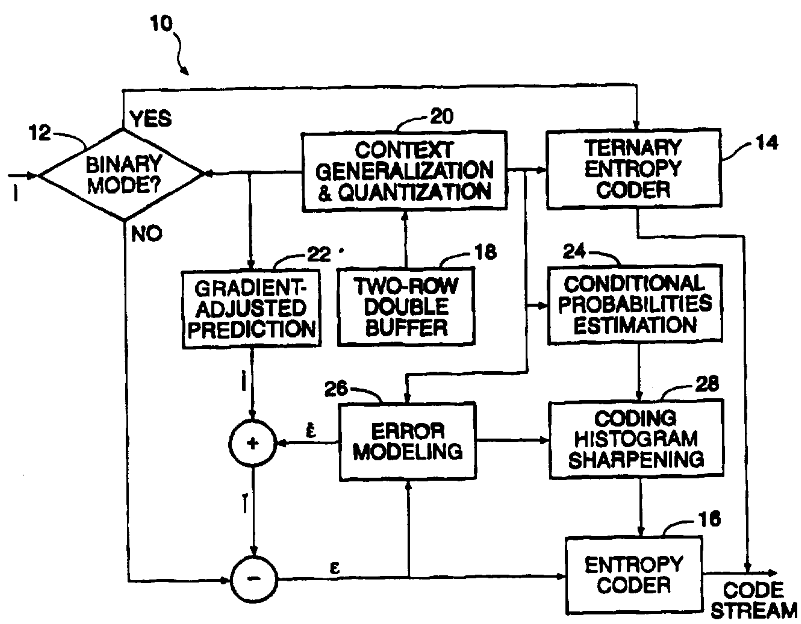

(57) Abstract

An encoding/decoding method is provided for lossless (reversible) compression of digital pictures of all types, including continuous-tone images, graphics, multimedia images of mixed text, graphics and photographs, binary documents and drawings. Continuous-tone mode and binary mode are identified on a pixel-by-pixel basis (12). In continuous-tone mode, context modeling and prediction (20, 22, 26) are employed involving mostly integer arithmetic and simple logic in a conceptually sophisticated scheme. Both the encoding and decoding techniques are suitable for sequential and progressive transmission, although different specific algorithms may be employed for the different ... The system is symmetric, meaning that the encoder and decoder have the same time and space complexities.

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CONTEXT-BASED, ADAPTIVE, LOSSLESS IMAGE CODEC

CLAIM OF PRIORITY

The present application claims partial priority of British Provisional Patent Application Serial No. 9422738-6 filed 10 November 1994.

BACKGROUND OF THE INVENTION

With rapidly-advancing computer, telecommunication, and digital imaging technologies, there is an astronomical amount of image data for a wide range of applications such as education, entertainment, medical imaging, space exploration, electronic publishing, visual arts, etc. This rapid growth of image data puts punishing burdens on computer storage and visual communication bandwidth. Thus image compression becomes a pressing technical challenge in visual communications and computing, without which it will be difficult to build, deploy, and use cost-effective multimedia information systems.

Lossless compression is a form of compression where an image can be reconstructed without any loss of information. Lossless image compression is required by medical imaging, satellite/aerial imaging, image archiving, preservation of precious art work and documents, the press, or any applications demanding ultra high image fidelity. Furthermore, lossless image coding is the necessary last step of many lossy image compression systems, such as lossless compression of codeword indices in vector quantization (VQ), and lossless compression of transform coefficients in Discrete Cosine Transform (DCT) and wavelet/subband-based coding.

There exists a large body of literature on lossless image compression algorithms and systems, such as the IBM Q-coder, and JPEG lossless coder. Among notable patents and publications are the US patents and research publications listed below:

4,463,342 1984 IBM.
4,749,983 07/1988 Langdon.
4,969,204 11/1989 Melnychuck et al.
5,050,230 09/1990 Jones et al.
Universal Modeling and Coding -- J. Rissanen and G. Langdon, 1981, IEEE, vol. IT-27.
A Universal Data Compression System -- J. Rissanen, 1983, IEEE, vol. IT-29.
Parameter Reduction and Context Selection for Compression of the Gray-Scale Images -- S. Todd, G. Langdon, and J. Rissanen, 1985, IBM J. Res. & Develop., vol. 29.
Comparing the Lossless Image Compression Standards and Universal Context Modelling -- R. Arps, M. Weinberger, T. Truong, and J. Rissanen, Proc. of the Picture Coding Symposium, Sacramento, September 1994.
On the JPEG Model for Lossless Image Compression -- G. Langdon, A. Gulati, and E. Seiler, Proc. of 1992 Data Compression Conf.
New Methods for lossless Image Compression Using Arithmetic Coding --P. Howard and J. Vitter, 1992, Info. Proc. & Manag., vol. 28.

The currently achievable lossless compression ratio is still modest, being typically from 1.5:1 to 2.5:1. For instance, in contrast to the success of JPEG's lossy compression standard, the current JPEG's lossless compression standard has sufficiently poor coding efficiency that it is seldom used in practice.

In 1994, ISO and JPEG solicited for proposals for the next international standard for lossless image compression. The present invention is a result of the inventors' response to the ISO solicitation. The lead inventor Xiaolin Wu, developed a context-based, adaptive, lossless image coding and decoding technique (herein CALIC). Among nine proposals that were submitted to ISO for its initial evaluation as candidates for the lossless image compression standard in 1995, the present CALIC system ranked first according to a criterion that accounts for both coding efficiency and algorithm simplicity.

Known prior art on lossless compression of continuous-tone images is based on the principle of predictive coding. An image is traversed, and pixels are encoded in a fixed order, typically in raster scan sequence. Previously encoded pixels that are known to both the encoder and the decoder are used to predict the upcoming pixels. The prediction errors rather than the pixels themselves are entropy encoded by Huffman or like arithmetic coding. The original image is reconstructed by adding the error term back to the prediction value. The predictive coding works because the histogram of the errors is much more concentrated (heavily biased toward 0) than the histogram of the pixel values, resulting in a significantly smaller zero-order entropy for the former than for the latter. Among numerous prediction schemes in the literature, the simplest type is a fixed linear predictor such as those used under the current lossless JPEG standard.

A linear predictor can be optimized on an image-by-image or even block-by-block basis via linear regression. However, such an optimization is expensive and brings only modest improvement in coding efficiency. Moreover the performance of linear predictors is not robust in the areas of edges. Adaptive, non-linear predictor can adjust parameters according to the local edge strengths and orientations, if edges exist. The adjustment of predictor parameters can be made very efficient since it is based on local information.

Historically, lossless image compression inherited the theoretical framework and methodology of text compression. Statistical modeling of the source being compressed plays a central role in any data compression systems. Suppose that we encode a finite source $x_1, x_2, \ldots, x_n$ sequentially. The optimal code length of the sequence in bits is then

$$-log\prod_{i=0}^{n-1} p(x_{i+1}|x_i,\ldots,x_1), \qquad (1)$$

given the assignments of conditional probabilities. Arithmetic coding can approach this code length of the source.

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