SCALABLE LOW COMPLEXITY CODER FOR HIGH RESOLUTION AIRBORNE VIDEO

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ABSTRACT

Real-time transmission of airborne images to a ground station is highly desirable in many telemetering applications. Such transmission is often through an error prone, time varying wireless channel, possibly under jamming conditions. Hence, a fast, efficient, scalable, and error resilient image compression scheme is vital to realize the full potential of airborne reconnaisance. JPEG2000, the current international standard for image compression, offers most of these features. However, the computational complexity of JPEG2000 limits its use in some applications. Thus, we present a scalable low complexity coder (SLCC) that possesses many desirable features of JPEG2000, yet having high throughput.

Keywords: JPEG2000, airborne reconnaisance, low complexity, scalable compression.

1. INTRODUCTION

With technological advances in image acquisition systems, use of high speed, high resolution video cameras are common in many telemetering applications. Such cameras [1, 2] have been developed for airborne applications [3] including reconnaissance, earth survey [4], and RDT&E [5]. These specialized video cameras can record images at 200-400 frames per second (fps) and use dual band imagery (visible and IR). Features required in an image compression algorithm for airborne reconnaissance are discussed in [6]. For real-time transmission, the image encoder needs to keep up with the image acquisition hardware. Additionally, the transmission of compressed images is often through an error prone wireless channel. Thus a fast, efficient, and error resilient image compression scheme is vital to realize the full potential of airborne reconnaisance [7].

JPEG2000 [8] is the current international image compression standard and offers rich scalability features that are beneficial for a wide variety of applications. It is used for archiving and disseminating images within the United States Imagery and Geospatial System (USIGS) and Distributed Common Ground System (DCGS) architectures [9]. However, the computational complexity of JPEG2000 can make it impractical for some real-time airborne reconnaissance and power constrained remote sensing applications [10]. Other compression standards such as MPEG-4 and H.264 may not be practical in these applications either. While the decoding complexities of these standards are lower, their encoding complexities are much higher than JPEG2000 [11]. In this work, we introduce a Scalable Low Complexity Coder (SLCC) which possesses many of the desirable features of JPEG2000, yet has high encoding and decoding throughput. We believe that this coder is suitable for use in airborne reconnaissance applications.

The paper is organized as follows. Section 2 gives an overview of scalable image compression methods and their use in airborne reconnaissance. Section 3 gives the algorithmic details of SLCC and describes the salient features that make it well-suited for airborne video transmission. In Section 4, we present compression and throughput performance of SLCC and compare it with JPEG2000. Section 5 concludes the paper.

2. SCALABLE IMAGE COMPRESSION FOR AIRBORNE RECONNAISSANCE

Scalability is a very desirable property in image compression systems. Scalable image codecs allow extraction of multiple image products from a single compressed codestream. Fig. 1 gives the architectural layout of an image compression scheme that possesses four dimensions of scalability. The input image samples first pass through an optional color transform to exploit the redundancy between the RGB components (if any). The resulting luminance (Y) and chrominance (Cb and Cr) components are then compressed independently. This independent compression allows extraction of Y, Cb, and Cr components separately from the codestream, thereby providing component scalability.

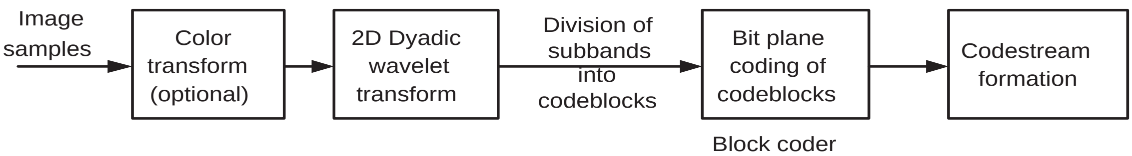

Figure 1. Schematic of a scalable image compression system.

Resolution scalability is achieved via the 2D dyadic discrete wavelet transform (DWT) which is applied to each component. This transform enables multi-resolution representation of the image [8] as illustrated in Fig. 2. In the figure, R0 denotes the lowest resolution level and R3 denotes the highest resolution level (Subbands belonging to different resolution levels are shaded differently). The image can be reconstructed at a desired resolution by combining the subbands at that and lower resolution levels. For example, the LL3 subband can be used as a low resolution version (R0) of the original image. When the HL3, LH3, and HH3 subbands are used together with the LL3 subband, the image can be reconstructed at the next higher resolution (R1). Note that this resolution scalability of the image compression system is enabled by independent compression (and thus decompression) of subbands, as discussed next.

