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Cadu Technique To Improve Image Compression At Low Bit Rates

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Abstract: This paper proposes a practical approach of uniform down sampling in image space and yet making the sampling adaptive by spatially varying, directional low-pass prefiltering. The high frequency information in an image is adaptively decreased to facilitate com- pression, The resulting down-sampled prefiltered image remains a conventional square sample grid, and, thus, it can be compressed and transmitted without any change to current image coding standards and systems. The decoder first decompresses the low-resolution image and then upconverts it to the original resolution in a constrained least squares restoration process, using a 2-D piecewise autoregressive model and the knowledge of directional low-pass prefiltering. The proposed compression approach of collaborative adaptive down-sampling and upconversion (CADU) outperforms JPEG 2000 in PSNR measure at low to medium bit rates and achieves superior visual quality, as well. The superior low bit-rate performance of the CADU approach seems to suggest that oversampling not only wastes hardware resources and energy, and it could be counterproductive to image quality given a tight bit budget.

Keywords: *Autoregressive modeling, compression standards, image restoration, image upconversion, low bit-rate image com- pression, sampling, subjective image quality.*

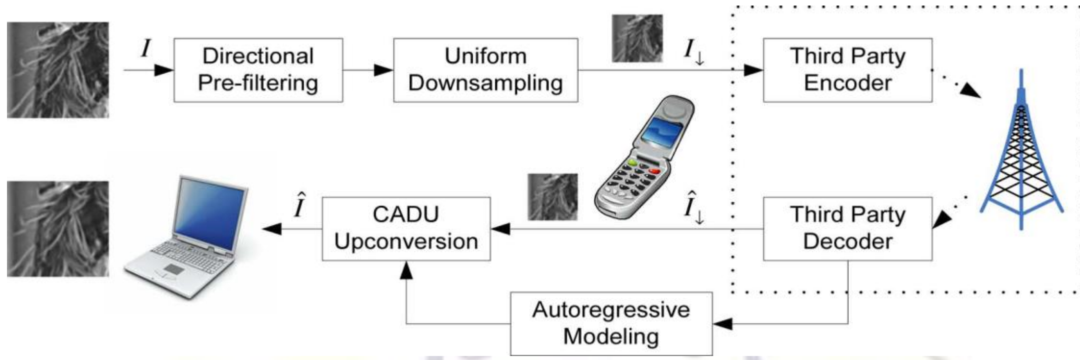
I. INTRODUCTION

Image enhancement techniques were studied the proper enhancement techniques for the specific application was found out. Various enhancement methods were implemented. The frames captured were enhanced using these methods and a later this was done in real time. It was found that for acquiring large number of frames at a faster rate Matlab to C interfacing was required. An interface was created and Matlab functions were called from C environment. This inturn was used to acquire real time images. The basic principles involved in image storage, techniques involved in image compression were studied. The image compression algorithms namely JPEG, JPEG2000 and MPEG-4 were studied in detail. JPEG algorithm was understood and implemented on image sub blocks and on the entire image. Various aspects of the algorithm such as effect of DC coefficient, blocking artifacts etc was studied and implemented in real time. The algorithm was implemented in real time in Matlab-7 and the results analyzed. The advantages and short comings of this algorithm were studied.The complete algorithm of JPEG2000 was studied. The short comings of JPEG were eliminated using JPEG2000. The algorithm was implemented in real time in Martlab-7.The advantages and key features of this algorithm were studied and implemented. The tradeoffs in both JPEG and JPEG2000 were also studied. An equivalent C code for the JPEG algorithm was developed and it was successfully compiled and executed. This was dumped on a Blackfinn DSP processor and a hardware model for a real time image acquisition and compression was set up. This was done by interfacing video to the Blackfin processor and also to the PC.Thus a complete system(A hardware model) for a real time image acquisition and compression was set up. The modifications if any can be simulated in Matlab-7 and if the results are improved can be incorporated on the hardware model by making equivalent changes in the C code. This system(algorithm) has important application in the modern world such as Telemedicine and other communication applications.

II. DOWN-SAMPLING WITH ADAPTIVE DIRECTIONAL PREFILTERING

Out of practical considerations, we make a more compact rep- resentation of an image by decimating every other row and every other column of the image. This simple approach has an oper- ational advantage that the down-sampled image remains a uni- form rectilinear grid of pixels and can readily be compressed by any of existing international image coding standards. To pre- vent the down-sampling process from causing aliasing artifacts, it seems

Fig. 1. Block diagram of the proposed CADU image compression system.

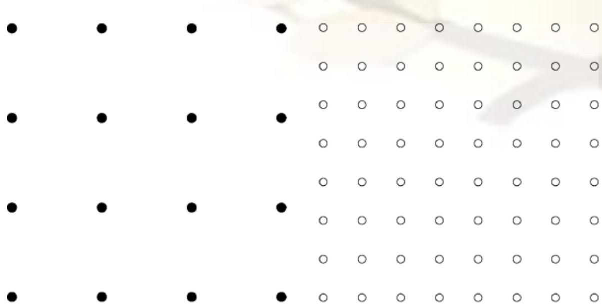


necessary to low-pass prefilter an input image to half of its maximum frequency $f_{\max}$. However, on a second reflection, one can do somewhat better. In areas of edges, the 2-d spec- trum of the local image signal is not isotropic. Thus, we seek to perform adaptive sampling, within the uniform down-sampling framework, by judiciously smoothing the image with directional low-pass prefiltering prior to down - sampling.

