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Compression of Color Medical Images in Gastrointestinal Endoscopy: A Review

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Abstract

This paper reviews the state of medical color digital imaging with respect to image compression. Only recently has the creation and storage of color medical images become technically and economically feasible. This has allowed medical images to become a part of an electronic medical record, to be used in telemedicine, or to be used for medical education. The Internet has become an important medium for the dissemination of medical images, whether through file transferring or through the World Wide Web. There is a growing need to evaluate the degree and types of image compression that are clinically acceptable (either for diagnostic or archival purposes) for different specialties. The focus will be on gastrointestinal endoscopic images, although work in other medical specialties will be mentioned.

Keywords

Image Processing, Computer-assisted; Diagnostic Imaging; Endoscopy

Introduction

Digital image data compression is a technology that allows for cost-effective implementation in the radiology arena of picture archiving and communications systems (PACS). PACS in radiology have focused on static greyscale images, such as chest radiographs, mammograms, CT scans or MRI scans. But with improvements in computer technology, storage of dynamic greyscale images, such as ultrasound, fluoroscopy, and angiography, has become technically if not economically feasible. Dynamic greyscale images are associated with video files, composed of specially compressed (e.g. MPEG) multiple sequential still images. Discussion of dynamic images is beyond the scope of this paper. With the rapid advances in computer technology along with a concomitant drop in its price, the creation and storage of digital images has spread to many other medical specialties. Some specialties, such as cardiology, have concentrated on both static (stills of coronary angiography) and dynamic (cine loops of coronary angiography and echocardiography) greyscale images.

Other specialties, however, have required a need for a PACS for color digital images. The ability to display true color (24-bit) images is no longer the realm of special graphical computer workstations but rather has entered the mainstream to the point where 24-bit color display is standard on personal computers sold today. Specialties that are starting to take advantage of color digital imaging include pathology, dermatology, ophthalmology, and those using endoscopes (gastroenterologists, surgeons, and pulmonologists).

Overall, there are two primary functions for medical images: diagnosis and archiving. Images for diagnosis are primarily in the realm of telemedicine, although enhancements in technology to create a working filmless radiology library appear to be just over the horizon. Specialties that are taking advantage of telemedicine technology are radiology, pathology, dermatology, and very recently ophthalmology. Introductory articles for these specialties in digital imaging can be found in the medical literature except for ophthalmology [1-3]. A third function that is starting to be exploited is medical education, as evidenced by the increasing amount of medical images on the World Wide Web and in teaching files, including at our institution.

Gastrointestinal Endoscopy

Gastrointestinal endoscopy manufacturers are beginning to produce image managers with their equipment that are equivalent in concept to PACS in radiology. It is estimated that over 10 million endoscopic procedures are performed yearly in the United States [4]. It is becoming increasingly important to document abnormal or significant findings during the course of an endoscopic procedure for medicolegal reasons. This is usually done by printing a still picture capture from a video charge-coupled device (CCD) with RGB sequencing, although some academic centers have the capability of also recording the procedure on videotape.

It is very convenient to have a stored image to print a hardcopy (for the patient, the referring physician, and the endoscopist's records) and to retrieve quickly in the future for reference during a future procedure or in the off-hours when the paper record is not easily available. In an academic institution, these images (with the patient's name and identifier removed) can be used for medical education in the form of a teaching file or incorporated into slide lectures.

However, there are two problems with the typical 24-bit endoscopic color screen capture file that is often 900 Kbyte in size

(640x480 pixels x 3 8-bit color planes/pixel). First, it would not take long to accumulate roughly 1,100 images to fill 1 Gigabyte of storage space, often necessitating a larger storage device or using removable storage media. Second, for file transmission over the Internet, assuming a 28.8K modem and a noiseless telephone line, a 900K file would take 4.3 minutes to transfer. This may be acceptable for occasional file transfers but not if done frequently. In comparison, a typical high-resolution digital mammogram is likely to be 10-40 Mbyte in size [5]. For simplification, a mammogram file of 18 Mbyte size would be 20 times larger than the color endoscopic file; only 55 images would fit onto a 1 Gigabyte hard drive; and the file would take an unreasonable 85.3 minutes to transfer.

The solution to this problem is to follow the lead of the radiologists and employ image compression techniques to reduce the size of the file while minimizing the loss of important visual information. Sufficient levels of data compression can reduce the size of stored endoscopic images, allowing increased capacity of current storage equipment, such as computer hard drives or removable storage media. In addition, reduction in file size makes transmission of the image practical over computer networks, such as the Internet.

Image Compression

There are two general categories of compression techniques: lossless and lossy. Lossless compression techniques preserve all the information in the compression/decompression process. This is especially important for documents or computer program files, where missing bytes could potentially wreak havoc. However, these techniques can only achieve compression ratios of 1.5-3.0:1 range [6], which is not a very significant savings for medical images, especially for radiological greyscale images. However, when images are used as a means of primary diagnosis, they are required to be stored and transmitted in a lossless fashion.

