TA-PB.3 3-D Mean-Separation-Type Short-Time DFT with Its Application to Moving-Image Denoising

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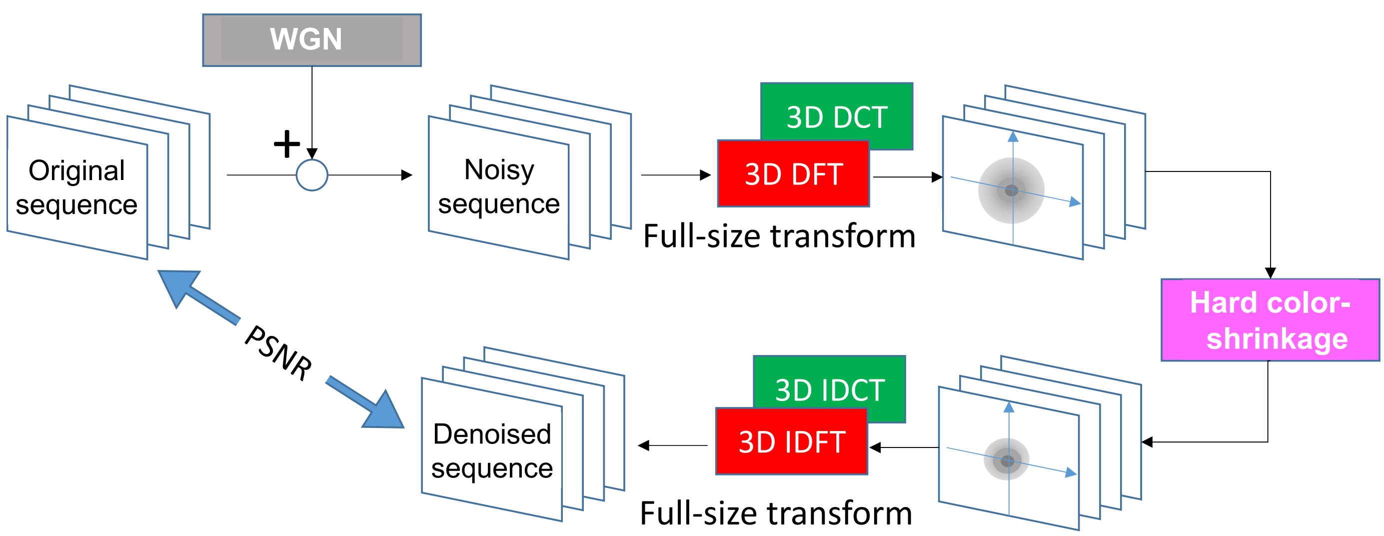
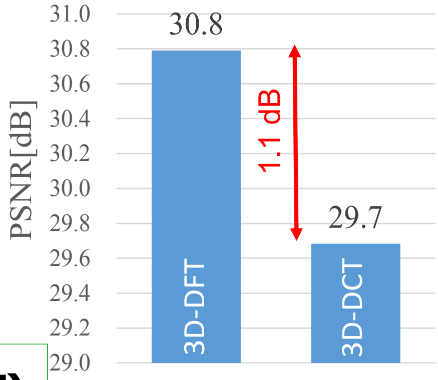
1 Abstract

- For a still image, ***2-D DFT*** and ***2-D DCT*** have similar properties.
- For a moving-image sequence, ***3-D DFT*** gets an advantage of representing the sequence more compactly over the ***3-D DCT***.
- Mathematical analysis on a simple model of a moving-image sequence shows that the even symmetry in ***3-D DCT*** causes deterioration of representation compactness and ***3-D DFT*** can achieve more compact representation than ***3-D DCT***. → ***See Proc. paper.***
- To improve the suitability of ***3-D short-time DFT*** (***3-D ST-DFT***) [1], [2] to moving-image processing, in this paper we
  - ✓ introduce a technique of local-mean-separation as a preprocess of the ***3-D ST-DFT***, thus to construct ***3-D mean-separation-type ST-DFT*** (***3-D MS²T-DFT***), and
  - ✓ apply ***3-D MS²T-DFT*** to color moving-image denoising, and
  - ✓ demonstrate its advantage over the existing methods through experimental simulations.
- As for denoising performance, ***3-D MS²T-DFT*** is superior to ***3-D redundant DCT*** (***3-D RDCT***) by 1.0 ~ 1.9 dB, and generally outperforms ***CVBM3D*** [5].

