Rapid Colour Image Reconstruction Using Colour Quadtress

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Abstract

A quadtree-based approach is described for representing colour images using variable spatial and colour resolution. This approach allows systematic refinement of images during reconstruction. Compression and noise results are presented for test images in several colour spaces.

Introduction

Progressive reconstruction of digital images is beneficial in many applications involving human viewing, where rapid retrieval of transmission is required. The initial response of the human visual system when an image is first presented for viewing relies strongly on general early vision responses across the whole image (e.g. strong contrast and edges) rather than on localised fine detail. The limited reproduction quality afforded by the initial stages of progressive reconstruction can thus be readily tolerated if the refinement information is provided rapidly thereafter.

Progressive reconstruction requires the image refinement information to be extracted systematically and represented in a structured manner. Many progressive schemes adopt uniform global data reduction strategies (e.g. resampling the spatial resolution in image pyramids, reducing the quanitization levels in JPEG). These strategies tend to ignore those effects of the human visual system performance which lead to the image content not being perceived as uniformly important over the whole image area.

To overcome such limitations, some attempts have been made to provide local reduction strategies, such as region-based image representations[1,2] or saliency and importance maps[3,4]. These approaches tend to be computationally expensive to encode and very sensitive to the choice of controlling parameter values. A simplified scheme which is non-uniform but relies on very few parameters would provide a useful compromise.

The scheme described here is based on the quadtree approach[5], which is widely used for greyscale image processing and compression. The quadtree structure is extended to cater for progressive colour image presentation. The construction of progressive representations for three standard test images is undertaken in four different colour spaces, and the compression rates and objective image quality achieved in these cases are compared.

Colour Quadtrees

Conventional quadtrees provide an image represented based on nodes describing square of rectangular blocks of pixels. New nodes are formed by subdividing a parent block to provide four children, if the value of a splitting criterion for the parent is beyond a certain threshold. Some typical splitting criteria are the difference in mean pixel intensity values of a parent and child, or the variation in pixel intensity values occurring within a parent.

Nodes in a quadtree which are not subject to further splitting (i.e. leaf nodes) contain representative values for use in reconstructing the image (e.g. mean pixel intensity for that block). Parent nodes contain pointers to their children, usually in a compacted format. Quadtree representation permits large savings of space to be achieved when a leaf node covers many pixels, and reduces the number of distinct pixel intensity values which need to be stored in order to display the reconstructed image.

Two complications arise when quadtrees are used to represent colour images. Firstly, each pixel now has a triplet of associated intensity values, so the formulation of splitting criteria and representative values is more complex. Secondly, the interrelationships of the three intensity values making up the pixel colour are far more irregular than the single value in a greyscale image, which follows a smooth monotonic curve of visual response against intensity.

The splitting criterion adopted here was based on the hypothesis that if any one component of the colour intensity values in a block varies greatly, then the block should be split. The variance of the components was used to assess this variability. The range of possible values for each component was first normalised to [0,1] over the whole image to ensure that no one component would dominate. The representative triplet of values for a block was taken to be the mean of each of the three component values of the whole block.

The progressive nature of the quadtree representation can be obtained by storing data values for a set of initial non-leaf nodes and successively applying a sequence of splitting criteria, to determine which nodes would form the leaf nodes at the corresponding levels of

Table 1. Results for Test Images at 3 Levels of Refinement, for 4 Colour Spaces.

