A STUDY ON THE 4D SPARSITY OF JPEG PLENO LIGHT FIELDS USING THE DISCRETE COSINE TRANSFORM

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1 - Context

- Light fields (LF): 4D structures that contain the images of a given scene from a sampled 2D dense range of viewpoints;
- An efficient coding scheme for LF is essential to reduce the large amount of data for LF storage and transmission;
- The need for efficient LF coding schemes is driving standardisation activities, notably from JPEG Pleno;
- 4D transforms are natural candidates for tools that can properly explore the full LF redundancy;

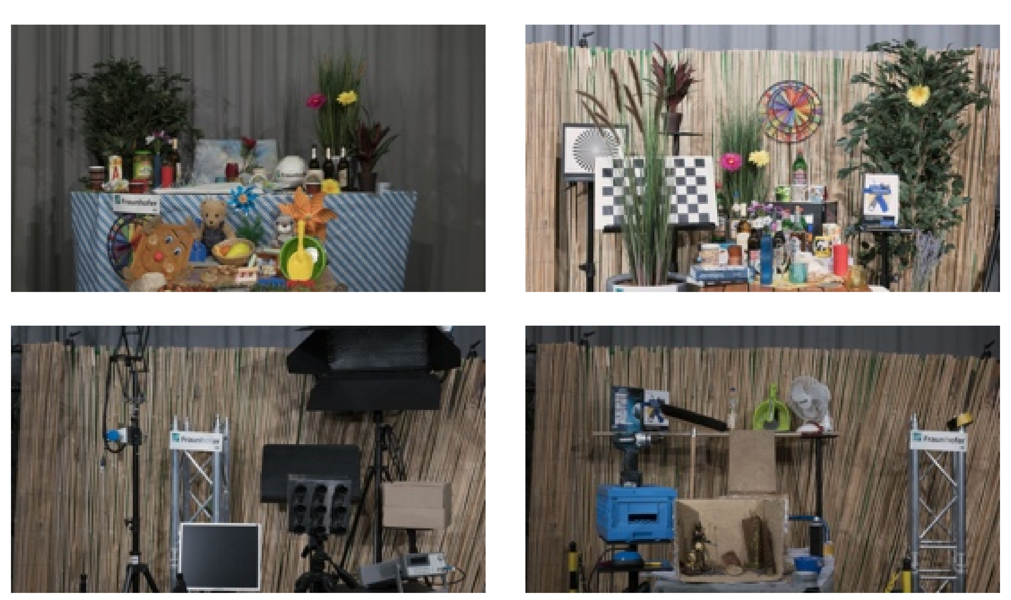
2 - Objective

- **This work proposes to use the 4D-DCT in order to investigate the 4D sparsity of the light fields;**
  - Sparsity: how much of the energy of the signal is concentrated in the $s\%$ transform coefficients with largest variances;
- Such a study can potentially impact the current and future design of LF coding solutions, notably within JPEG Pleno;

3 - JPEG Pleno Light Fields Datasets

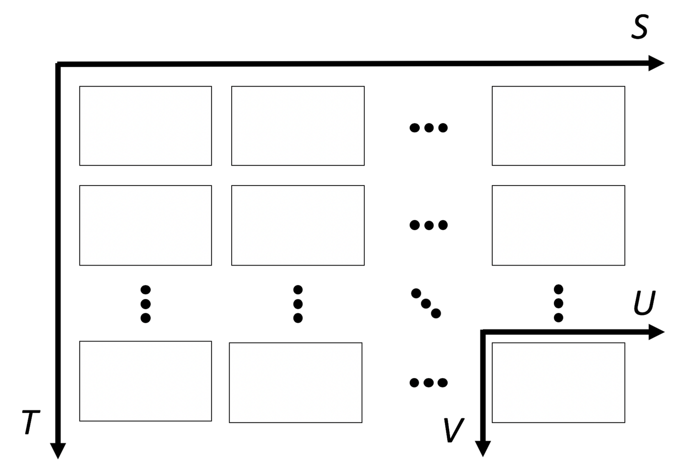
- Lenslet-based Datasets.
  - Each light field: 15×15 views with 626×434 pixels each.