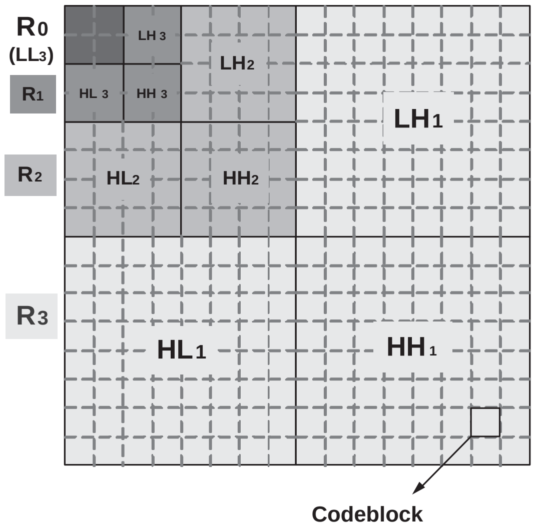

Figure 2. Image samples subjected to three levels of wavelet transform. Each subband is divided into codeblocks.

Each wavelet subband is subdivided into codeblocks which are compressed independently by a block coder. In addition to allowing independent compression of subbands (thus resolution scalability), this scheme allows finer granularity of access to wavelet coefficients within each subband. This finer granularity of access to wavelet coefficients enables spatial scalability, as illustrated in Fig. 3. In the figure, the codeblocks containing the wavelet coefficients which contribute to a spatial region of interest (ROI) are highlighted. Since each codeblock is compressed independently, decompressing the portions of the codestream corresponding to these codeblocks is sufficient to reconstruct the desired ROI.

JPEG2000 has adopted the scalable compression scheme presented in Fig. 1 and thus possesses all three scalability features described above. In addition, JPEG2000 also enables quality scalability. The quality scalability is enabled by using a context adaptive arithmetic coder which compresses the bitplanes of each codeblock in order, starting from the most significant bitplane (MSB) to the least significant bitplane (LSB). Thus, decompression of the initial portion of each codeblock's bitstream facilitates the reconstruction of the most significant bitplanes of the codeblock. Continued decompression allows reconstruction of the least significant bitplanes of the codeblock. Since each bitplane is actually compressed using three passes (referred to as coding passes), JPEG2000 can provide very fine granular quality scalability.

In airborne video transmission, the scalability features described above can be used to achieve ample bandwidth savings and functionality. With resolution scalability, only parts of the compressed data, corresponding to the resolution required at the ground station needs to be transmitted in real-time. Similarly, quality scalability can be very beneficial as well. While a small portion of the compressed codestream can be transmitted to the ground station for real-time analysis, the entire compressed codestream yielding a much higher quality (perhaps even lossless) can be stored onboard for further processing at a later time. Spatial scalability may allow real-time transmission of the data that corresponds to a desired ROI to the ground station, while the data for the rest of the scene is saved on board for later processing. Alternatively, spatial scalability can be used in conjunction with quality scalability to separately adjust the quality of the ROI and the background. This can ensure high quality reconstruction of the ROI when sufficient bit budget is not available to provide high quality throughout the entire image. This is illustrated in Fig. 3 where the ROI is reconstructed at higher quality level than the background. This feature, when used with an object tracking mechanism, can be very useful in surveillance applications as shown in [12].

While these scalability features of JPEG2000 are very desirable, the computational complexity of JPEG2000 can be too high for some real-time airborne reconnaissance and power constrained remote sensing applications. Thus, an image coder that retains most of these scalability features and yet has low complexity can be very useful in practice. We introduce such a coder in the following section.