For the purpose of practical archival storage and transmission of medical images, compression ratios of 20:1 or higher are required. For example, if the images were compressed at a 20:1 ratio, the 900K full-color image would then take 12.5 seconds (vs. 256 seconds), and the 18M greyscale image would take 4:16 (vs. 85:20) minutes to transfer. These times would be considered much more acceptable [7].

In order to achieve compression ratios of 20:1 or higher, lossy compression techniques need to be employed. Lossy compression implies that some information is lost in the compression/decompression process, but algorithms can be designed to minimize the effect of data loss on the diagnostic features of the images. Because of this issue's importance, many techniques have been evaluated, especially on JPEG (Joint Photographic Experts Group) and other discrete cosine transform (DCT)-based algorithms. Although JPEG has essentially become an industry standard, it suffers from blocking artifacts that become more evident with increasing compression ratios [8].

JPEG compression is also important because files using this compression are only one of three file formats used for graphical images on the World Wide Web (the others being GIF [Graphical Interchange Format] and PNG [Portable Network Graphics]). JPEG files have the advantage of remaining 24-bit true color files during compression, while GIF files are limited to 8-bit color (256 colors). This was not a problem 3 years ago when displaying 24-bit color was not an affordable option on personal computers, but with 24-bit color displays standard on today's personal computers, JPEG has become preferred for Web pages [9] and for scanned and captured color medical images. The PNG file format shows promise as a lossless compression method for the Web, but it is too new to have gained acceptance at this time.

It is important to keep in mind two points: (1) some computers in hospitals or physician's offices may only be able to display 256 colors and not see color images as clearly as on a 24-bit color display; (2) if compressing an image for use in displaying on the web, the file size probably should be 40-60K or less to reduce the user's annoyance at waiting for a graphic image to load.

There is one final note about JPEG and greyscale images in general. While color images using JPEG can typically achieve 10:1 to 20:1 compression ratios without visible loss and can compress 30:1 to 50:1 with small to moderate defects, greyscale images do not compress by such large factors. Because the human eye is much more sensitive to brightness variations than to hue variations, JPEG can compress hue (color) data more heavily than brightness (greyscale) data. A greyscale JPEG file is generally only about 10% - 25% smaller than a full-color JPEG file of similar visual quality. But the uncompressed greyscale data is only 8 bits/pixel, or 1/3 the size of the color data, so the calculated compression ratio is much lower. The threshold of visible loss is often around 5:1 compression for greyscale images, which we will explore in the next section [10].

There are other compression methods besides JPEG, however, that use different approaches, which are mentioned in the next section. These include wavelets, fractals, and vector quantization.

Finally, as we will also see in the next section, another way to reduce the file size is to decrease the possible number of colors displayed from 24-bit (16.7+ million) to either 16-bit (65K or high color) or 8-bit (256 colors) using an adaptive color reduction algorithm that is supplied by commercial graphics programs [11,12].

Review of the Medical Literature

When one searches through the medical literature for clinical evaluation of color medical images, there appears to be a paucity of published literature. There may be several reasons for this. First, color digital imaging is a more recent phenomenon compared with greyscale images used by radiologists. Second, many practitioners, especially in gastrointestinal endoscopy, may not be aware that the archived images are compressed and appear to be satisfied with the image quality. Third, funding for trials of this nature do not fall under the traditional banner of clinical trials.

Gastrointestinal Endoscopy

In the gastrointestinal endoscopy literature, there have been two studies examining color endoscopic images. In 1995, Vakil and Bourgeois [12] conducted a trial to determine the amount of color information required for a diagnosis from an endoscopy image. The least amount of color information in an endoscope image that carries sufficient diagnostic information was unknown. Ten lesions of upper gastrointestinal lesions were presented in an 8-bit format, 16-bit format, and a 24-bit format blindly side-by-side on a Macintosh II system with a 19" monitor that could display 24-bit color. Eleven observers (6 nurses and 5 endoscopists) were asked to rank each format for each lesion. There were a total of 330 observations, and for each format and total the results were similar: the observers could not tell a difference on 41% of the images; identified correctly the images in 22%; and identified incorrectly in 37% of the images. Also, the lesions were correctly identified 100%. From this study for endoscopic images, the color resolution does not appear to affect an endoscopist's ability to make a diagnosis.

In the second study, Maycon, Korman, and this author performed a pilot trial to examine whether compression of color endoscopic images had any effect on recognition of the clinical content [13]. Five images of gastrointestinal lesions of different sizes were compressed at different quality levels (90, 70, 50, 30, 20) (range 18:1 to 190:1) using JPEG (LViewPro 1.b; Leonardo Loureiro) from 24-bit TIFF color images. Images (compressed and original) were presented one at a time at different levels of compression with levels blinded to 13 endoscopists. Each was asked to rate the images as excellent, good, poor, or unacceptable. An adequate compression ratio was defined as the minimum ratio where more than half the ratings were excellent or good. Depending on the lesion, the adequate compression ratio ranged from 31:1 to 99:1. What these results seem to indicate is that endoscopists can tolerate very significant compression of endoscopic images without loss of clinical image quality.