2 3-D DFT vs. 3-D DCT: Application to Video Denoising



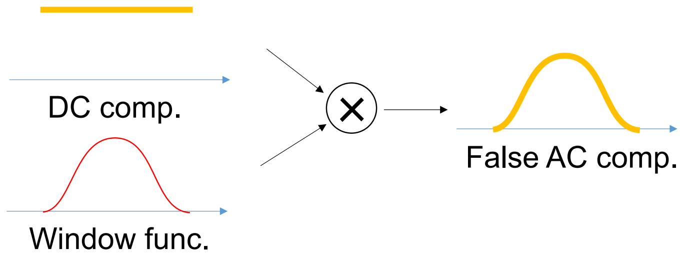
Additive WGN	Approx. 25.3 dB
3D DFT/3D DCT	Full frame-size
Shrinkage	Hard color-shrinkage
Shrinkage of DFT coefficients	Phase-preserving-type shrinkage; Magnitude alone is processed.



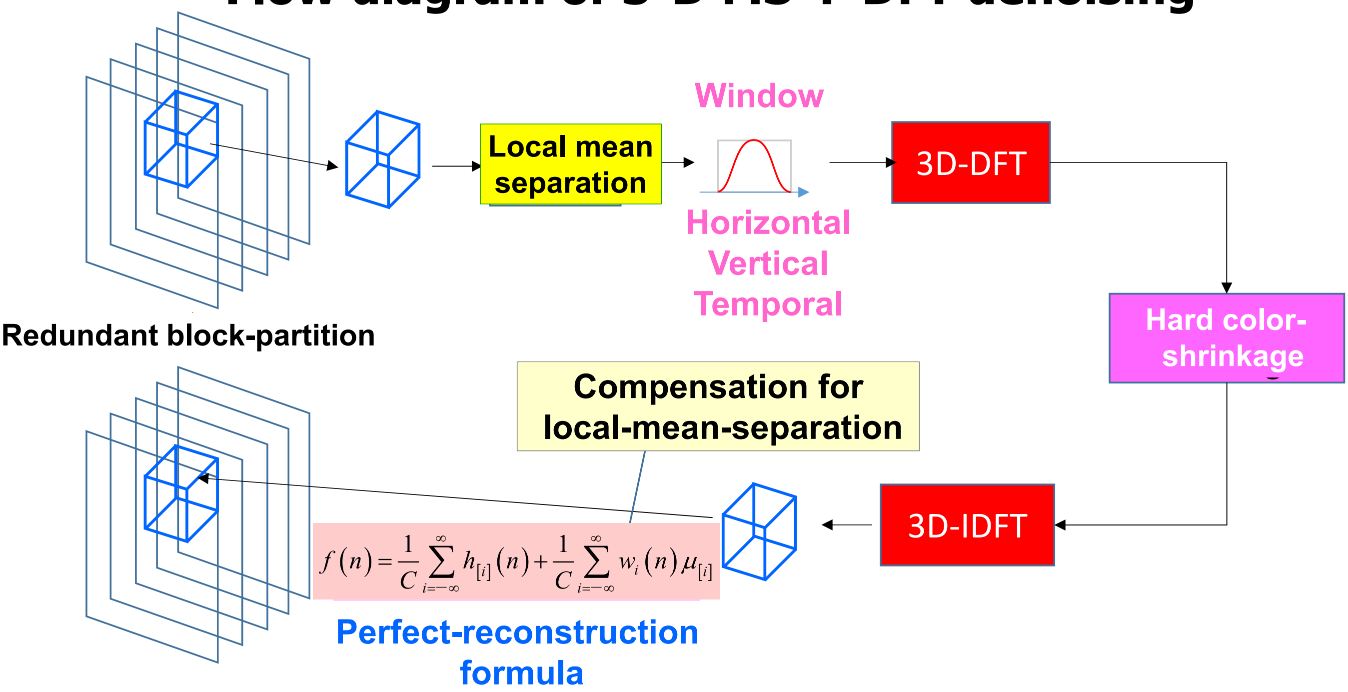
Denoising performance

3 Mean-Separation-Type 3-D ST-DFT (MS^2-DFT)

- ***Subblock-based DFT*** produces distortions, i.e. blocking artifacts.
- ***ST-DFT*** is a practical technique to suppress the blocking artifacts, and in the field of acoustic signal processing, ***ST-DFT*** has been used as a basic tool [1] ~ [2].
- In ***ST-DFT***, an input signal is multiplied by a window function, each windowed subblock is transformed with DFT, and then DFT coefficients are processed.
- In 1980, J. S. Lim proposed a ***still-image denoising method with 2-D ST-DFT*** [2], but there has been no further extension to image and/or video processing.
- Oscillatory signals such as acoustic signals do not have any DC components, whereas *image signals have significant local DC components carrying important information*.
- If ***ST-DFT*** is directly applied to image signals, *the multiplication of DC components by the window causes false AC components*, whose bad effect spreads over a wide range in the frequency domain, and hampers denoising.
