New Format for Coding of Single and Sequences of Medical Images

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Abstract The recent development and use of huge image databases creates various problems concerning their efficient archiving and content protection. A wide variety of standards, methods and formats have been created, most of them aimed at the efficient compression of still images. Each standard and method has its specific advantages and demerits, and the best image compression solution is still to come. This chapter presents new format for archiving of still images and sequences of medical images, based on the Inverse Pyramid Decomposition, whose compression efficiency is comparable to that of JPEG. Main advantages of the new format are the comparatively low computational complexity and the ability to insert resistant and fragile watermarks in same digital image.

Keywords Image archiving · Lossy and lossless image compression · Image formats · Coding of medical image sequences

1 Introduction

The most famous contemporary file formats, widely used for image scanning, printing and representation, are TIF, JPG and GIF [1–3]. These are not the only choices of course, but they are good and reasonable choices for general purposes.

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Newer formats like JPG2000 never acquired popular usage, and are not supported by web browsers. The most popular format for medical images is DICOM (based on the JPEG standard) [4]. A brief survey of the most important contemporary image formats is given below.

The TIF format (Tag Image File Format) is the format of choice for archiving important images [5]. It is the most universal and widely supported format across all platforms, Mac, Windows, and UNIX. The main disadvantage is that TIF files are generally pretty large (uncompressed TIF files are about the same size in bytes as the image size in memory).

The JPG format (Joint Photographic Experts Group) [6] always uses lossy compression, but its degree is selectable: for higher quality and larger files, or lower quality and smaller files. However, this compression efficiency comes with a high price: some image quality is lost when the JPG data is compressed and saved, and this quality can never be recovered. This makes JPG be quite different from all the other usual file format choices. Even worse, more quality is lost every time the JPG file is compressed and saved again, so ever editing and saving a JPG image again is a questionable decision. JPG files are very small files for continuous tone photo images, but JPG is poor for graphics. JPG requires 24 bit color or 8 bit grayscale, and the JPG artifacts are most noticeable in the hard edges in the picture objects.

The GIF format (Graphic Interchange Format) [6] uses indexed color, which is limited to a palette of only 256 colors and is inappropriate for the contemporary 24-bit photo images. GIF is still an excellent format for graphics, and this is its purpose today, especially on the web. GIF uses lossless LZW compression and offers small file size, as compared to uncompressed data.

The PNG (Portable Network Graphics) format was designed recently, with the experience advantage of knowing all that went before [6]. It supports a large set of technical features, including superior lossless compression from LZ77 algorithm. The main disadvantage is that it incorporates special preprocessing filters that can greatly improve the lossless compression efficiency, but this introduces some changes in the processed image.

Depending on the format used, image compression may be lossy or lossless. Lossless compression is preferred for archival purposes and often for medical imaging, technical drawings, clip art, or comics. Lossy methods are especially suitable for natural images such as photographs in applications where minor (sometimes imperceptible) loss of fidelity is acceptable to achieve a substantial reduction in bit rate.

The basic methods for lossless image compression are:

- Run-length encoding—used as default method in PCX (Personal Computer eXchange—one of the oldest graphic file formats) and as one of possible in TGA (raster graphics file format, created by Truevision Inc.), BMP and TIFF;
- DPCM (Differential Pulse Code Modulation) and Predictive Coding;
- Adaptive dictionary algorithms such as LZW (Lempel–Ziv–Welch data compression)—used in GIF and TIFF;

- Deflation—used in PNG and TIFF
- Chain codes.

The most famous contemporary methods for lossy image compression are based on:

- Reducing the color space to the most common colors in the image;
- Chroma subsampling: this approach takes advantage of the fact that the human eye perceives spatial changes of brightness more sharply than those of color, by averaging or dropping some of the chrominance information in the image;
- Transform coding: a Fourier-related transform, such as DCT or the wavelet transform are applied, followed by quantization and entropy coding.
- Fractal compression: it differs from pixel-based compression schemes such as JPEG, GIF and MPEG since no pixels are saved. Once an image has been converted into fractal code, it can be recreated to fill any screen size without the loss of sharpness that occurs in conventional compression schemes.

The best image quality at a given bit-rate (or compression ratio) is the main goal of image compression, however, there are other important properties of image compression schemes:

Scalability generally refers to a quality reduction achieved by manipulation of the bitstream or file (without decompression and re-compression). There are several types of scalability:

- **Quality progressive** or layer progressive: The bitstream successively refines the reconstructed image.
- **Resolution progressive**: First encode a lower image resolution; then encode the difference to higher resolutions.
- **Component progressive**: First encode grey; then color.