Currently, there are three manufacturers of gastrointestinal endoscopy equipment in the United States. All three provide an image manager or a prototype. Pentax Image Management System 2.2 produces 16-bit color endoscopic images in the TGA format (5 bits per color, 192x165 pixels) that are ~62K in size. Fujinon, Inc., has a device (DF-20M) that can capture and write color images to a floppy disk. There are 4 settings with the highest (uncompressed 24-bit color TIFF file, 640x480, 900K) and good (default, 24-bit color JPEG, 640x480, ~47K = ~20:1 compression ratio). Olympus EndoWorks allows one to save (and crop, if desired) a captured image in a variety of file formats, including an uncompressed 24-bit color TIFF file and a JPEG file with a compression ratio of ~ 33:1. These stored files appear to be commercially acceptable to gastrointestinal endoscopists at this time.

Dermatology

The only other study of compression on color medical images was a comparison of JPEG and fractal compression of color medical images for dermatology performed by Sneiderman, et al, in 1994 [14]. Fractal compression is a form of vector quantization that employs a virtual codebook; has a patented technology; has slow compression but fast decompression; and the fractals are Iterated Function Systems. Readers are invited to other articles for a more thorough introduction [15-16]. Four images of skin lesions were first color-reduced to 8-bits and then compressed to 15:1, 30:1, and 40:1 using both JPEG and fractal compression. The original and the compressed files were presented to 30 dermatologists who were to rate their diagnostic assessment as well as image quality. The diagnostic assessment was not affected by compression ratios even up to 40:1 with either type of compression. However, there appeared to be a statistically significant difference in the image quality between the original and any of the compressed slides of either method. There did not appear to be any statistical differences between the two algorithms nor between the dermatologists.

Pathology

One last study of interest regarding color medical images is from the field of telepathology. Doolittle and colleagues investigated the necessity of transmitting 24-bit full color images [11]. In this study, 30 pathologists looked 30 random pairs of images on a telepathology monitor (one 24-bit color; one 8-bit color) and were asked if they could tell any difference in quality between the pair and to choose the better quality image regardless of their answer. Overall, there was no statistically significant ability to consciously detect differences between the image pairs. In fact, when forced to choose, there was a significant preference for the 8-bit image. Using the adaptive color reduction algorithm with diffusion dithering, they were able to achieve a 64% reduction in the average file size (1.37Mb for 24-bit vs. 0.494Mb for 8-bit). Again, we have another study with color images that, in this case with telepathology, take advantage of color reduction to reduce file size without sacrificing image quality.

Other Compression Methods with Greyscale Images

Other compression technologies have been explored by radiologists for greyscale images, but it is too early to tell if they will be adopted by other specialties that use color medical images. Wavelets, discovered in 1987, constitute a new compression technology that has only recently been described and used in the radiology field. An introduction to this technology can be found in other articles [15, 18]. A study done by Goldberg and his colleagues in 1994 [8] showed no clinically relevant image degradation on radiographs below a compression ratio of 30:1. Other studies have explored wavelet technologies in digitized mammograms and MRI scans [17-18].

Another compression technology that has been getting more attention recently is vector quantization, often used in conjunction with neural networks. This concept is based on dividing the image into small blocks of pixels. Each block from an original image is compressed or encoded by selecting a good approximation from a relatively small collection of possible blocks called code words. The collection of code words is called a code book. When a code word is chosen as a good match to the original pixel block, its index in binary form provides a digital representation for the original pixel block. These indexes represent the image in compressed form. Early studies show that acceptable compression ratios that can be achieved depend on the lesion and modality: thoracic CT (9:1) [19], cranial CT (10:1) [20], chest radiograph (30-40:1) [21], and ultrasound [22] without sacrificing image quality. Please see [19] for a further introduction. Time will tell if this technology pans out and is adapted in the mainstream. What does not appear to be elucidated is the computational complexity (and thus, slowness) of this method, and this may hinder this method's acceptance until more cheap and powerful computational resources become readily available.

Summary

Compression of color medical images is still in its infancy compared with work with compression with greyscale images. Because the human eye can tolerate changes in hue (color) better than in brightness (greyscale), larger compression ratios (31-99:1 in endoscopic images and 40:1 in dermatologic images) appear to be clinically acceptable in early studies of color images than in greyscale images. Endoscopists have an advantage with image compression over other specialists who deal with color images. Most regions of interest in the alimentary tract are large and easily recognizable even with some loss of resolution with image compression. Ophthalmologists looking for neovascularization in the eyes of diabetic patients; pathologists performing light microscopy; dermatologists looking at skin lesions at times require fine resolution or detail to help make a diagnosis from a static color image. They cannot afford to trade loss of detail for a smaller file size and thus cannot use compression ratios as high for color medical images.

For this reason, broader analysis using multicenter trials with a library of data images, a larger testing sample, and different testing schemes will be needed to define clinically acceptable digital compression for endoscopic color images. This kind of analysis needs to be done as well for other specialties using color digital images because a clinically acceptable compression ratio for the endoscopist may not be acceptable to the ophthalmologist, pathologist, or dermatologist.

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