- HDCA Datasets.
  - Full datasets: 101×21 views with 3840×2160 pixels each;
  - Subsampled datasets: 33×11 views with 3840×2160 pixels each.

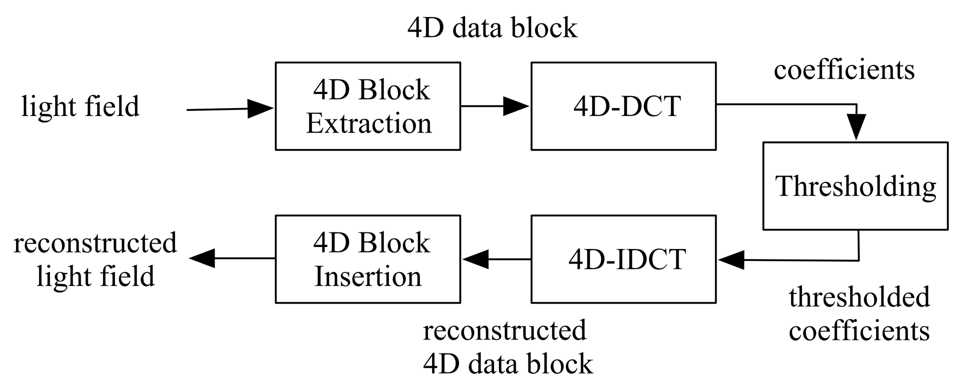


4 - Experimental Framework

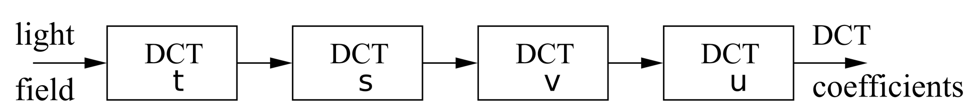
- 4D or 2D DCT is applied to (t, s, v, u) blocks:



- Experimental processing pipeline:



- Separable 4D-DCT pipeline:



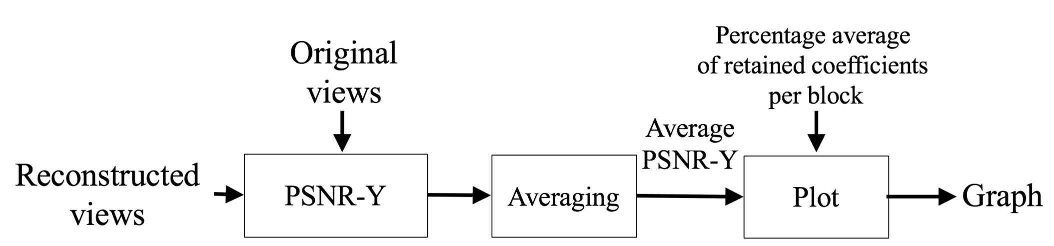
- Sizes:

	Lenslet-Based	HDCA
DCT Sizes	$8 \times 8 \times 8 \times 8$ (4D) $1 \times 1 \times 8 \times 8$ (2D intra view) $8 \times 8 \times 1 \times 1$ (2D inter view)	$8 \times 8 \times 8 \times 8$ (4D) $8 \times 8 \times 64 \times 64$ (4D) $1 \times 1 \times 8 \times 8$ (2D intra view) $8 \times 8 \times 1 \times 1$ (2D inter view)
Views Used	8×8 central views	Original: 16×96 Subsampled 8×32
Views Dimensions	432×624	2160×3840

- Only luminance is used.

