Image Compression Concepts Overview

Alan Wee-Chung Liew
Griffith University, Australia

Ngai-Fong Law
The Hong Kong Polytechnic University, Hong Kong

INTRODUCTION

Image compression aims to produce a new image representation that can be stored and transmitted efficiently. It is a core technology for multimedia processing and has played a key enabling role in many commercial products, such as digital camera and camcorders. It facilitates visual data transmission through the Internet, contributes to the advent of digital broadcast system, and makes possible the storage on VCD and DVD. Despite a continuing increase in capacity, efficient transmission and storage of images still present the utmost challenge in all these systems. Consequently, fast and efficient compression algorithms are in great demand.

The basic principle for image compression is to remove any redundancy in image representation. For example, simple graphic images such as icons and line drawings can be represented more efficiently by considering differences among neighbor pixels, as the differences always have lower entropy value than the original images (Shannon, 1948). These kinds of techniques are often referred to as lossless compression. It tries to exploit statistical redundancy in an image so as to provide a concise representation in which the original image can be reconstructed perfectly.

However, statistical compression techniques alone cannot provide high compression ratio. To improve image compressibility, lossy compression is often used so that visually important image features are preserved while some fine details are removed or not represented perfectly. This type of compression is often used for natural images where the loss of some details is generally unnoticeable to viewers.

This articles deals with image compression. Specifically, it is concern with compression of natural color images because they constitute the most important class of digital image. First, the basic principle and methodology of natural image compression is described. Then, several major natural image compression standards, namely JPEG, JPEG-LS, and JPEG 2000 are discussed.

BACKGROUND

A common characteristic of most images is that the neighboring pixels are correlated and thus contain redundant information. The main goal of image compression is to reduce or remove this redundancy. In general, two types of redundancy can be identified (Gonzalez & Woods, 2002):

- **Spatial redundancy:** This refers to the correlation between neighboring pixels. This is the only redundancy for grayscale images.
- **Spectral redundancy:** This refers to the correlation between different color planes or spectral bands. This redundancy occurs in color images or multispectral images and exists together with the spatial redundancy.

Image compression techniques aim at reducing the number of bits needed to represent an image by removing the spatial and spectral redundancies as much as possible. The compression is lossless if the redundancy reduction does not result in any loss of information in the original image.

Besides redundancy, an image may also contain visually irrelevant information. The visually irrelevant information refers to information that is not perceived by human observers. Irrelevancy reduction thus aims at removing certain information in the image that is not noticeable by the Human Visual System (HVS). In general, some form of information loss is incurred when irrelevancy reduction is performed (Xiao, Wu, Wei, & Bao, 2005).

A number of standards have been established over the years for natural image compression. JPEG is the most common image file format that is found in existing Internet and multimedia systems (Pennebaker & Mitchell, 1993; Wallace, 1991). JPEG stands for Joint Photographic Experts Group. It is the name of the joint ISO/CCITT committee that created the image compression standard in 1992. There are two compression modes in the JPEG compression standard: lossless and lossy. However, the lossy mode dominates in almost all applications. The JPEG image compression codec has low complexity and is memory efficient. However, its main criticism is the appearance of the blocking artifacts, especially at high compression ratios.

In 2001, the Joint Photographic Experts Group created another new image compression standard, called the JPEG 2000 (Taubman & Marcellin, 2002). This new standard provides an improved compression performance over JPEG and avoids the blocking artifacts completely. Besides the better compression performance, it also provides progressive capability in which the JPEG 2000 bitstream is organized in such a way that the image quality gets better progressively in terms of quality or resolution (Lee, 2005). Compared to the JPEG standard, JPEG 2000 is not widely supported at present. It is hindered by the fact that some of the algorithms are patented. As a result, it cannot be included in open-source Web browsers, which affects its popularity.

IMAGE COMPRESSION METHODOLOGY

Basic Compression Scheme

In general, most natural image compression schemes have a common structure, as shown in Figure 1. The first stage is usually a color space conversion module. Typically, a color image is stored in the RGB format. Because compression in the RGB domain is very inefficient, the image is converted into a luminance-chrominance color representation, that is, YCbCr, where the Y component represents the luminance information while the Cb and Cr components represent the color information. The image is then subjected to a transformation like the discrete cosine transform (DCT) (Ahmed, Natarajan, & Rao, 1974) or discrete wavelet transform (DWT) (Heil, Walnut, & Daubechies, 2006). The transformation decorrelates the image data, and thus reduces redundancy. The resulting coefficients are next quantized and entropy encoded. To quantize a signal means to describe it with less precision. Hence, some image information is inevitably discarded. Scalar quantization quantizes each coefficient separately using a predefined quantization table. It is the most common quantization scheme due to its simplicity. The rate-distortion (RD) unit controls the quantization step-size as a function of the bit-rate R and distortion D (Sarshar & Wu, 2007). Sometimes a RD unit is not explicitly defined, but is indirectly controlled by the nature of the quantizer.

Instead of quantizing each coefficient separately as in a scalar quantizer, vector quantization (VQ) can be used to represent a signal piecewisely by short vectors from a codebook. The codebook generally contains a limited number of entries that approximate the signal pieces. Compression is achieved in VQ because only the index of the best codebook entry needs to be encoded and transmitted.

Exploiting the Limitations of the Human Visual System (HVS)

High compression ratio is usually achieved by aggressively exploiting the limitations of the HVS. Psycho-visual experiments have shown that the HVS has reduced sensitivity for patterns with high spatial frequencies. The phenomenon is parameterized by the contrast sensitivity function (CSF). Exploiting this behavior can significantly improve the compression ratio without incurring noticeable distortion. The quantization table in JPEG makes use of this phenomenon to some extent by using a large quantization step for high spatial frequency DCT transform coefficients in the luminance channel.

The sensitivity of the HVS for compression artifacts also varies with respect to the strength of local contrasts. Thus, an artifact might be hidden by the presence of strong contrasts or locally active image regions. This phenomenon, referred to as masking, is exploited in some sophisticated compression schemes (Gonzalez & Woods, 2002).

Subjective quality evaluations showed that the HVS is very sensitive to the loss of texture information. Blurred image with texture loss usually appear unnatural. However, the exact encoding of texture information is bit-rate intensive. To overcome this problem, a generative approach for texture region encoding is sometime employed in advance compression algorithms (Egger, Fleury, Ebrahimi, & Kunt, 1999; Ryan et. al. 1996). In this approach, the texture is characterized by only a few parameters that can be encoded for a modest increase in bit-rate. During decoding, the texture is synthe-

Figure 1. General structure of image compression algorithms