A 3D DCT COMPRESSION ALGORITHM FOR OMNIDIRECTIONAL INTEGRAL IMAGES

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ABSTRACT

A compression scheme for Omnidirectional Integral Image data is described which uses a three dimensional DCT to exploit the intra-sub-image correlation together with the horizontal and vertical inter-sub-image correlation, resulting in a very efficient de-correlation of the source intensity distribution. The nature of the recorded intensity distribution data with respect to redundancies present and the structure of the data representing the image object are investigated. A three dimensional scalar quantisation array is applied to the DCT coefficients, which are then entropy encoded by a Huffman-based coder. The results obtained after applying the 3D DCT based scheme to OII data are presented and discussed, and compared with simulations produced using the JPEG scheme.

1. INTRODUCTION

The development of three-dimensional (3-D) imaging systems is a constant pursuit of the scientific community and entertainment industry. Many applications exist for 3-D display and video communication systems. One much discussed application is 3-D television.

Integral imaging is a technique that is capable of creating and encoding a true volume spatial optical model of the object scene in the form of a planar intensity distribution by using unique optical components [1,2,3]. It is akin to holography in that 3-D information is recorded on a two dimensional medium and can be replayed as a full 3-D optical model. However, in contrast to holography, coherent light sources are not required for integral imaging, conveniently allowing for more conventional live capture and display procedures to be adopted. Never the less there are a number of technological challenges that need to be overcome, for example real time processing, improved optical components and high resolution displays, before integral imaging (II) can be fully evaluated as an imaging modality.

Recently there has been a renewed interest in multiview and integral imaging [4, 5, 6, 7, 8]. Most researchers have concentrated on establishing appropriate viewing parameter characterisation and improved image generation. In respect of stereoscopic systems a number of groups have tackled data compression [9]. However there are many data processing issues that require specialist solutions unique to II.

Recently, a lossy compression scheme for use with unidirectional integral images (UII) (parallax in the horizontal direction only), making use of a three dimensional discrete cosine transform (3D-DCT) has been developed [10, 11]. It was shown that the performance with respect to compression ratio and image quality is vastly improved compared with that achieved using baseline JPEG for compression of unidirectional integral 3D image data.

This paper deals with the compression of omnidirectional integral images (OII) (parallax in all directions), using the 3D DCT scheme. The main reason for using the DCT, is that the integral 3D images are recorded as 2D planar data and are inherently divided into nonoverlapping sub-images (microlens images). As a result, a very low bit rate can be achieved without visible blocking artefacts.

2. OMNIDIRECTIONAL INTEGRAL IMAGE CAPTURE

In an integral imaging system shown in figure 1, in which the image is formed around the captured microlens array, each individual microlens sees a unique, (directional) part of the total image field [3]. Adjacent microlenses record an angularity-displaced view of the same image field. In this way each image point is represented by a series of related image intensity distributions. A full 3D image is achieved by the integration of all the directionally intersecting, intensity modulated beams of light generated by the lens array. In addition, the depth of field is increased by ensuring that the object space is contained within the range of sharp focus of the array.

The capture and display processes make use of microlens arrays in the encoding and decoding of the planar intensity distribution. In order to maximise the array efficiency (100% fill), hexagonal microlens can be used to eliminate the dead space in omnidirectional integral image. This is due to its properties and the fact that the structure fits well to form full-fill array.

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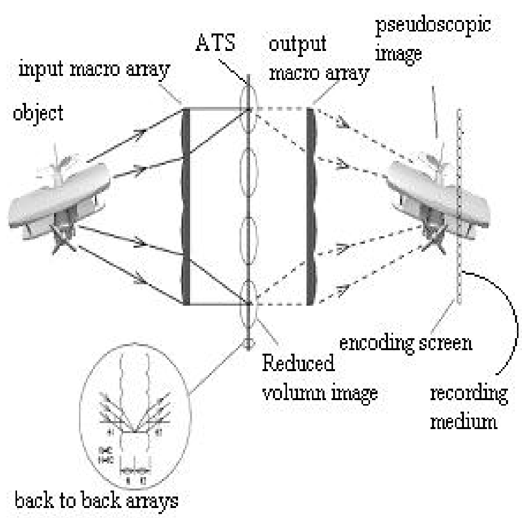


