United States Patent [19]

Jacobs et al.

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[45] **Date of Patent: Jan. 19, 1999**

[54] **METHOD OF ENCODING A DIGITAL IMAGE USING ADAPTIVE PARTITIONING IN AN ITERATED TRANSFORMATION SYSTEM**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, D.C.

[21] Appl. No.: **859,782**

[22] Filed: **Mar. 30, 1992**

[51] **Int. Cl.**[6] **G06K 9/36**

[52] **U.S. Cl.** **382/249**; 348/397; 348/438

[58] **Field of Search** 382/56, 14; 358/426, 358/430, 433, 133, 135, 136

[56] **References Cited**

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Jacquin, "Fractal Image Coding Based on a Theory of Iterated Contractive Image Transforms" Oct. 1990 pp. 227–239.

Wu et al, "Image Coding by Adaptive Tree–Structured Segmentation" 1991 pp. 73–82 DCC '91.

Primary Examiner—Leo Boudreau
Assistant Examiner—Chris Kelley
Attorney, Agent, or Firm—Harvey Fendelman; Michael A. Kagan; Peter A. Lipovsky

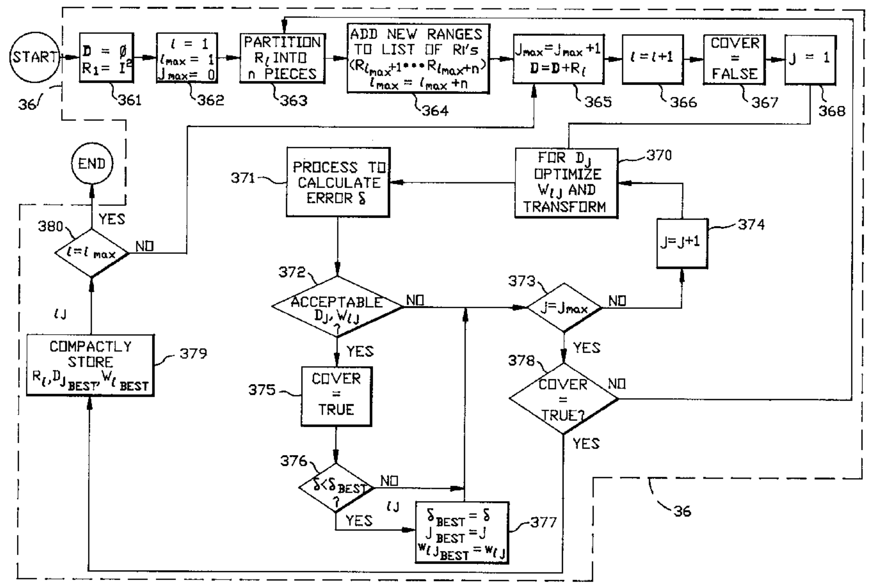
[57] **ABSTRACT**

A method of encoding a digital image using adaptive partitioning in an iterated transformation image compression system is provided. A set of ranges R is initialized to include at least two uncovered ranges. A set of domains D is initialized to include only one member which is the entire image area.

For each uncovered range in the set R: A transformation is generated for each domain in the set of domains. Each domain is transformed into corresponding transformed images to map onto each uncovered range in the set R. Each domain's transformation is optimized and is indicative of a domain's corresponding optimized transformation image for an associated uncovered range. Each optimized transformation image is compared with the associated uncovered range to provide error data as a function of the difference therebetween. The associated uncovered range is redefined as a covered range when the error data for the associated uncovered range is within predefined limits. The covered range is then added to the set of domains D. The associated uncovered range is partitioned into a plurality of non-overlapping image areas. Partitioning is based upon the features of the image bounded by the associated uncovered range and takes place when the error data for the associated uncovered range exceeds the predefined limits. Each of the non-overlapping image areas is added to the set R of uncovered ranges and the associated uncovered range is added to the set of domains D.