Region of interest coding: Certain parts of the image are encoded with higher quality than others. This quality is of high importance, when medical visual information is concerned.

Meta information: Compressed data may contain information about the image which may be used to categorize, search, or browse images. Such information may include color and texture statistics, small preview images, and author or copyright information.

Processing power (computational complexity): Compression algorithms require different amounts of processing power to encode and decode.

All these standards and methods aim processing of single images. The contemporary medical practice involves also processing of large sequences of similar images, obtained from computer tomographs, and there is no special tool for their archiving.

In this chapter is presented one new format for still image compression and its extension for group coding of similar images. The chapter is arranged as follows: In Sect. 2 are given the basics of the methods, used for the creation of the new image archiving format; in Sect. 3 is presented the detailed description of the new format; in Sect. 4 are outlined the main application areas and Sect. 5—the Conclusion.

2 Brief Representation of the Methods, Used as a Basis for the Creation of the New Format

Two methods were used for the creation of the new format: the Inverse Pyramid decomposition (IDP) and the method for adaptive run-length data encoding (ARL).

2.1 Basic Principles of the IDP Decomposition

The IPD essence is presented in brief below for 8-bit grayscale images, as follows. The digital image matrix is first processed with two-dimensional (2D) direct Orthogonal Transform (OT) using limited number of low-frequency coefficients only. The values of these coefficients build the lowest level of the pyramid decomposition. The image is then restored, performing Inverse Orthogonal Transform (IOT) using the retained coefficients' values only. In result is obtained the first (coarse) approximation of the original image, which is then subtracted pixel by pixel from the original one. The so obtained difference image, which is of same size as the original, is divided into 4 sub-images and each is then processed with 2D OT again, using a pre-selected part of the transform coefficients again. The calculated values of the retained coefficients build the second pyramid level. The processing continues in similar way with the next, higher pyramid levels. The set of coefficients of the orthogonal transform, retained in every decomposition level, can be different and defines the restored image quality for the corresponding level (more coefficients naturally ensure higher quality). The image decomposition is stopped when the needed quality for the approximating image is obtained—usually earlier than the last possible pyramid level. The values of the coefficients got in result of the orthogonal transform from all pyramid levels are then quantitated, sorted in accordance with their spatial frequency, arranged as one-dimensional sequence, and losslessly compressed. For practical applications the decomposition is usually "truncated", i.e. it does not start from the lowest possible level but from some of the higher ones and for this, the discrete original image is initially divided into sub-blocks of size $2^n \times 2^n$. Each sub-block is then represented by an individual pyramid, whose elements are calculated using the corresponding recursive calculations. For decomposition efficiency enhancement is used a "truncated" decomposition, i.e. the decomposition starts after dividing the original image into smaller sub-images, and stops when the sub-image becomes of size 4×4 pixels.

The so presented approach was modified for the processing of a group of related images (usually these are images obtained by a computer tomography or in other similar cases). For this, one of the images is used as a reference one, and its first approximation for the lowest decomposition level is used by the remaining images in the group for the calculation of their next approximations. The detail presentation of the method and its applications are given in related publications of the authors [7, 8].

2.2 Description of the ARL Coding Method

The method for adaptive run-length data coding is aimed at efficient compression of sequences of same (or regularly changing) n-dimensional binary numbers without data length limitation. The coding is performed in two consecutive stages. In the first one, the input data is transformed without affecting their volume in such a way, that to obtain sequences of same values (in particular, zeros) of maximum length. The transform is reversible and is based on the analysis of the input data histograms and on the differences between each number in the processed data and the most frequent one. When the first stage is finished, is analyzed which data sequence is more suitable for the further processing (the original, or the transformed one) depending on the fact in which histogram were detected longer sequences of unused ("free") values. In case that the analyzed histograms do not have sequences, or even single free values, the input data is not suitable for compression; else, the processing continues with the second stage. In this part of the processing the transformed data is analyzed and sequences of same numbers are detected. Every such sequence is substituted by a shorter one, corresponding to the number of same values which it contains. Specific for the new method for adaptive run-length data coding is that it comprises operations of the kind "summing" and "sorting" only, and in result, its computational complexity is not high. The method is extremely suitable for compression of still images, which comprise mainly texts or graphics, such as (for example): bio-medical information (ECGs, EEGs, etc.), signatures, fingerprints, contour images, cartoons, and many others. The method is highly efficient and is suitable for real-time applications. The detailed presentation of the method is given in earlier publications of the authors [9, 10].

The new format, presented in detail below, comprises short descriptions of all parameters of the pyramid decomposition and of the lossless coding method, together with the basic parameters, needed for the group coding of similar images.