Image Name	LENNA			PEPPERS			MANDRILL		
Refinement	1	2	3	1	2	3	1	2	3
RGB Mean BPP	0.2	0.7	1.9	0.4	0.7	1.9	0.7	1.8	2.1
RGB Low PSNR	4.4	5.7	8.5	5.0	6.4	10.5	3.0	5.6	6.0
RGB # Blocks	1969	5683	12673	3226	5740	14104	5731	13438	15862
HSV Mean BPP	0.6	1.3	1.9	0.7	1.2	1.9	1.3	1.9	2.1
HSV Low PSNR	4.2	7.2	8.6	2.6	3.0	3.6	2.6	3.4	3.6
HSV # Blocks	4882	10009	14209	5806	9085	14128	9961	14281	15763
YIQ Mean BPP	0.4	1.1	2.0	0.3	0.7	1.6	1.6	1.9	2.1
YIQ Low PSNR	3.4	7.3	9.8	4.2	6.1	9.1	4.7	5.7	6.0
YIQ # Blocks	3601	8503	15016	2392	5713	11908	11086	14353	16069
L*u*v* Mean BPP	0.1	0.7	1.7	0.1	0.3	0.9	0.9	1.9	2.2
L*u*v* Low PSNR	2.6	5.7	8.3	2.4	4.4	6.1	3.4	5.7	6.0
L*u*v* Blocks	1057	5683	12646	1144	3019	7360	7264	14227	16225

refinement. As human visual system sensitivity to detail (e.g. spatial frequency) follows a non-linear response, a power law was used here to construct the threshold values for the successive refinements. Based on this approach and taking into account the statistical properties of the nodes, the splitting criterion used was:

Max (Variance(child 1),..., Variance(child 4)) < k. Variance(parent)

where k=1/Sqrt(n), 1/n, 1/n**2 respectively for the first three levels of refinement. Here n denotes the side length of the current parent node and k denotes the current scale factor for the splitting criterion.

Use of the global splitting criterion described above provides a scalable refinement process which very roughly mimics the response of a viewer to the image contents, by allowing wide variations in colour in a node to be increasingly overcome as the level of refinement increases. Other methods for determining the levels of refinement could be used instead of the above, to cater for different rates of refinement and for local weighting during refinement.

Experimental Results

The progressive representation scheme was applied to three commonly used 256×256 8-bit colour images: LENNA, PEPPERS and MANDRILL. The images were converted to four different colour spaces: RGB, HSV, YIQ and CIE L*u*v*. The images were reconstructed at three progressive refinement stages corresponding to the above choices of k. The minimum block size allowed was 2×2 pixels, as the variance of a single pixel cannot be computed. The image quality, expressed as PSNR for the normalised colour component having the highest variance, was evaluated for each case as shown in Table 1. The total number of leaf nodes at each stage is also given. This is directly proportional to the compression rate achieved, with further gains at each refinement stage due to repeated values occurring at some leaf nodes.

As shown by the results, the scheme consistently performed worst for MANDRILL, giving poor compression rates and poor PSNR values for all colour spaces. This is due to the large areas of colour texture in this image, leading to unusually high variance values. This image might therefore be regarded as an extreme case.

However, the representations for the other two images all achieved good compression rates in the stage 1 refinements, with a typical compression factor of around 50:1. The compression rate was at best halved at the stage 2 refinements and in all these cases an improvement of PSNR was obtained. For the stage 3 refinements, where the majority of leaf nodes were reduced to 2×2 blocks, a typical compression factor of 5:1 was obtained.

Performance did not vary significantly between the four different colour spaces considered. This suggests that the method is reasonably robust due to the normalisation step, so that the separation of colour components in luminance-chrominance terms has no strong effect on this type of compression. Although PSNR values obtained are fairly low, the visual quality of the reconstructed images at stage 3 is comparable with that of other lossy schemes such as JPEG, at far higher PSNRs.

Some block artifacts were visible in the stage 3 images, at locations where block splitting did not proceed and so isolated large blocks remain. This was a consequence of using a global splitting criterion, and applying it independently of the treatment of surrounding blocks. The problem could be overcome by using an adaptive approach to the choice of splitting criterion, based on more complex information about the block contents, or by weighting the splitting criterion so as to encourage splitting of blocks where there is a high incidence of splitting in neighbouring blocks.

Conclusion

The scheme proposed here has been shown to produce reasonable results on several test images and is stable across several choices of colour spaces. Further work is currently being undertaken on improving the splitting criterion formulation and reducing the node representation cost further by colour subsetting. Using this scheme, an image can be reconstructed rapidly from only the node positions, sizes and representative colours. The colour quadtree approach can thus be considered a viable alternative to conventional image representations for progressive reconstruction applications, on the grounds of both computational efficiency and visual reconstruction quality.

References

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