The steps of generating, transforming, optimizing, comparing, redefining, partitioning and adding are repeated to select a set of covered ranges, domains and corresponding optimized transformations. The set of covered ranges form a non-overlapping tiling of the image and some iterate of the set of selected transformations is contractive. Information that identifies the set of covered ranges, domains and corresponding optimized transformations is stored compactly in an addressable memory.

9 Claims, 3 Drawing Sheets



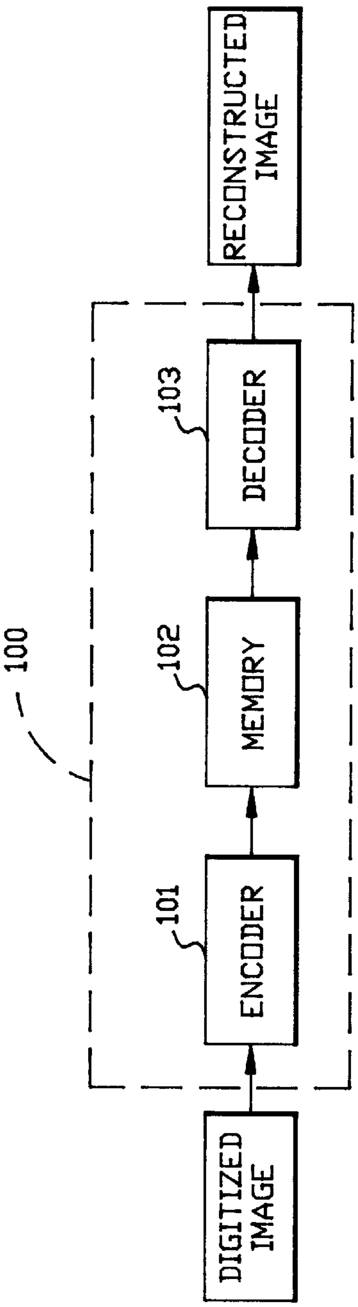


FIG. 1

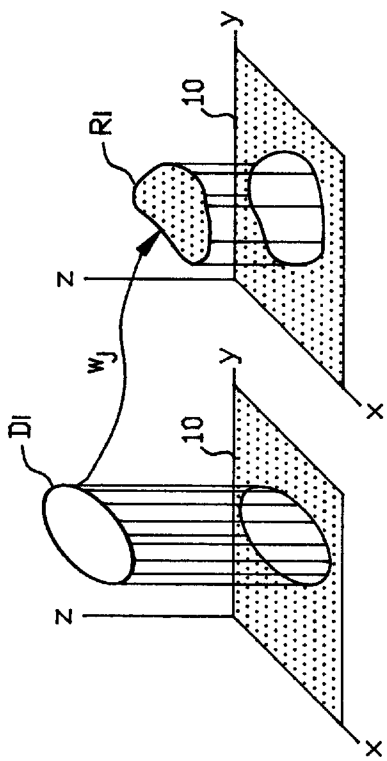


FIG. 2

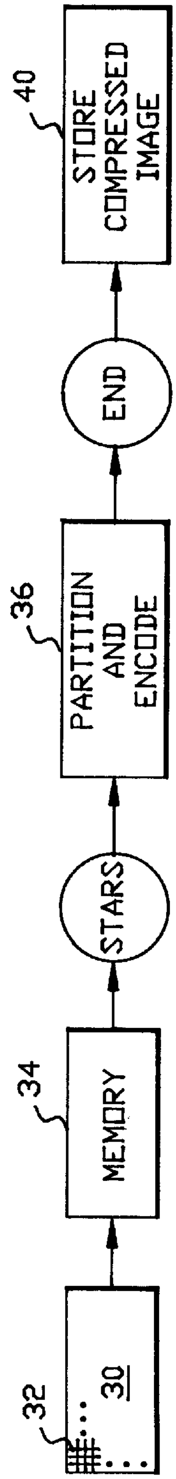


FIG. 5

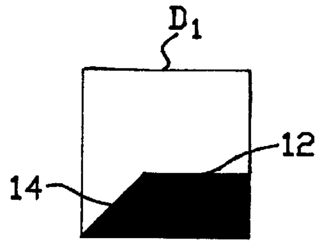


FIG. 3a

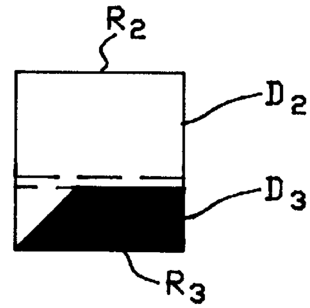


FIG. 3b

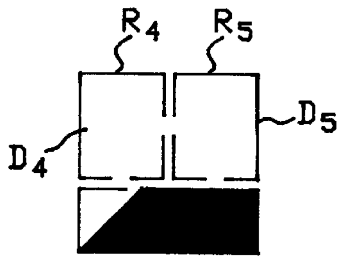


FIG. 3c

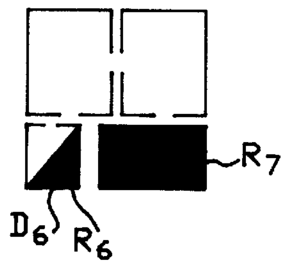


FIG. 3d

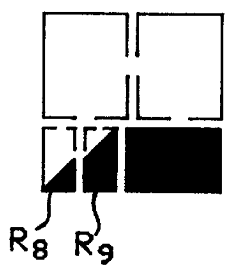


FIG. 3e

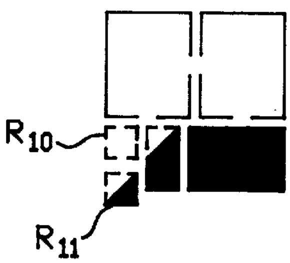


FIG. 3f

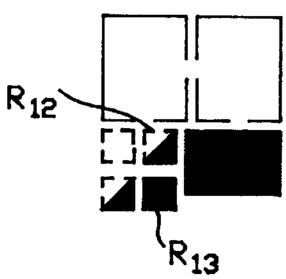