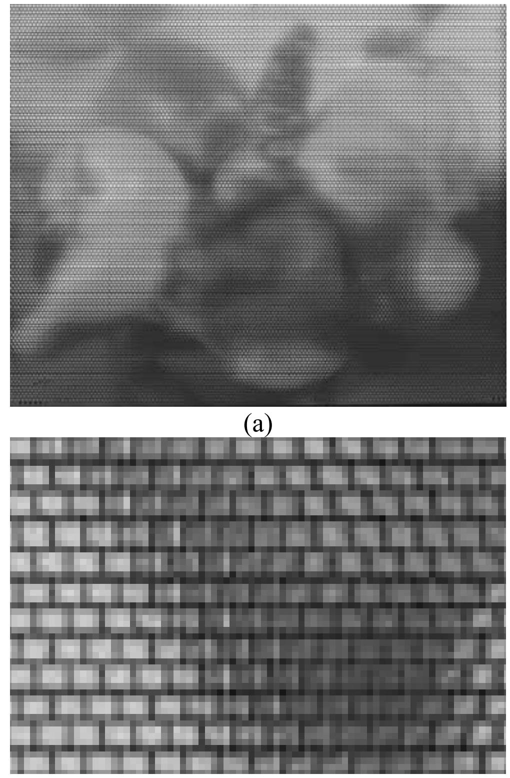
Figure 1: An advanced Integral Imaging system

3. COPMPRESSION OF OMNIDIRECTIONAL INTEGRAL IMAGES

The regular structure of the hexagonal microlenses array used in the hexagonal grid gives rise to a regular ‘brick structure’ in the intensity distribution as illustrated in Figure 2. The captured intensity distribution is structured in horizontal and vertical sub-images. A significant cross correlation exists between both horizontal and vertical sub-images in the intensity distribution. These features should be exploited when designing a compression scheme for use with the OII distribution. In order to maximise the efficiency of a compression scheme for use with the integral image intensity distribution, both inter and intra sub-image correlation should be evaluated.

To achieve the decorrelation of the image data, in both the inter and intra sub-image dimensions, a 3D-DCT compression scheme is employed. The input data for the 3D-DCT is produced by placing N neighbouring sub-images together along the third dimension. The 3D-DCT is then applied to the resulting fixed size volume to produce the decorrelated sub-image group.

Due to the hexagonal microlenses array used for capturing a 3D scene, the omni-directional integral sub-images form a ’brick structure’ arrangement. In order to facilitate the 3D-group configuration a shifting step was introduced. This procedure consists in circular shifting all the odd rows of sub-images in the OII data to the left by 4 pixels. After the compression scheme is applied on the OII data, the reconstructed intensity distribution is re-arranged using a similar procedure. The odd sub-image rows are shifted back making subjective and objective evaluation criteria of the compression scheme possible.



(a)

(b)

Figure 2: (a) Example of a 3D OII. (b) magnified section

Figure 2 also shows that the structure of OII data is such that each sub-image has a rectangular shape and is comprised of (8x7) pixels. For computation purposes, sub-images comprising (8x8) pixels are preferred. To obtain 8 pixels height for each sub-image in an OII data, an average row was computed for each group of seven row data and inserted in the OII after each of those groups.

In the 3D DCT based OII compression scheme, both the horizontal and vertical inter-sub-image and the intra-sub-image decorrelation of the source intensity distribution data are performed simultaneously by a 3D DCT. A fixed group of neighbouring sub-images from the source intensity distribution, between which inter-sub-image correlation is high, is taken to form a volume of input data for the DCT. The group length *N* is a parameter of the system, and due to implementation considerations $N=2^p$; $p\in\{2, 3\}$. The process is illustrated in figure 3 for $N=8$ for two different cases: horizontal and horizontal-vertical grouping. In the horizontal-vertical grouping the order in which the sub-images are grouped is another parameter of the system. In this paper, the overall effectiveness of the 3D DCT mapping stage for both horizontal and horizontal-vertical grouping methods shown in figure 3 are compared and discussed.