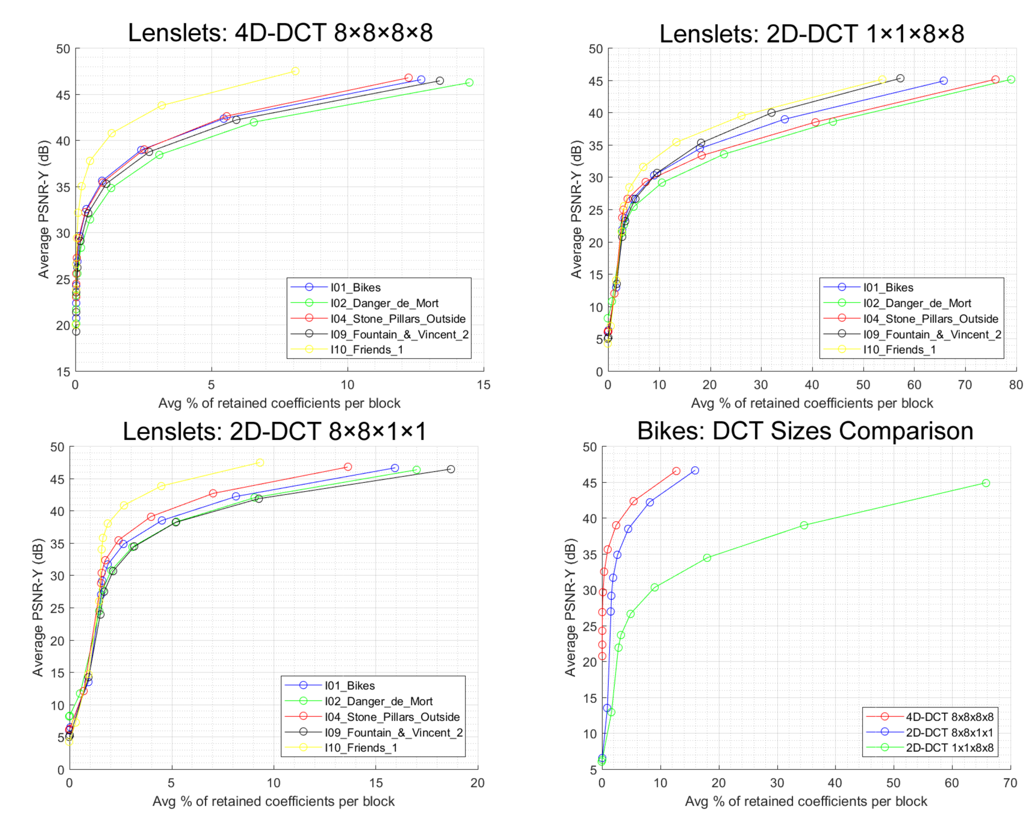
5 - Analysis

- Plot: average PSNR of the reconstructed views VS average percentage of retained coefficients per block:
  - PSNR: equivalent to the concentration of energy;
  - Percentage of retained 4D-DCT coefficients per 4D block: equivalent to the sparsity.