FIG. 3g

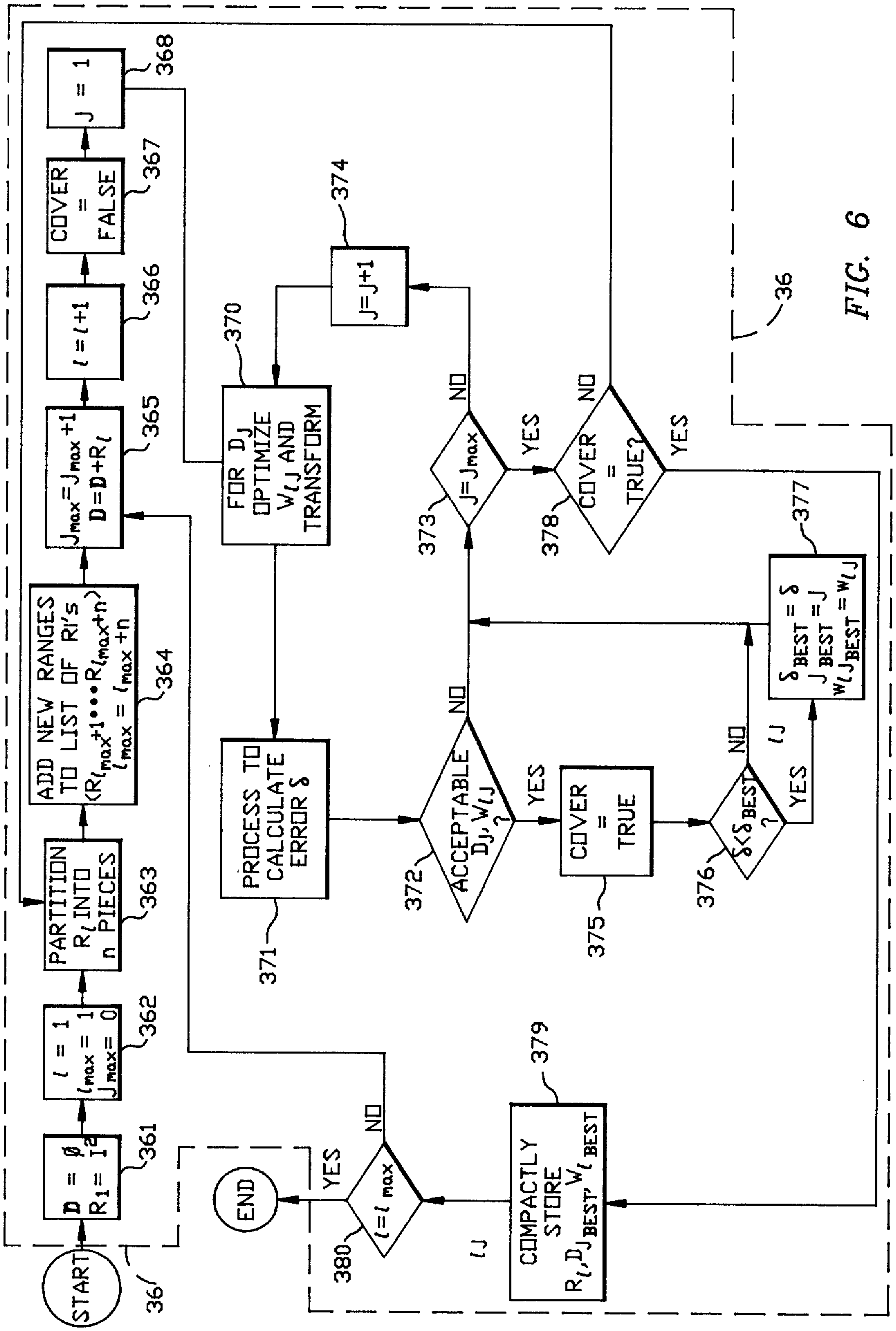

START
D = Ø
$R_1 = I^2$
361
$l = 1$
$l_{max} = 1$
$J_{max} = 0$
362
PARTITION R_l INTO n PIECES
363
ADD NEW RANGES TO LIST OF Ri's
364
365
$l = l + 1$
366
COVER = FALSE
367
J = 1
368
FOR D_J OPTIMIZE W_{lJ} AND TRANSFORM
370
PROCESS TO CALCULATE ERROR δ
371
372
$J = J_{max}$
373
J=J+1
374
COVER = TRUE
375
376
377
COVER = TRUE?
378
379
380
END
YES
NO
36

FIG. 6

METHOD OF ENCODING A DIGITAL IMAGE USING ADAPTIVE PARTITIONING IN AN ITERATED TRANSFORMATION SYSTEM

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment of any royalties thereon or therefor.

This patent application is copending with our related patent application entitled "Method of Encoding a Digital Image Using Iterated Image Transformations to Form an Eventually Contractive Map" filed on the same date as subject patent application.

FIELD OF THE INVENTION

The present invention relates to the field of digital image compression, and more particularly to a method of encoding a digital image using adaptive partitioning in an iterated transformation system.

BACKGROUND OF THE INVENTION

Advances in computer hardware and software technology have brought about increasing uses of digital imagery. However, the amount of memory necessary to store a large number of high resolution digital images is significant. Furthermore, the time and bandwidth necessary to transmit the images is unacceptable for many applications. Accordingly, there has been considerable interest in the field of digital image compression.

The basic elements of a digital image compression system are shown schematically in FIG. **1**, and are referenced by those elements contained within dotted line box **100**. A digitized image is processed by an encoder **101** to reduce the amount of information required to reproduce the image. This information is then typically stored as compressed data in a memory **102**. When the image is to be reconstructed, the information stored in memory **102** is passed through a decoder **103**.

