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Research Article

Discrete Anamorphic Stretch Transform based Image Compression with Watermarking

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Abstract

In order to handle the big data problem, a physics-based transform called Discrete Anamorphic Stretch Transform (DAST) is used which enables image compression by increasing the spatial coherency. DAST emulates diffraction of the image through a physical medium with specific non-linear dispersive property. This diffraction-based compression is achieved through a mathematical restructuring of the image. By performing space-bandwidth compression, it reduces the data size required to represent the image for a given image quality. This transform is being used as a pre-compression step to improve the performance of standard image compression algorithms. In this work, an image compressed using DAST followed by JPEG 2000 is being watermarked and its efficiency is analyzed.

Keywords: *Anamorphic Stretch Transform, Space-bandwidth product.*

1. Introduction

Image compression, one of the most useful and dynamically changing fields in digital image processing, focuses on the reduction of amount of data required for the representation of image along with its visual quality. The neighboring pixels of most images are highly correlated and therefore contain redundant information. So the main aim of image compression is to remove the irrelevant redundancies of image data and thus reduce the number of bits required for the storage and transmission of image without appreciable loss of information. Image compression plays a vital role in diverse applications such as tele-video conferencing, remote sensing (the use of satellite imagery for weather and other earth source applications), medical imaging and many more. These applications make use of various techniques and algorithms in compressing images.

JPEG (W. B. Pennebaker *et al*, 1993) and JPEG 2000 (D. S. Taubman *et al*, 2004) are the most commonly used methods for image compression. JPEG is a lossy compression standard which employs a transform coding method using discrete cosine transform (DCT). Although JPEG compression schemes have various advantages such as simplicity, satisfactory performance and availability of special purpose hardware for implementation, they are not without shortcomings. Since the input image needs to be blocked, correlation across the block boundaries is not eliminated. This results in noticeable and annoying blocking artifacts particularly at low bit rates. JPEG 2000, which is based on wavelet transform, outperforms JPEG in many aspects like high compression efficiency, lossless color transformation, random code stream access and processing, and error resilience (M. Rabbani *et a*l, 2002).

In this work, a physics-inspired transformation called Discrete Anamorphic Stretch Transform (DAST) (M. H. Asghari *et a*l, 2014) is used as a pre-compression step. DAST emulates diffraction of the image through a physical medium with specific non-linear dispersive property. It reshapes the image by performing space-bandwidth compression. DAST warps the image such that the intensity bandwidth is reduced without proportional increase in the image size. Thus it increases the spatial coherence and reduces the amount of data needed to represent the image for a given image quality.

2. Methodology and Design

For dealing with the exponential increase of digital data, a new compression technique is introduced based on DAST and it is watermarked to verify its integrity. Discrete Anamorphic Stretch Transform (DAST) is a physics-inspired transformation which mimics diffraction of the image through a physical medium with specific non-linear dispersive property. It is a non-linear transform, both in terms of amplitude and in terms of the phase operation. It achieves diffraction-based compression through a mathematical restructuring of the image. This technique does not need feature detection and is non-iterative.

Different steps for the implementation of DAST based image compression are shown in Fig. 1. The

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original image is represented by B[n,m] where n and m represent the two dimensional discrete spatial variables. To compress the image using this method, it is first passed through the DAST and then is uniformly re-sampled (down-sampled) at a rate below the Nyquist rate of original image. Finally, the compressed image is watermarked using DWT-SVD method. To recover the original image from the compressed one, the compressed image is first up-sampled and then inverse DAST is applied.

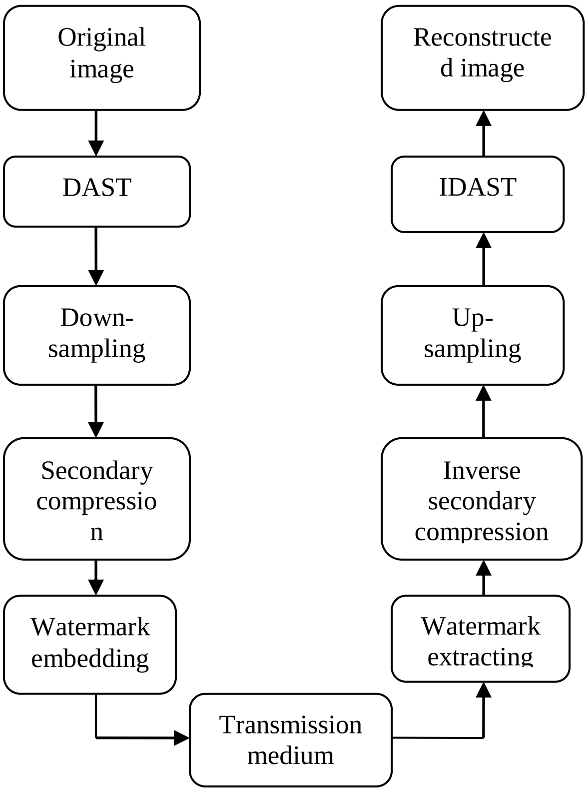


Fig.1 Proposed method

2.1 Discrete Anamorphic Stretch Transform (DAST)

The Discrete Anamorphic Stretch Transform (DAST) is mathematically defined as:

$$B_1[n,m] = \left| \sum_{k_1,k_2=-\infty}^{\infty} K[n-k_1, m-k_2] . B[k_1,k_2] \right|^N \qquad (1)$$

where | | is the absolute operator. For DAST operation, the original image is convolved with DAST kernel K[n,m], and then the N-th power magnitude of the result is computed. Here case of N=1. The kernel K[n,m] is described by a non-linear phase operation,

$$K[n,m] = e^{j\cdot\phi[n,m]} \qquad (2)$$

In order to compress the image, the non-linear phase profile Φ[n,m] should be chosen such that the DAST applies a spatial warp to the image with a particular profile. To describe the applied warp, we define the DAST Local Frequency (LF) profile as the 2D spatial gradient (derivative) of the DAST kernel phase function. LF is the equivalent of time domain instantaneous frequency but in 2D spatial domain. In this technique, the superlinear LF profile used in DAST kernel is the tangent function which is one of the simplest and effective profiles that exist and it is given by,

$$LF[n,m] = a_1 \cdot \tan(b_1 \cdot n) + a_2 . \tan(b_2 \cdot m); \qquad (3)$$

where a_1, b_1, a_2 and b_2 are real numbers. This LF profile results in the following DAST kernel phase profile:

$$\phi[n,m] = \frac{a_1}{b_1} \cdot \ln(\cos(b_1 \cdot n)) + \frac{a_2}{b_2} \cdot \ln(\cos(b_2 . m)) \qquad (4)$$

where ln is natural logarithm and cos is cosine function. The parameters b_1 and b_2 are always normalized to the image size to ensure that b_1 .n & b2 .m < π/2. The slope of the LF profile at the origin (related to a_1 and a_2) determines the amount of intensity bandwidth compression. After the proper choice of a_1 and a_2, the resulting spatial image size is related to the warping strength (related to b_1 and b_2).

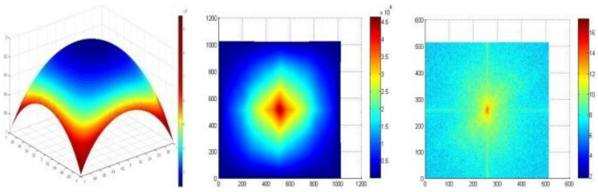
Fig.2 shows the effect of DAST on Pepper image. When auto-correlation of original image B[n,m] is compared to that of transformed image using DAST, the broader is the auto-correlation which indicates increased coherency without increase in image size. In the case of image intensity spectrum, intensity bandwidth is been compressed after DAST. The compression is a result of reshaping the image where sharp features are stretched more than coarse ones.

2.2 Down-sampling

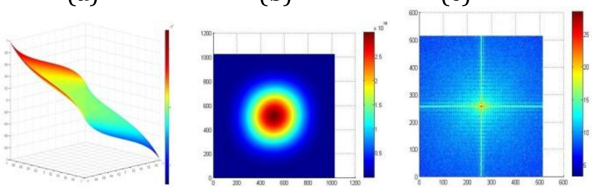
After the transformation, the reshaped image is uniformly down-sampled at a rate below the Nyquist rate of original image. The reshaping is such that it increases the spatial coherence (i.e, it compresses the intensity bandwidth), hence, sub-Nyquist re-sampling does not cause loss of information. In the decoder side, phase discrimination is used to recover the original image.

2.3 Secondary compression

The down-sampled image is compressed further by a secondary compression such as JPEG or JPEG 2000. In this work I have used JPEG 2000.



(a) (b) (c)



(d) (e) (f)

Fig.2 Analysis of DAST effect on Pepper image, (a) DAST kernel phase profile, (b) Auto-correlation before DAST, (c) Image intensity spectrum before DAST, (d) DAST Local Frequency (LF) profile, (e) Auto-correlation after DAST and (f) Image intensity spectrum after DAST

2.4 Watermark embedding

This DWT-SVD watermarking method is based on the Mohammad's embedding algorithm (A. A. Mohammad *et al*, 2008). In this method, the host image (H) and watermark images (W) used are color images. First, one-level Haar DWT is used to decompose the compressed host image and watermark image (i.e., h_LL, h_LH, h_HL, h_HH and w_LL, w_LH, w_HL, w_HH). Then lower bands h_LL and w_LL are selected and their R, G and B planes are separated. SVD is applied on each plane and decompose into U, S and V. Next, the singular values of each plane (p) are modified as,

$$S_{nwp} = S_{hp} + \alpha S_{wp} \tag{5}$$

where S_{nwp} is the modified singular matrix of plane 'p', S_{hp} and S_{wp} are the singular matrices of host and watermark subband planes and α is a scalar constant value. Inverse SVD is applied to get the modified subband and inverse DWT is applied to produce the watermarked image.