3 New Format Description

The format works with 8 and 24 bpp images of practically unlimited size. The compressed image data consists of two basic parts: the header and the data, obtained after the processing (i.e. the coded data). The header contains the information, which represents the values of the basic parameters of the IDP decomposition, needed for the proper decoding. It comprises 3 main parts: the IDP header, sub-headers for image brightness and color data, and information about the lossless coding of the transform coefficients' values. Additional information is added, needed for the processing of a group of similar images and compound images. The detailed description of the header follows below.

3.1 General Header

3.1.1 IDP Header

The first part of the header contains general information for the IDP decomposition configuration used:

Number of bytes after run-length coding (binary)—32 bits;
Final number of bytes, after entropy coding (binary)—32 bits;

IDP parameters—16 bits (truncated decomposition used, starting after image dividing into smaller sub-images):
Most significant byte (MSB):

MSB	X1	X2	X3	X4	X5	X6	X7	X8

X1–X4 Number of the selected initial decomposition level (1 hexadecimal number);
X5–X8 Number of the selected end decomposition level (1 hexadecimal number);

Least significant byte (LSB):

LSB	X9	X10	X11	X12	X13	X14	X15	X16

X9–X12 Maximum number of pyramid levels (1 hexadecimal number)—depends on the processed image size;
X13 Direct coding (optional);
X14 Free;
X15 Color/Grayscale;
X16 Color palette type

Description of the basic decomposition parameters—16 bits:

MSB	X1	X2	X3	X4	X5	X6	X7	X8

X1 Gray type color image;
X2 Inverse Pyramid decomposition;

X3	Difference/Direct image coding;
X4, 5	Free/Lossless compression;
X6, 7	Color space used (PAL, NTSC, RCT, YCrCb);
Coding	00—PAL; 01—NTSC; 02—RCT; 03—YCrCb;
X8	Color space RGB selected

LSB	X9	X10	X11	X12	X13	X14	X15	X16

X9	Horizontal image scan;
X10	Run-length coding performed in horizontal direction;
X11	Right shift for brightness components data (quantization);
X12	Right shift for color components data (quantization);
X13	Entropy coding enabled;
X14	Run-length encoding enabled;
X15	Flag indicating that the U values in the YUV color transform had been used;
X16	Flag indicating that the V values in the YUV color transform had been used

3.1.2 Sub-Header for the Image Brightness Data

Mask for the transform coefficients in the initial pyramid level (4 hexadecimal numbers)—16 bits:

MSByte	MSb	….	LSb		LSByte	MSb	….	LSb

Common mask for the transform coefficients in the middle levels of the pyramid decomposition (4 hexadecimal numbers)—16 bits:

MSByte	MSb	…..	LSb		LSByte	MSb	…..	LSb

Mask for the transform coefficients in the highest pyramid level (4 hexadecimal numbers)—16 bits:

MSByte	MSb	…..	LSb		LSByte	MSb	…..	LSb

Run-length type, 8 types—8 bits (patented);

First Run-length code—8 bits (patented);

Last (second) Run-length code—8 bits (patented);

Quantization coefficient for the first pyramid level—binary number (8 bits);

Selected approximation method for each level (WHT, DCT, etc.)—6 bits: 2 bits for each group: Initial level, Middle levels and Last level. Approximation coding: 00—WHT; 01—DCT; 02—Plane; 03—Surface.

Original image size (vertical direction)—binary number (16 bits);
Original image size (horizontal direction)—binary number (16 bits).

3.1.3 Sub-Header for the Image Color Data

Number of the selected initial level (2 hexadecimal numbers)—8 bits:

MSb	…..	LSb

Number of the selected end level (2 hexadecimal numbers)—8 bits:

MSb	…..	LSb

Mask for the used coefficients selection in the initial decomposition level (4 hexadecimal numbers)—16 bits:

MSByte	MSb	….	LSb		LSByte	MSb	….	LSb

Mask for the used coefficients selection in the middle decomposition levels (common mask for all levels)—16 bits:

MSByte	MSb	….	LSb		LSByte	MSb	….	LSb

Mask for the used coefficients selection in the highest decomposition level—16 bits:

MSByte	MSb	….	LSb		LSByte	MSb	….	LSb

- Division coefficient for the first pyramid level (binary number)—8 bits;
- Selected approximation method for each level (WHT, DCT, etc.)—6 bits, 2 bits for each group: Initial level, Middle levels and Last level.