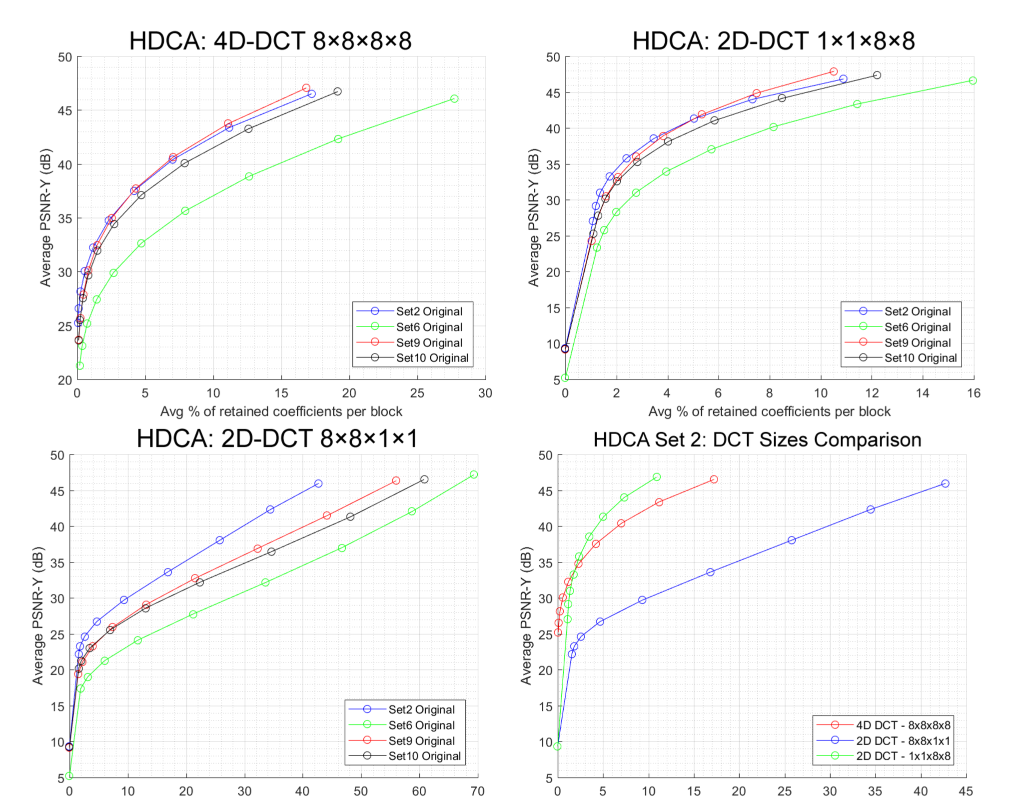
- Geometric Space View Redundancy (GSVR) descriptor:
  - Expresses the permanence probability of the image of a point in 3D space across the views from a 4D space-view block;
  - Characterises LFs in terms of space-view redundancy.

6 - Results: Lenslets



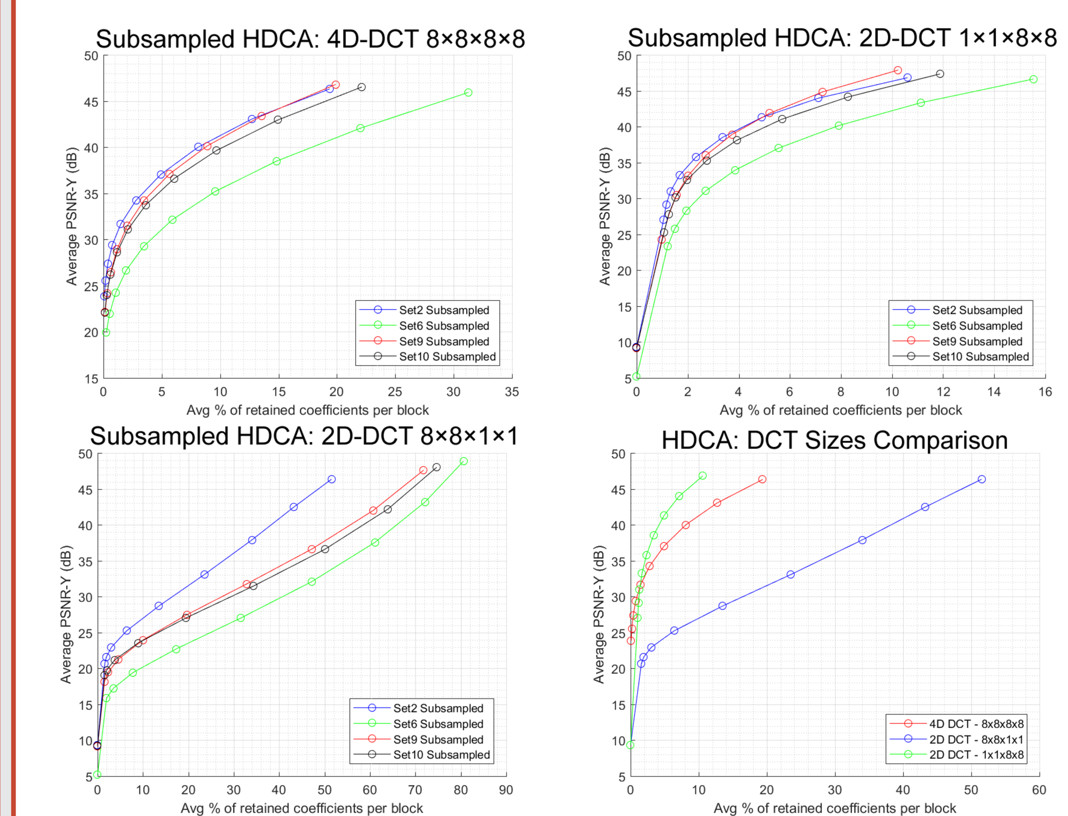
- Larger sparsity for 4D-DCT. It is worthy to exploit the 4D redundancy in a DCT-based coding scheme;
  - The exploration of 4D redundancy as a whole may lead to better coding efficiency;
- Inter-view sparsity is larger than the intra-view one: It is more effective to use an inter-view transform than an intra-view one;
  - 2D inter-view DCT is much closer to 4D DCT than 2D intra-view DCT;
- Similar behaviour for all lenslet-based datasets.