- To alleviate this bad effect, **3-D MS^2T-DFT** *subtracts a local mean within each subblock from input signals* in advance of the application of the ST-DFT.
- To restore an image from processed ST-DFT coefficients, **3-D MS^2T-DFT** *compensates for the local-mean separation*.



Flow diagram of 3-D MS^2T-DFT denoising

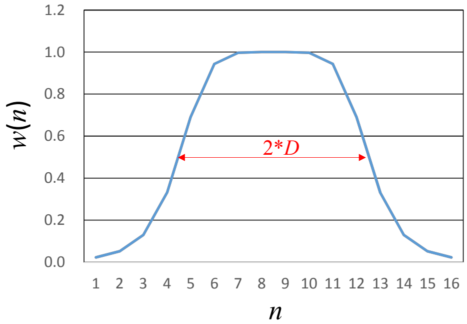


4 Experimental Simulations

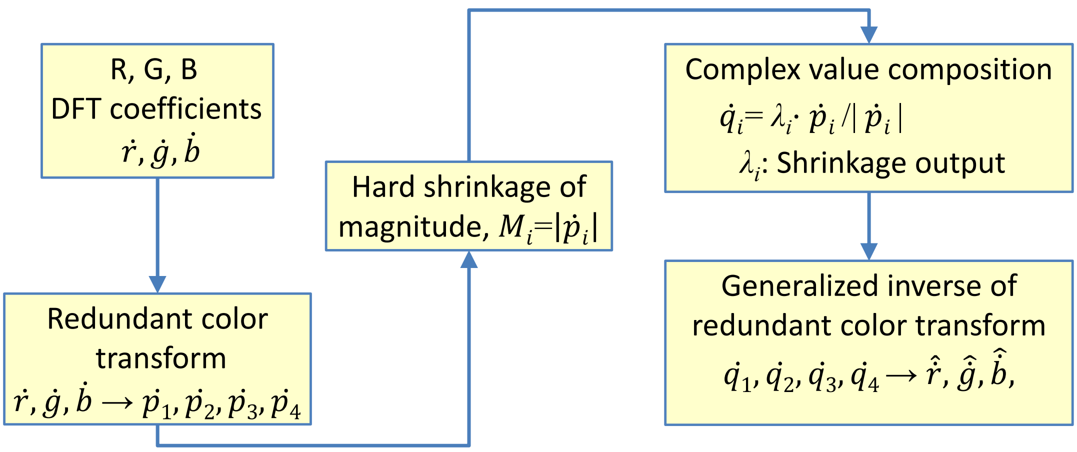
- Evaluations of denoising performance through experimental simulations of noisy color moving-image sequences
- Test sequences: ITE Standard Color Moving-Image Sequences: “Woman with Bird Cage”, “Whale Show”, “Walk through the Square” & “Harbor Scene”
- Noise: *Additive White Gaussian Noise*
- Window function: *Butterworth-type window function*
- Shrinkage of DFT coefficients: *Phase-preserving-type hard color shrinkage* [3] with the *redundant color transform* [4]
- Comparison with the state-of-the-art denoising method, “**CVBM3D** [5] ”

Butterworth-type Window Function

$$w(x)=\begin{cases}\dfrac{1}{1+\left(\left|x-2D\right|/D\right)^{2n}}, & 0\le x<4D,\\ 0, & \text{otherwise.}\end{cases}$$