Coding: 00—WHT; 01—DCT; 02—Plane; 03—Surface;

- Original image size (vertical direction)—binary, 16 bits;
- Original image size (horizontal direction) – binary, 16 bits;
- Used color format (4:1:1, 4:2:2, 4:4:4, 4:2:0)—16 bits.

Coding: 00—4:2:0; 01—4:4:4; 02—4:2:2; 04—4:1:1.

3.1.4 Sub-Headers for Transform Coefficients Quantization

- Sub-header for the last level (brightness): 16 binary numbers, for coefficients (0–15): 8 bits each;

- Sub-header for the last level (color): 16 binary numbers, for coefficients (0–15): 8 bits each.

3.1.5 Entropy Coding Table

- Number of bytes representing the Entropy Table (8 bits);
- Coding tree:
  - most frequent value;
  - second most frequent value;
  - next values (up to 19 or 31), depending on the coding tree length permitted (selected after better performance evaluation).
  - Coded image data.

3.2 Coding of Group of Images: Additional Header

3.2.1 Group Header (First IDP Header)

Group coding identifier—16 bits (binary number);
Number of images in the group—8 bits (binary number);
Length of the reference image name—8 bits;
String of length equal to reference image name;
Length of the processed image name;
String of length equal to processed image name.

3.2.2 Header of the First Approximation of the Reference Image (Second Header)

- IDP header—contains the description of the predefined decomposition parameters.
- Coded data

3.2.3 Next Header (for Higher Level Approximations of Each Multispectral Image in the Group)

- Regular header—IDP decomposition parameters.
- Coded data

3.3 Coding of Compound Images: Additional Header

The basis is the IDP header—i.e. the first header.

Additional information placed at the header end:

- Layer file identifier—16 bits (binary number)—layers correspond to number of objects detected in the image: pictures, text, graphics, etc.

For each part (object):

- Coordinates of the image part segmented (in accordance with the object segmentation—text or picture)—2 × 16 bits (horizontal and vertical coordinate of the lower left corner of the image part);
- Corresponding regular IDP header;
- Coded data.

3.4 Additional Information

The new format is very flexible and permits the addition of meta information, which to enhance image categorization, search, or browsing: special data about the disease, the patient age, medication, etc. This could also include the kind of IDP watermarking used for the image content protection (resistant or fragile), the number of watermarks, or other similar information.

4 Application Areas

The everyday IT practices require intelligent approach in image compression and transfer. Usually such applications as image archives, e-commerce, m-trade, B2B, B2C, etc., need fast initial image transfer without many details, which are later sent to customers on request only. For such applications the IDP method is extremely suitable because it permits layered image transfer with increasing visual quality. Additional advantage of the IDP method is that because of the layered decomposition it permits insertion of multiple digital watermarks (resistant and fragile) in each layer [11]. Special attention requires the ability of the method for scalable image representation. For this, the image approximations, which correspond to lower decomposition layers, are represented scaled down. In result, the quality of the restored images is visually lossless for very high compression ratios [12]. Additional advantage is that the specially developed format permits easy insertion of meta-information of various kinds. The computational complexity of the method is lower than that of other contemporary methods for image compression. Detailed evaluation of the computational complexity and comparison with JPEG2000 is given in [12]. One more advantage is, that unlike JPEG, in which more quality is lost every time the file is compressed and saved again, the IDP format retains the restored image quality regardless of the number of compressions/decompressions. The method is suitable for wide variety of applications: still image compression and archiving; creation of contemporary image databases with reliable content protection; efficient compression of multispectral and multi-view images, medical images and sequences of medical images.

The flexible IDP-based image processing, used for the creation of the new format, permits setting of regions of interest and building of individual decomposition pyramids for each region of interest. This approach is the basis for adaptive processing of compound images, which contain pictures and texts.

5 Conclusions

The new format, presented in this chapter, is already implemented in software (Visual C, Windows environment) developed at the Technical University of Sofia. Several versions are already developed for still image compression, image group coding, image content protection with multiple watermarks, image hiding, archiving of multi-view and multispectral images and video sequences. The software implementation of the IDP method based on the new format confirms its flexibility and suitability for various application areas. The new format answers the requirements for the most important properties of the image compression schemes: Scalability, Region of interest coding, Processing power and Meta information. Compared to basic image compression standards, the new format offers certain advantages, concerning efficiency, computational complexity, ability to set regions of interest, and the insertion of meta information (setting regions of interest after image content analysis, digital watermarks insertion, etc.) [11]. The relatively low computational complexity permits its ability for real-time applications also.

Special advantage is the method version for lossless image and data compression, which is extremely efficient for graphics (EEGs and ECGs also) and text images [10].

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