The goal of a good compression method implemented by encoder **101** is to attain a high compression ratio with minimal loss in fidelity. One of the latest approaches to the image compression problem has been put forth by Arnaud Jacquin in a paper entitled "Fractal Image Coding Based on a Theory of Iterated Contractive Image Transformations", appearing in The International Society for Optical Engineering Proceedings Volume 1360, Visual Communications and Image Processing, October 1990, pp. 227–239.

As is known in the art, fractal image generation is based on the iteration of simple deterministic mathematical procedures that can generate images with infinitely intricate geometries (i.e. fractal images). However, to use these fractal procedures in digital image compression, the inverse problem of constraining the fractal complexity to match the given complexity of a real-world image must be solved. The "iterated transformation" method of Jacquin constructs, for each original image, a set of transformations which form a map that encodes the original image. Each transformation maps a portion of the image (known as a domain) to another portion of the image (known as a range). The transformations, when iterated, produce a sequence of images which converge to a fractal approximation of the original image.

In order for a transformation to map onto some portion of the original image within a specified error bound, the

transformation must be optimized in terms of position, size and intensity. If the transformation cannot be optimized within the specified error bound for a given set of ranges and domains, predefined subdivisions of the ranges are selected. The search for an optimized transformation then continues using these subdivisions. One method of predefining the subdivisions is known as quad-tree partitioning which divides a square sized range in a fixed way. Essentially, the range is subdivided into four equally sized squares without considering any of the image's features.

Thus, the need exists for a method of adaptively partitioning the image in an iterated transformation system based upon the features of the image. Accordingly, it is an object of the present invention to provide a method of encoding a digital image in an iterated transformation system by using adaptive partitioning in determining suitable ranges and domains to encode the image. Another object of the present invention is to provide a method of encoding a digital image in an iterated transformation system that adjusts to the features of the image during its partitioning process.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method of encoding a digital image using adaptive partitioning in an iterated transformation image compression system is provided. The digital image is represented by an array of pixels defining an entire image area. Each pixel is defined by a three-dimensional vector identifying the position of the pixel in the array and an intensity level of the pixel. A set of ranges R is initialized to include at least two uncovered ranges. Each uncovered range is a section of the entire image area such that the union of the uncovered ranges tile the entire image. A set of domains D is initialized to include only one member which is the entire image area. For each uncovered range in the set R, a transformation is generated for each domain in the set of domains. The transformation comprises a 3×3 matrix identifying positional scaling coefficients and an intensity scaling coefficient, and a 3×1 vector identifying positional offset coefficients and an intensity offset coefficient. Each domain is transformed into corresponding transformed images scaled in size and intensity, based upon each domain's transformation, to map onto each uncovered range in the set R. For each uncovered range in the set R, each domain's transformation is optimized in terms of the intensity scaling and offset coefficients. An optimized transformation is indicative of a domain's corresponding optimized transformation image for an associated uncovered range. For each uncovered range in the set R, each optimized transformation image is compared with the associated uncovered range to provide error data as a function of the difference therebetween. For each uncovered range in the set R, the associated uncovered range is redefined as a covered range when the error data for the associated uncovered range is within predefined limits. The covered range is then added to the set of domains D. For each uncovered range in the set R, the associated uncovered range is partitioned into a plurality of non-overlapping image areas. Partitioning is based upon the features of the image bounded by the associated uncovered range and takes place when the error data for the associated uncovered range exceeds the predefined limits. For each uncovered range in the set R, each of the non-overlapping image areas is added to the set R of uncovered ranges. The associated uncovered range is added to the set of domains D. The steps of generating, transforming, optimizing, comparing, redefining, partitioning and adding are repeated to select a set of covered ranges, domains and corresponding optimized transformations. The set of cov-

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