Phase-preserving-type hard color-shrinkage



Redundant color transform

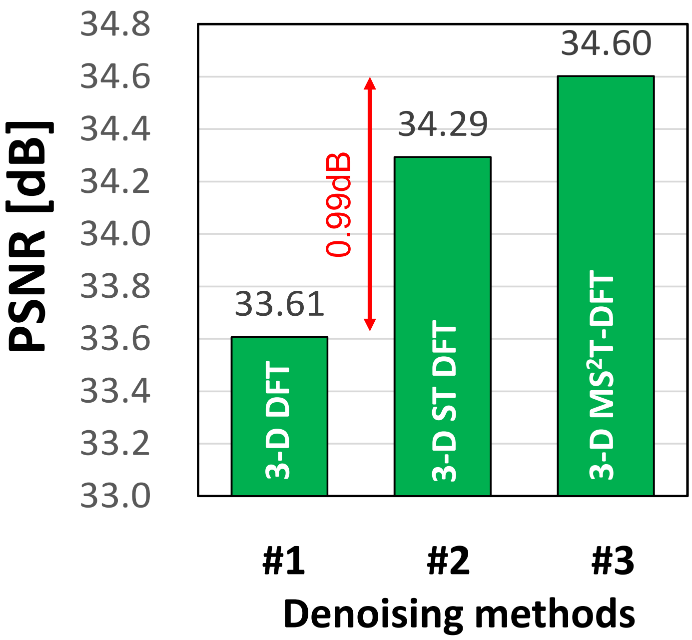
$$\begin{pmatrix}\dot{p}_1\\ \dot{p}_2\\ \dot{p}_3\\ \dot{p}_4\end{pmatrix}=\begin{pmatrix}1 & 1 & 1\\ 1 & -1 & 0\\ 0 & 1 & -1\\ -1 & 0 & 1\end{pmatrix}\begin{pmatrix}\dot{r}\\ \dot{g}\\ \dot{b}\end{pmatrix}$$

Generalized inverse of redundant color transform

$$\begin{pmatrix}\hat{r}\\ \hat{g}\\ \hat{b}\end{pmatrix}=\frac{1}{3}\begin{pmatrix}1 & 1 & 0 & -1\\ 1 & -1 & 1 & 0\\ 1 & 0 & -1 & 1\end{pmatrix}\begin{pmatrix}\dot{q}_1\\ \dot{q}_2\\ \dot{q}_3\\ \dot{q}_4\end{pmatrix}$$

Simulation #1

Test sequence	**Walk through the square**
Additive noise	**22.2 dB**
Block size	**16 × 16 × 16**
Method #1	**3-D redundant DFT without mean separation**
Method #2	**3-D ST-DFT without mean separation**
Method #3	**3-D MS^{2}T-DFT**

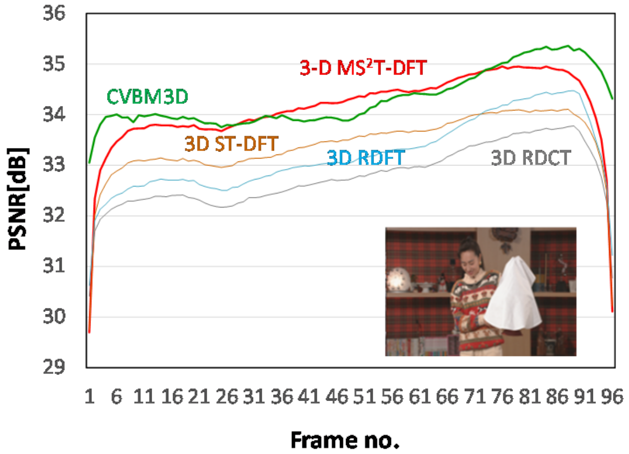


Simulation #2

Test sequences for denoising simulations

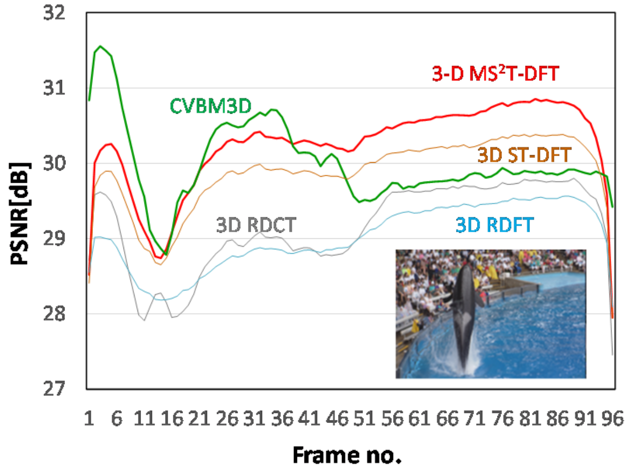
Sequence No.	Sequence title	Object motion	Camera work
1	Woman with Bird Cage	Moving woman with a bird cage	Slow panning
2	Whale Show	Jumping whale	Panning
3	Walk through the Square	Waking girl	Horizontal dolly
4	Harbor Scene	Walking crowds	Slow panning