2.5 Watermark extraction

The watermarked image is decomposed using Haar DWT and its LL subband is separated into R, G and B planes. Apply SVD on each plane and modify the singular values of each plane by performing the reverse step of embedding procedure as

$$S^*_{wp} = \frac{S^*_{nwp} - S_{hp}}{\alpha} \tag{6}$$

By applying inverse SVD followed by inverse DWT, the watermark image can be extracted.

3. Implementation

The algorithm is implemented in MATLAB simulation tool. The Boats image with 512 x 512 pixels in TIF format is used as input image. First of all, Discrete Anamorphic Stretch Transform of the original image is computed. The parameters used in the DAST kernel profile, b_1 and b_2 are selected such that $b_1 . n$ & $b_2 . m < \pi/2$. The transformed output is down-sampled at 0.8 (at a lower rate) in order to prevent the loss of information. Next, the down-sampled image is compressed using a secondary compression. In this work, I have used JPEG 2000 standard.

The compressed image is watermarked using DWT-SVD method. Both host and watermark images which are color images are decomposed using Haar DWT. The LL subbands are separated into R, G and B levels and they are decomposed using SVD. The singular matrix is modified with scaling factor α = 0.10. Inverse SVD is applied followed by inverse DWT to obtain watermarked image.

At the decoder side, the decoding algorithm which consists of up-sampling followed by inverse propagation through the DAST which incorporates 2D local frequency measurement is carried out. The performance evaluation parameters PSNR and CR are manually programmed in MATLAB and values are obtained. The same procedure is carried out on two more images such as pepper and plane. Various attacks are applied on the watermarked images and their NC values are calculated using

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)\cdot W'(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)^2 \cdot \sum_{i=1}^{M}\sum_{j=1}^{N} W'(i,j)^2}} \tag{7}$$

where W(i,j) and W'(i,j) represents original and extracted watermark images both of size M x N. The value of NC lies between 0 and 1.

4. Results

The watermark image used is copyright image of size 512 x 512 as shown below.

Fig.3 Watermark image

The results obtained for the three input images are shown below.

(a) (b)

(c) (d)

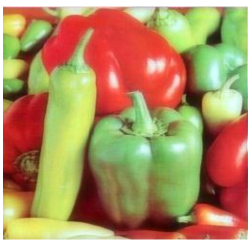
Fig.4 (a) Original image, (b) Compressed image, (c) Watermarked image and (d) Extracted watermark

(a) (b)

(c) (d)

Fig.5 (a) Original image, (b) Compressed image, (c) Watermarked image and (d) Extracted watermark

(a) (b)



(c) (d)

Fig.6 (a) Original image, (b) Compressed image, (c) Watermarked image and (d) Extracted watermark

From the table 4.2 it is clear that, in the case of Boats image compressed using JPEG 2000, the Peak Signal to Noise Ratio is 30.9763 dB. The compression factor (original over compressed image file sizes) in this case is 2.8. The image pre-compressed by DAST followed by JPEG 2000 is of almost similar PSNR value 30.9338dB. In this case we achieved a compression factor of 5.8625. Thus it is clear that DAST pre-compression gives more than twice compression factor without much difference in PSNR. It is valid in the case of other images also.

Table 4.1 Comparison based on Compression Ratio

Images	JPEG 2000	DAST + JPEG 2000
Boats	2.8	5.8625
Plane	3.2	6.6207
Pepper	2.4	4.8917

Table 4.2 Comparison based on PSNR value

Images	JPEG 2000	DAST + JPEG 2000
Boats	30.9763	30.9338
Plane	30.8983	30.8885
Pepper	30.5804	30.5447

Table 4.3 Effect of attacks on NC values

Attacks	Boats	Plane	Pepper
No attack	1.000	1.000	1.000
Salt and pepper noise	0.9945	0.9931	0.9939
Gaussian noise	0.9846	0.9938	0.9844
Mean attack	0.9983	0.9988	0.9991
Sharpening	0.9985	0.9988	0.9989

Table 4.3 shows the effect of various attacks such as salt and pepper noise, sharpening, Gaussian noise etc on the DWT-SVD based watermarked images and gives the values of the correlation coefficient between the extracted and original watermark images using different host images. It is seen from the table that the values of the correlation coefficient are almost invariably larger than 0.9 for the various attacks, regardless of the watermark and host images used in the experiment.

Conclusions

For solving the problem of big data problem, physics inspired Discrete Anamorphic Stretch Transform can be used. It warps the image such that the intensity bandwidth is reduced without proportional increase in the image spatial size. This increases the spatial coherence and helps to reduce the amount of data required to represent the image. The DAST pre-compression step can improve the performance of JPEG 2000 for high compression factor without much change in PSNR value. By this method a watermark can be hidden in the compressed image and transmitted such that it can be extracted without much error. So this method can be used for various applications which need to verify authenticity or integrity. This method can be extended by using other compression methods instead of JPEG 2000. Other watermarking methods also can be used for increasing the robustness which increases the security of information in many applications.

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