Near-Lossless Compression of Hyperspectral Imagery Through Crisp/Fuzzy Adaptive DPCM

Bruno Aiazzi[1], Luciano Alparone[2], Stefano Baronti[1],
Cinzia Lastri[1], and Leonardo Santurri[1]

[1] Institute of Applied Physics "Nello Carrara", National Research Council,
Via Panciatichi, 64, 50127 Florence, Italy
[2] Department of Electronics and Telecommunications, University of Florence,
Via Santa Marta, 3, 50139 Florence, Italy

1 Introduction

It is a widespread belief that the new generation of spaceborne imaging spectrometers (NASA/JPL's MODIS on Terra and Aqua, NASA/GSFC's Hyperion on EO-1, and ESA's MERIS on EnviSat) will create several problems, on one side for on-board compression and transmission to ground stations, on the other side for an efficient dissemination and utilization of the outcome hyperspectral images. In fact, the huge amount of data due to moderate ground resolution, but extremely high spectral resolution (around 10 nm), together with the high radiometric resolution (typically 12 bit wordlength of the raw, i.e., uncalibrated, data from the digital counter) originates an amount of data of approximately 300 bytes/pixel. Therefore, the use of advanced compression techniques and of suitable analysis/processing procedures for dissemination to users of thematic information is mandatory.

Data compression consists of a decorrelation, aimed at generating a memoryless version of the correlated information source, possibly followed by quantization, which introduces a distortion to allow a reduction in the information rate to be achieved, and entropy coding. If the decorrelation is achieved by means of an orthonormal transformation, e.g., the discrete cosine transform (DCT) or the discrete wavelet transform (DWT), the variance of quantization errors in the transformed domain is preserved when the data are transformed back into the original domain. Thus, the mean square error (MSE) can be easily controlled through the step sizes of quantizers. However, quantization errors in the transformed domain, which are likely to be uniformly distributed and upper bounded in modulus by half of the step size, are propagated by the inverse transformation and yield broad-tailed distributions, whose maximum absolute amplitude cannot be generally set a "priori". Therefore lossy compression methods, e.g., those proposed by the Joint Photographic Expert Group, the current standard JPEG [1] and the new standard JPEG 2000 [2], are not capable of controlling the reconstruction error but in the MSE sense; hence, apart from the lossless case, relevant image features may be locally distorted by an unpredictable and unquantifiable extent.

Compression algorithms are said to be fully reversible (lossless) when the data that are reconstructed from the compressed bit stream are identical to the original, or lossy otherwise. The difference in performance expressed by the compression ratio (CR) between lossy and lossless algorithms can be of one order of magnitude without a significant visual degradation. For this reason lossy algorithms are extremely interesting and are used in all those application in which a certain distortions may be tolerated. Actually these algorithms are more and more popular and their use is becoming widespread also in such remote sensing applications as those in which it was rightly believed that the data had to exactly retain their original values for further processing and quantitative evaluations [3]. This aspect is crucial for transmission from satellite to Earth receiving stations [4]; in fact, once the data were lossy compressed, they would not be available as they were acquired for the user community. The distortions introduced might influence such research activities as modeling, classification and postprocessing in general. As a matter of fact, however, the intrinsic noisiness of sensors prevents from adopting strictly lossless techniques in order to obtain a considerable bandwidth reduction [5, 6]. In this light, error-bounded near-lossless algorithms [7, 8] are growing in importance since they are capable of guaranteing that at every pixel of the reconstructed image the error is bounded and user-defined.

In the medical field objective measurements, like MSE, maximum absolute distortion (MAD), widely known as *peak error*, and percentage MAD (PMAD) may be integrated with qualitative judgements of skilled experts, e.g., expressed in terms of Receiver Operating Characteristic (ROC) curves [9]. In remote sensing applications, however, photoanalysis is not the sole concern. The data are often postprocessed to extract information that may not be immediately available by user inspection. In this perspective, if the MAD error is constrained to be, e.g., one half of the standard deviation of the background noise, assumed to be additive, Gaussian, and independent of the signal, the decoded image will be *virtually lossless*. This term indicates not only visual indistinguishability from the original, but also that possible outcomes of postprocessing are likely to be practically the same as if they were calculated from the original data. The price of compression becomes a small and uniform increment in noisiness.

When higher compression ratios are demanded, a PMAD-constrained approach may be rewarding in terms of scientific quality preservation of the decompressed data [10]. The rationale is that automatic analysis and processing algorithms may be more sensitive to *relative* errors on pixels, than to *absolute* errors. For best performance, however, relative error-constrained compression requires logarithmic quantization [8], which is penalized with respect to lin-