SHAPE ADAPTIVE DISCRETE FOURIER TRANSFORM FOR CODING OF IRREGULAR IMAGE SEGMENTS

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ABSTRACT
In the paper the new transform adapting to shapes of irregular image segments is introduced, the shape-adaptive (SA) DFT. Its definition is based on periodic –data extension rather than data shifts, hence, in contrast to SA DCT segment reconstruction is possible even if part of contour data is missing. Visually the quality of images reconstructed from the part of the SA DFT samples is almost as good as for the SA DCT, especially for high compression ratios.

1. INTRODUCTION
The introduced in the paper shape adaptive discrete Fourier transform (SA DFT) has been devised as an alternative to the shape-adaptive discrete cosine transform (SA DCT) [1]. SA DCT is a method for coding of irregularly shaped image segments. It is included in the MPEG-4 image compression standard as an auxiliary technique. It consists in defining the two-dimensional DCT in such a way that samples inside an irregular image region are transformed, only, hence, shape adaptivity of the transform. This is an obvious advantage in applications in which an image is treated as a collection of objects, like multimedia, data bases etc. Namely, after segmentation of an image into regions (‘objects’) we can code them without any excess of information, as the coding blocks need not be rectangular anymore. Moreover, the technique performs much better than simple shape adaptive methods based on DCT for rectangular blocks, probably due to the lack of interference with arbitrary defined samples situated outside the processed region [2], [4].

Nevertheless, when compared with other shape-adaptive coding methods the SA DCT exhibit some drawbacks. Namely, the method is very susceptible to shape errors caused by transmission channel or storage media noise, which is in contrast to extrapolation methods [4]. That is why the use of DFT instead of DCT is considered in the paper, section 2. The DFT of a vector can be interpreted as the Fourier transform of a periodic signal one period of which is processed. We need not to shift the signal as in the SA DCT, it suffices to extend it periodically and to compute the DFT starting from the beginning of a row/column. Secondly, if part of information about the shape border is missing, but we can deduce correct row/column DFT sizes, the image can be correctly reconstructed by periodic extension of inverse DFTs in the decoder, section 3, Fig.3. Then, some device or a human should decide which image samples belong to the shape, and which are obtained by shape periodic extension. Similarly as the SA DCT, SA DFT can be easily extended to process correctly signal DC component, section 4.

2. SA DFT DEFINITION
Let us consider a one-dimensional vector \( x(n) \) of size \( N \), in which \( N_s \) samples belong to a shape, and the remaining ones are background samples. Assume for the moment that the shape is convex, i.e. that shape samples form contiguous clusters inside image rows and columns, i.e. they are not separated by background samples. The one-dimensional SA DFT method is:

- Extend periodically shape samples in the data vector, i.e. if \( x(n) \) is a shape sample, then set \( x(n+kN_s)=x(n), \ k=\ldots,-1,0,1,\ldots, 0\leq n+kN_s\leq N \). In fact, only the beginning vector samples \( x(0),x(1),\ldots,x(N_s-1) \) should be defined.
- Compute the \( N_S \)-point DFT for the first \( N_S \) vector samples. Due to the DFT redundancy for real valued data DFT samples for indices greater than \( N_s/2 \) should be rejected.
- Scale the results. In the paper the scaling factor is \( \frac{1}{\sqrt{N_S}} \), which makes the 2-D transform orthogonal [2-4].

The method is generalized to two-dimensions in the same way as separable transforms: firstly, each signal row is processed by the 1-D algorithm above, secondly, the algorithm is applied to each column of the results. For avoiding column DFT redundancy row DFT samples \( X(N_s/2) \) should be removed from the rows and processed by a separate column DFT (they exist for even \( N_s \) and are real-valued). Additionally, if the shape is not convex, then before making row/column periodic extensions we should ‘shrink the holes’ in shape filled with background samples by shape samples shifts. The order of computations can be reversed, column transformations can precede the row ones, which usually leads to different results [4], Fig.1.
3. EXPERIMENT

The SA DFT has been realized as a Matlab function and tested on the segment ‘face’ from image #6 from QCIF sequence ‘Carphone’ used in experiments in [4]. For making the results comparable to those from [4], the logarithms of the basis restriction errors have been compared. It appears that due to worse data compression properties basis restriction error curves for SA DFT lay below those for the SA DCT and are less steep, Fig.1, the difference grows from zero when only the greatest transform samples are preserved up to approximately 2 dB when 40% of the greatest transform samples is used for image reconstruction. Nevertheless, when 5-10% greatest transform samples are retained the subjective visual qualities of reconstructed images are quite similar, Fig.2. This is in part due to the fact that errors of images reconstructed from SA DFT concentrate on the shape border, which is not that important visually, Fig.2. Namely, because of implied periodicity of signals processed by the DFT the last data sample is followed by the first one, and if they are very different, then we have an edge, hence, usual problems with edge distortions.

In Figure 3 shape reconstruction property of the SA DFT is illustrated. The first image shows the shape of the convex version of the ‘face’ segment used for experiments in [4], pixels belonging to the segment are gray, and those of the background are black. To the right the segment reconstructed from the 10% greatest SA DFT coefficients is shown. Then, incomplete shape information is visualized, it is assumed that we know only the sizes of row DFTs, actual positions of segment samples inside rows are missing. Finally, the segment reconstructed from 10% greatest SA DFT coefficients using incomplete shape information is shown, inverse DFT samples have been extended periodically along rows. As can be seen, shape pixels are identical to those above, only the background is not black anymore.

4. SA DFT IMPROVEMENTS

For the sake of simplicity the compared in the paper SA DFT and SA DCT versions are orthogonal, which means that they are not DC preserving [2-4]. Nevertheless, for such large data segments as the ‘face’ one the differences between results for SA DCT (and SA DFT) versions are negligible. Moreover, the construction of DC preserving SA DFT version is straightforward. Namely, similarly as for the SA DCT the structure of the DC separated and ΔDC corrected [2] SA DFT is as follows:

- Subtract mean segment value from the data.
- Compute the SA DFT.
- Replace transform $X(0,0)$ sample by the segment mean value (possibly multiplied by a constant).

Basis restriction error curves for the DC corrected SA DFT and SA DCT are almost the same as those in Fig.1.

5. CONCLUSION

The problem of reducing SA DCT susceptibility to contour reconstruction errors is addressed in the paper. It is proposed to replace shift operations of this transform by periodic data extension, and the DCT by the DFT; in this way the SA DFT is obtained. The transform indeed allows correct reconstruction of irregular segment samples when nothing more than numbers of samples in either rows or columns are provided. Visually partly reconstructed images from the new transform are almost as good as those for the SA DCT.

6. REFERENCES


Fig.1: SA DFT/DCT basis restriction error as a function of used transform samples fraction for segment ‘face’, upper curves are valid when rows are processed first.
Fig. 2: 'Face' segment reconstructed from 10% of greatest transform samples of the SA DFT (upper left), and SA DCT (upper right), and absolute values of errors between the reconstructions and original image for SA DFT (lower left) and SA DCT (lower right). Note high error values (bright pixels) on the border of the image reconstructed from SA DFT.
Fig. 3: Convex version of the ‘face’ segment reconstructed from the 10% of the greatest SA DFT samples (right images) on the basis of full shape information (upper left image), and row DFT sizes (lower left image).