Noisy test sequences, 19.3 [dB]



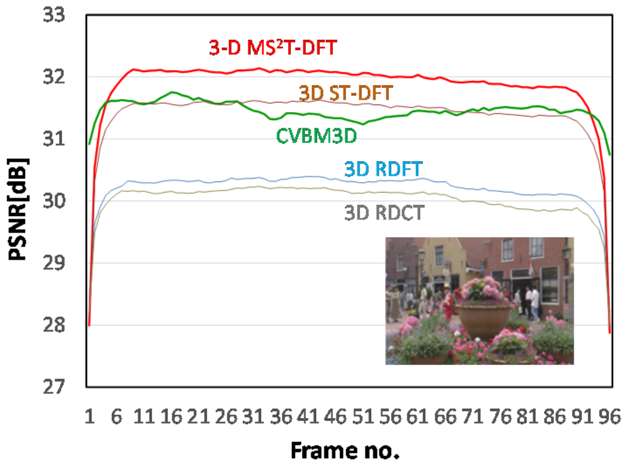
Specification of denoising methods

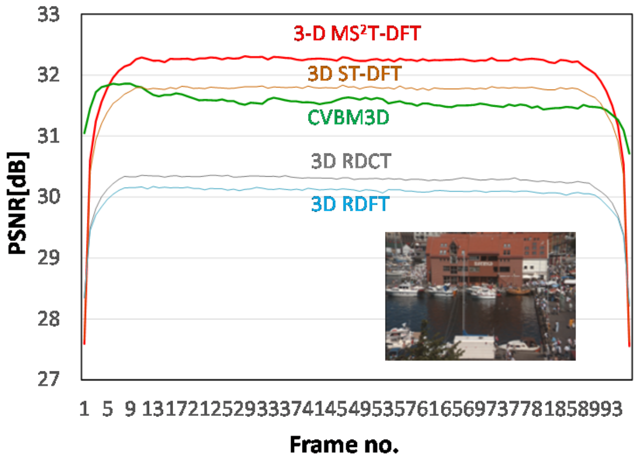
Denoising methods	Specification
3-D M^{S}2T-DFT	Our proposed denoising method
3-D ST-DFT	16×16×16 ST-DFT, Butterworth-type window, No mean-separation
3-D RDFT	8×8×8 redundant DFT
3-D RDCT	8×8×8 redundant DCT
CVBM3D	8×8×8 DCT



PSNR's [dB] of denoised sequences

Denoising methods	Sequence number 1	2	3	4
	all frames	all frames	all frames	all frames
	66 frames	66 frames	66 frames	66 frames
3-D MS^{2}T-DFT	34.018	**30.189**	**31.786**	**31.979**
	34.279	**30.343**	**32.023**	**32.261**
3-D ST-DFT	33.328	29.835	31.335	31.562
	33.496	29.955	31.530	31.792
3-D RDFT	33.125	28.992	30.000	30.027
	33.190	29.017	30.117	30.114
3-D RDCT	32.723	29.108	30.184	30.204
	32.785	29.137	30.300	30.310
CVBM3D	**34.279**	29.968	31.451	31.548
	34.208	29.953	31.451	31.556





References

1) T. F. Quantieri, "Chap. 7: Short-time Fourier transform analysis and synthesis," in *Discrete-Time Speech Signal Processing*, Prentice Hall Inc., Englewood Cliffs, NJ, USA, 2002.
2) J. S. Lim, "Image restoration by short space spectral subtraction", *IEEE Trans. Acoust., Speech, & Signal Process.*, vol.ASSP-28, no.2, pp.191-197, April 1980.
3) P. Kovesi, "Phase preserving denoising of images," *Proc. Fifth International/National Biennial Conference on Digital Image Computing, Techniques & Applications* (*DICTA 99*), pp.212-217, Perth, Australia, Dec. 1999.
4) T. Saito, Y. Ueda, and T. Komatsu, "Color shrinkage for sparse coding of color images," *Proc. 18th European Signal Process. Conf. (EUSIPCO 2010)*, pp.1023-1027, Aug. 2010.
5) K. Dabov, A. Foi, and K. Egiazarian, "Video denoising by sparse 3D transform-domain collaborative filtering," *Proc. 15th European Signal Process. Conf. (EUSIPCO 2007)*, pp.145-149, Poznań, Poland, Sept. 2007.