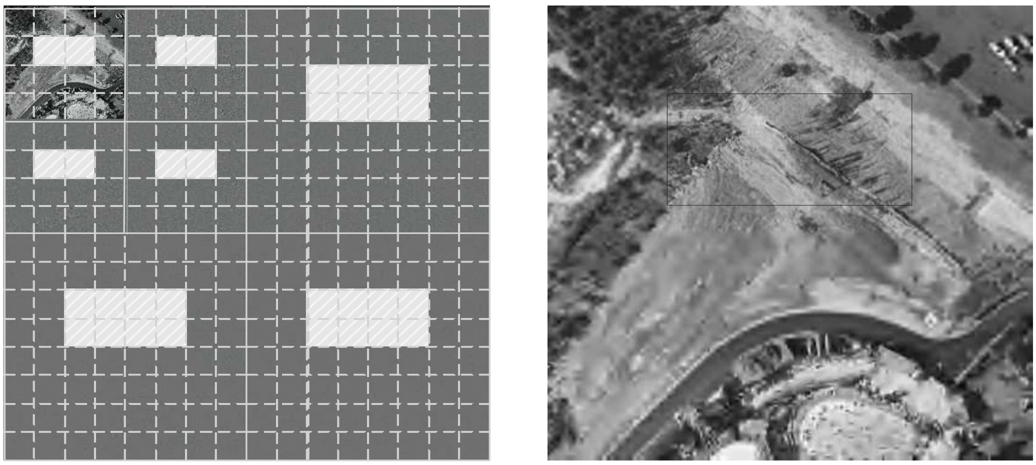

Figure 3. Codeblocks from different subbands (left) that correspond to a region of interest in the original image (right).

3. SCALABLE LOW COMPLEXITY CODER

In this section, we introduce a low complexity image coder that retains most of the desirable scalability features of JPEG2000. The first step in the proposed coder is the application of a color transform to decorrelate the R, G, and B color components of the input image, if any. The resulting luminance and chrominance components are then individually transformed using a 2D discrete wavelet transform. Each wavelet subband is then divided into codeblocks and these codeblocks are encoded independently. Note that these steps are similar to JPEG2000 and they ensure that our coder has component, resolution, and spatial scalability. However, in contrast to JPEG2000, we sacrifice some granularity in quality scalability to significantly reduce the computational complexity. In our approach, a limited amount of quality scalability is introduced into the codestream by allowing two quality layers. Our entropy coder encodes each codeblock in the following fashion: The all-zero MSBs of each codeblock (referred to as *missing MSBs*) are recorded in the header and the remaining bitplanes are divided into two stacks. To form the first quality layer, bitplanes in the first stack are coded in a single pass. The coding method depends on the stack length of the codeblock. Entropy coding is restricted to three (or less) MSBs in the first stack. When there is one bit-plane, the position indices of 'ones' in that bit-plane are coded. Run-value and Quad-Comma coding [13] are used for stack lengths of 2 and 3, respectively. For codeblocks with more than 3 bit planes, Quad-Comma coding is used for the three MSBs and raw bits are coded for the remaining ones. No entropy coding is used in the second layer; Uncompressed (raw) bits are simply included into the bitstream.

Fig. 4 illustrates the configuration of the two quality layers with an example. In the figure, the missing MSBs, the bitplanes in the first stack, and the bitplanes in the second stack are illustrated using different shades. For the LL2 subband shown in the figure, all bit planes above the 4^{th} bit plane contribute to the first layer. Note that the other subbands have fewer bit planes included in the first layer. This is because the SLCC takes into account the relative amplification of the quantization noise in different subbands due to the wavelet synthesis filters [14, 15]. To account for this relative amplification, weighting factors, referred to as energy weights, are calculated for each subband. These energy weights are rounded to the nearest power of two and used to adjust the stack lengths. In the example of Fig. 4, codeblocks belonging to the HL2 and LH2 subbands will have one less bit plane in the first layer while the HH2, HL1 and LH1, and HH1 subbands have two less.

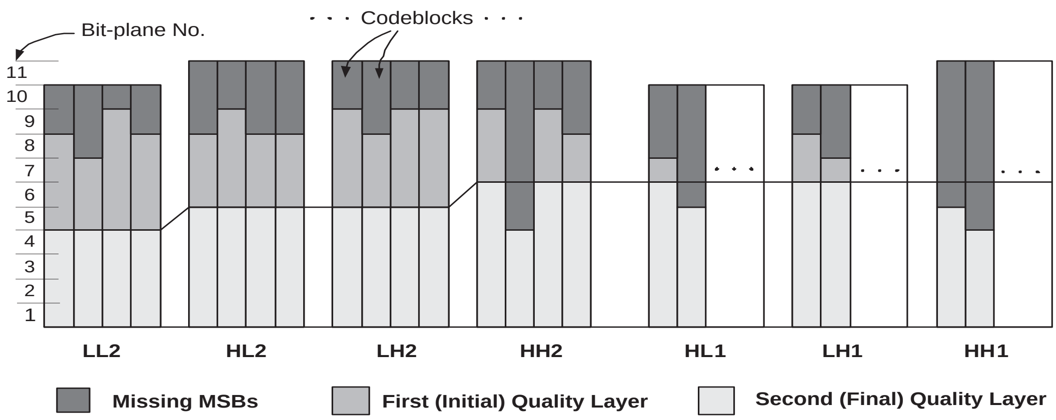

Figure 4. Selection of the quality layers in SLCC.