7 - Results: HDCA



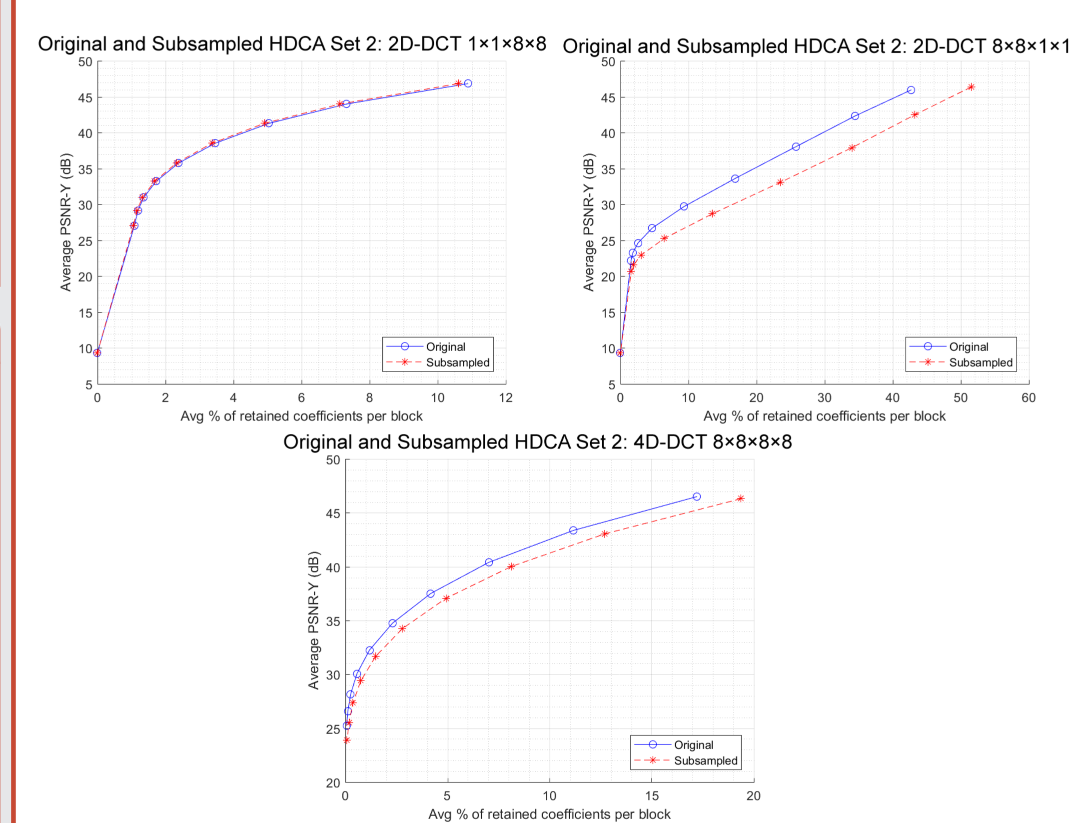
- The sparsity is larger for the 4D-DCT transform only for smaller percentage of retained coefficients;
  - 2D intra-view DCT has larger sparsity for larger percentage of retained coefficients;
- The sparsity is dominated by the intra-view redundancy, unlike the lenslet-based datasets;
- The inter-view sparsity is much smaller than the intra-view one;
- The HDCA dataset has much less 4D redundancy than the lenslet-based datasets.
- The same behaviour is observed for all HDCA datasets.