When the transform is complete, integral image data in the relevant portion of the intensity distribution has been decorrelated in both intra sub-image and inter-sub-image spatial domains. A three-dimensional quantisation array is then applied. The resulting coefficients are encoded with a hybrid run-length/Huffman entropy algorithm similar to that used in the JPEG standard.

Simulations were performed by using a fixed step size quantisation array. The step size determines the overall coarseness of quantisation, thereby controlling the output bit rate and image fidelity. The step size was varied from 1 to 50 with a step of 2 to provide a spread of results at various bit rates and objective fidelity values.

An entropy coder is used to reduce the high statistical redundancy present in the quantised coefficient blocks. The entropy coder is a Huffman-based coder as used by JPEG system for AC coefficients coding. In the results presented here, all coefficients are treated in the same way, which means that the DC coefficients in a block are not coded differentially and separately from the AC coefficients as in a JPEG scheme.

In the 3D DCT based coding of UII presented in [10], the quantised coefficients in each block are ordered into a sequence using all_plane, per-row zigzag scanning and coding strategy. In this case, a 1-D coefficient sequence is obtained. In this stage, a special symbol 'ESG' (end of sub-image group) is defined. It is used where all remaining coefficients in the scanned sequence are zero. This ordering of coefficients proved to be more efficient for coding each transformed sub-image group in the case of Unidirectional Integral Images. One of the main reasons is that the horizontal coefficients have more significance than the vertical ones due to the vertical running bands in the recorded UII image data.

However, this is not the case for OII, where the sub-images have a 'brick structure' arrangement. Hence, a Per-plane zigzag ordering of 3D DCT coefficients is also considered here. In this case, each plane is scanned using a zigzag strategy and the resulting N coefficient sequences are mapped to Huffman coder symbols using the same strategy described by JPEG. Two special symbols are used; 'ESB' (end of subimage bloc) which signify that the remaining coefficients in each (u,v)-plane are zero and 'ESG' (end of subimage group) which indicates that the group of subimages is terminated.

4. SIMULATION RESULTS

This section presents the results of simulations based upon the proposed 3D DCT based compression scheme using OII data. To provide a reference for comparison of this scheme, the JPEG system was used to generate results in parallel with the scheme under test.

The results are presented using objective quality methods in the form of peak signal to noise ratio versus output bit rate. Each plot corresponds to a given scheme that has been applied on four monochrome OII intensity distributions as source data. In all examples, the mean curves are produced.

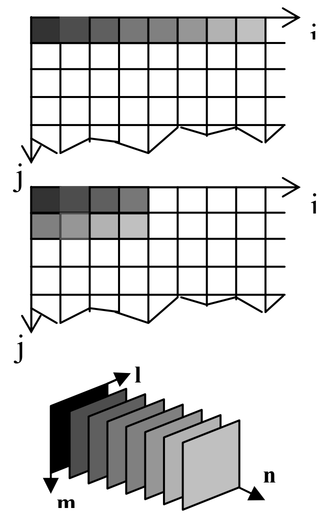


Figure 3: Two possible assembly of sub-images for 3D DCT based OII coding for N=8

The plot in figure 4 shows the difference in objective fidelity obtained between the application of the 3D DCT and a baseline sequential JPEG scheme across a range of output bit rates. The 3D DCT compression scheme using (8x8) pixels with a group length of N=8 was initially simulated on the original OII data. Due to the structure of the 3D omnidirectional integral intensity distribution where each sub-image is formed by (8x7) pixels, grouping the pixels in a group size of (8x8) the vertical structure of the sub-images and the vertical cross correlation are changed. Even so, a substantial increase in rate-distortion performance of the 3D DCT scheme over the baseline JPEG system is observed. This improvement is expected since the 3D DCT scheme, in this case, takes account of the horizontal sub-image correlation inherent in the structure of the OII data. Further improvement in the average of 1.2dB, can be achieved when the 3D DCT compression scheme is applied on the added line image in which case both horizontal and improved vertical correlation are exploited.