Since airborne video is transmitted through error prone wireless channels, error resilience of the image compression scheme is important. SLCC has several desirable properties in terms of error resilience. First, the independent block coding in SLCC prevents errors from propagating beyond codeblock boundaries. Thus, errors are isolated in terms of spatial location. Selection of smaller codeblock sizes can further isolate the errors spatially at the cost of reduced compression performance. Errors in a codeblock are also isolated in spatial frequency since each codeblock only contains data from a single wavelet subband. Further localization of errors within each codeblock may also be possible. Recall that SLCC encodes only the first three bit-planes (following the missing MSBs) in each codeblock. The remaining bits are sent raw. Thus, a bit error in these raw bits will only corrupt a single wavelet coefficient and will have limited impact on overall image quality.

4. RESULTS

In this section, the performance of SLCC is compared to that of JPEG2000 using an efficient JPEG2000 implementation, Kakadu V5.0 [16]. Results are reported for a 720x576 grayscale aerial video sequence with 100 frames. All the timing experiments were carried out on a PC with a 2.8GHz P4 processor and 512MB RAM. Fig. 5 compares the end-to-end encoding times of JPEG2000 and SLCC at different bit-rates (bits/pixel). The end-to-end encoding time comprises reading the input image from memory, 2D DWT, block encoding and writing the compressed data to memory. As seen in the figure, SLCC is 3 to 5 times faster than JPEG2000.

Fig. 6 shows the compression performance of the two coders averaged over 100 frames for the above aerial video sequence. Peak Signal to Noise Ratio (PSNR) is used as the quality metric. In the figure, SLCC incurs a 0.6 to 1 dB loss at low to moderate bit rates compared to JPEG2000. Alternatively, for a given image quality, SLCC produces a 15-20% larger compressed codestream when compared to JPEG2000. However, due to its significantly reduced complexity, SLCC can deliver a much higher frame rate for a desired quality level. This can be seen in Fig. 7 where the achievable frame rate (reciprocal of end-to-end encoding time) is plotted against PSNR. For example, at a quality level of 30 dB PSNR, SLCC can deliver images at 98 fps while JPEG2000 can only deliver at 30 fps. At a PSNR of 45 dB, SLCC can run at 70 fps where JPEG2000 can only run at 15 fps. Note that SLCC and JPEG2000 have roughly symmetric encoder/decoder complexity. That is, complexities of the encoder and the decoder are roughly equal. Thus, the above results are representative for decoder performance as well.

5. CONCLUSION

In this work, a fast and scalable image coder is designed for airborne video transmission. The proposed coder matches all of the component, resolution, and spatial scalability properties of JPEG2000. A small amount of compression performance and granularity in quality scalability are traded to obtain a significant reduction in computational complexity. The throughput performance of SLCC is compared to JPEG2000 and it is shown that SLCC can achieve much higher frame rates for a given image quality.

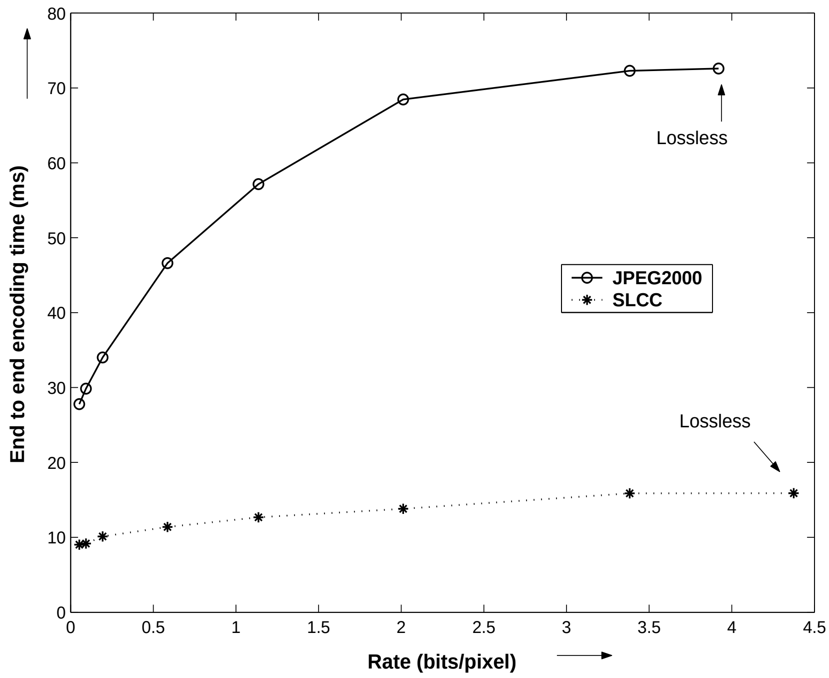

Figure 5. Comparison of end-to-end encoding times for SLCC and JPEG2000.