8 - Results: Subsampled HDCA



- Behaviour very similar to original HDCA;
- Sparsity is also dominated by the intra-view redundancy, with a much smaller inter-view redundancy.

9 - Comparison HDCA: Original vs Subsampled

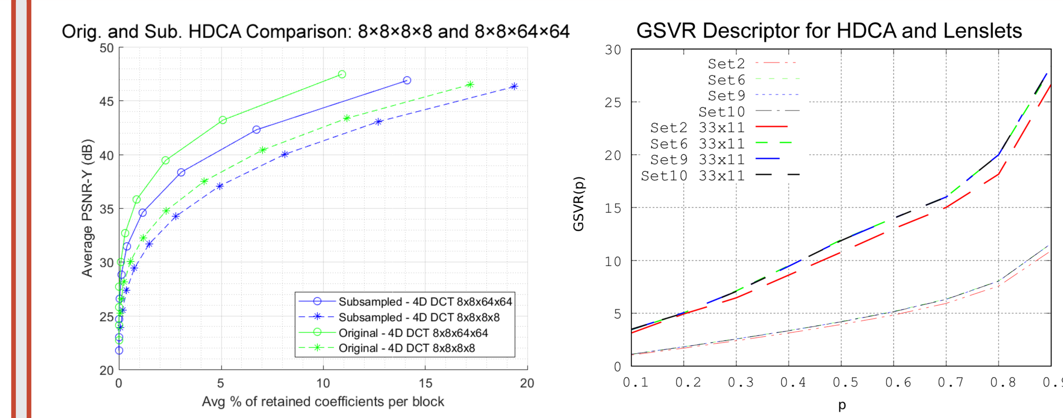


- Almost no difference between the original and subsampled datasets for 2D intra-view DCT - as expected;
- Large difference for 2D inter-view DCT: expected due to the larger spacing between adjacent views, introduced by the view subsampling;
- The difference between the original and subsampled HDCA datasets in terms of 4D redundancy is quite large.

10 - Comparison: HDCA vs Lenslets

- Lenslet-based datasets have a great deal of 4D sparsity, the inter-view redundancy being significantly larger than the intra-view;
- Unlike the lenslet dataset, the intra-view sparsity of the HDCA dataset is much larger than the inter-view;
- HDCA datasets have a much smaller amount of 4D redundancy than the lenslet-based datasets;
- It is likely that the coding solutions that are more efficient to the lenslet-based datasets will not be the more efficient ones to the HDCA datasets.

11 - HDCA: DCT $8 \times 8 \times 8 \times 8$ vs DCT $8 \times 8 \times 64 \times 64$



- DCT sizes differ only on the intra-view dimensions (8×8 and 64×64);
- The datasets differ only in the inter-view redundancy;
- For the same sparsity level, the difference in PSNR values between the two 4D-DCT sizes is higher for the original datasets;
- Conclusion: intra-view block size impacts on the exploitation of the inter-view redundancy. Larger intra-view dimensions are better.
  - Note: if intra-view dimensions are too large, the intra-view redundancy cannot be well exploited.
- The results are in accordance with the GSVR curves.

12 - Final Remarks

- Lenslet-based and HDCA datasets have a great amount of 4D redundancy that can be explored for coding purposes;
- Not exploiting the 4D redundancy as a whole may be a limitation to the design of LF codecs;
- HDCA and lenslet-based datasets may require distinct coding solutions due to the different nature of their 4D redundancy;
- The conclusions are restricted to the JPEG Pleno datasets. A more extensive study should be done using more general LF data.

Acknowledgements

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