A second sub-image grouping method termed 'horizontal-vertical' is now considered. The number of *(8x7)* sub-images involved in a single 3D DCT computation is chosen as $N \in \{4,8\}$ but the index of the sub-images taken from the OII data to form a group is different from that previously described, the difference being that when $N=4$, two vertical sub-groups of two neighbouring horizontal sub-images (2x2) are placed together into a single volume. The sub-image group with length $N=8$ is comprised of: (i) two vertical sub-groups of four neighbouring horizontal sub-images (2x4); (ii) four vertical groups of two neighbouring horizontal sub-images (4x2). A comparison between the 3D DCT compression scheme performances using (4x2), (2x2), (2x4) 'horizontal-vertical' sub-image grouping can be made from figure 5. The three curves are given for each of the three methods of sub-image grouping. The 3D DCT coefficients are scanned using the per-plane zigzag scanning strategy. The best 3D DCT scheme performance was obtained for (4x2) grouping as shown in figure 5.

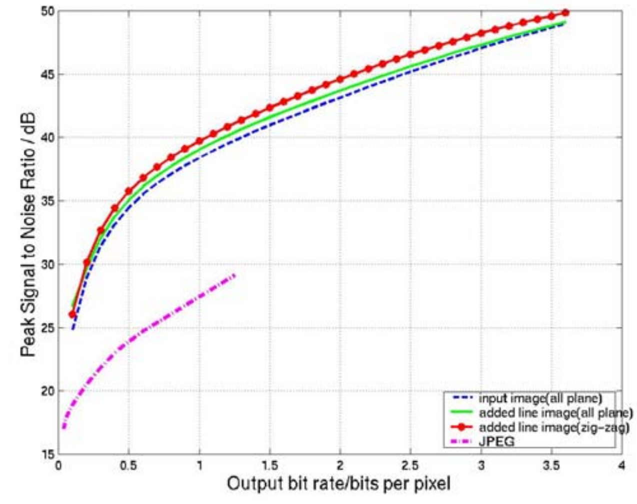


Figure 4: Performance of the 8x8x8 3D DCT based scheme using different scanning strategy on the original OII data and 'added line image' data; baseline DCT JPEG performance is shown for reference

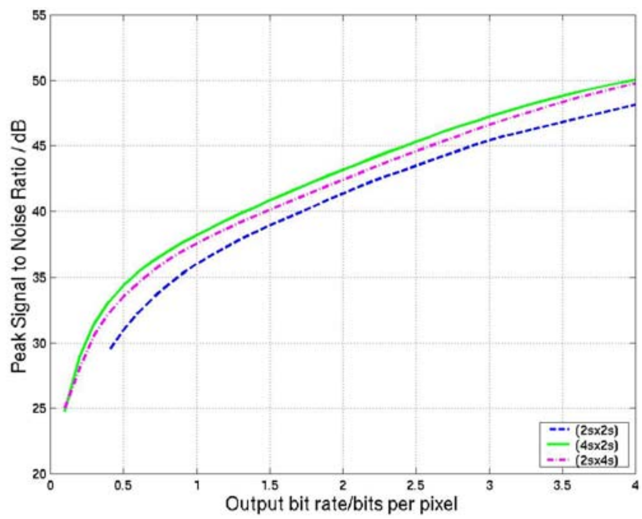


Figure 5: The average values of PSNR/bpp as a result of applying the 3D DCT scheme using (4x2), (2x2), (2x4) horizontal-vertical sub-image grouping on OII data.

5. CONCLUSIONS

In this chapter, a 3D DCT compression scheme for OII data has been presented. It has been established that there is strong intra-sub-image correlation in tandem with horizontal and vertical inter-sub-image correlation. The nature of the initial data is such that sub-images of (8x7) pixels are available. It has been shown that these can be converted to sub-images of (8x8) pixels to allow a more efficient computation of the 3D DCT without producing degradation of the horizontal correlation values, while the vertical correlation values are slightly affected. The performance of compression scheme works better when the 8th line is added to the sub-image to form (8x8) sub-images. The process of compression is described, based on a fixed volume of data as the input for the 3D DCT. The results also show that different groupings of the sub-images give different rate-distortion performances. It is also shown that the proposed compression technique outperforms the Baseline JPEG coding scheme.

11. REFERENCES

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