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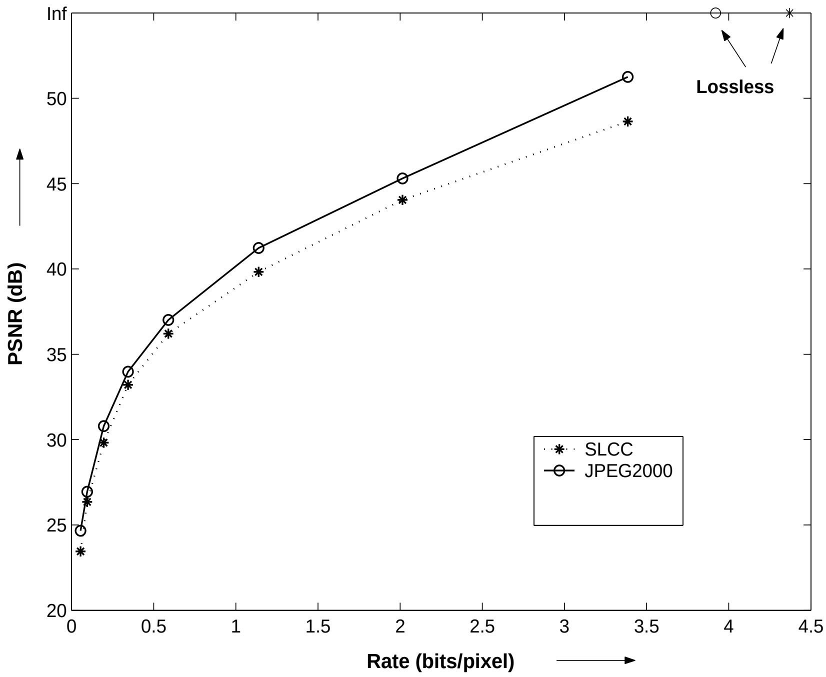

Figure 6. Comparison of rate vs. quality for SLCC and JPEG2000.

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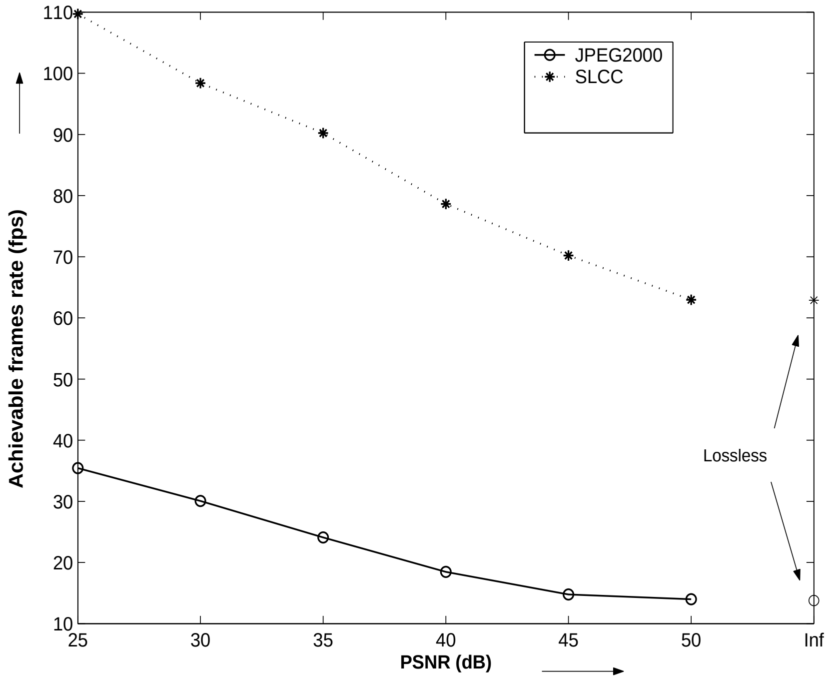

Figure 7. Achievable frame rate at different quality levels for SLCC and JPEG2000.