In the directional prefiltering step, the CADU encoder first computes the gradient at the sampled position. Despite its simplicity, the CADU compression approach via uniform down-sampling is not inherently inferior to other image compression techniques in rate-distortion performance, as long as the target bit rate is below a threshold. The argument is based on the classical water-filling principle in rate-distortion theory. To encode a set of K Independent Gaussian random variables $\{X_1, X_2, \ldots X_k,\}$, X_k $N(0,\sigma_k)$ the rate-distor- tion bounds, when the total bit rate being $R=\sum_{k=1}^{k} R_k$ and the total mean-squares distortion being $D=\sum_{k=1}^{k} D_k$, are given by

$$R(D) = \sum_{k=1}^{k} \max\{0, \frac{1}{2} \log_2 \frac{\sigma^2{}_k}{\tau}\}$$

$$D(R) = \sum_{k=1}^{k} \min\{\tau, \sigma^2{}_k\}$$



(a) Downsampled prefiltered image (b) Original image

Fig: Relationship between the down-sampled prefiltered image and the original image. The illustrated kernel size of the filter is 3. Low-resolution pixel [black dots in (a)] is the filtered value of the corresponding nine original pixels [white dots in (b)]. (a) Downsampled prefiltered image; (b) original image.

Most natural images have a rapidly (e.g., exponentially) de- caying power spectrum $\Phi(\omega)$. Suppose that the input image is 2-d. in the Fourier domain and its power spectrum is monotonically decreasing. Therefore, given a target rate r^*, if the rate-distortion function of the image signal satisfies

$$D(r^*)=\int_{\frac{\pi}{2}}^{\pi} \Phi(w)dw$$

then uniform down-sampling by the factor of two will not limit the rate-distortion performance in information theoretical sense. Indeed, our experimental results (see Section IV) demonstrate that the CADU approach outperforms the state-of-the-art JPEG2000 standard in the low to medium bit rate range.

III. CONSTRAINED LEAST SQUARES CONVERSION WITHAUTOREGRESSIVE MODELING

In this section, we develop the decoder of the CADU image compression system.We formulated the constrained least square problem using two PAR models of order 4 each: the model of parameters **a** and the model of parameters ***b***. The two PAR models characterize the axial and diagonal correlations, respectively, as depicted in Fig. 4. These two models act, in a predictive coding perspective, as noncausal adaptive predictors. This gives rise to an interesting interpretation of the CADU decoder: adaptive noncausal predictive decoding constrained by the prefiltering operation of the encoder.

Therefore the par model parameters **a** and **b** can be estimated from the decoded image by solving the following least square estimation

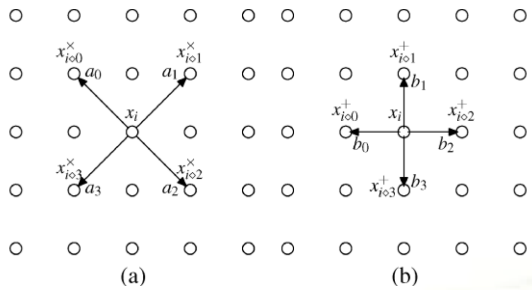


Fig: Sample relationships with PAR model parameters (a) **a** = (a_0,a_1,a_2,a_3), (b) **b** = (b_0,b_1,b_2,b_3)

$$\hat{\boldsymbol{a}} = \arg\min_{\boldsymbol{a}} \left\{ \sum_{i\in W} \left(y_i - \sum_{0\le t\le 3} a_t y^{\times}_{i\diamond t} \right)^2 \right\}$$

$$\hat{\boldsymbol{b}} = \arg\min_{\boldsymbol{b}} \left\{ \sum_{i\in W} \left(y_i - \sum_{0\le t\le 3} b_t y^{+}_{i\diamond t} \right)^2 \right\}$$

The closed form solution for the above equations is

$$\hat{\boldsymbol{a}} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{v}$$
$$\hat{\boldsymbol{b}} = (\mathbf{B}^T\mathbf{B})^{-1}\mathbf{B}^T\mathbf{v}$$

The constrained least square problem can be converted to the following unconstrained least square problem:

$$\min_{\boldsymbol{x}} \left\{ \xi^{\times} \sum_{i\in W} \left(x_i - \sum_{t=0}^{3} a_t x^{\times}_{i\diamond t} \right)^2 + \xi^{+} \sum_{i\in W} \left(x_i - \sum_{t=0}^{3} b_t x^{+}_{i\diamond t} \right)^2 + \lambda(\boldsymbol{x} * \boldsymbol{h} - \boldsymbol{y})^2 \right\}$$

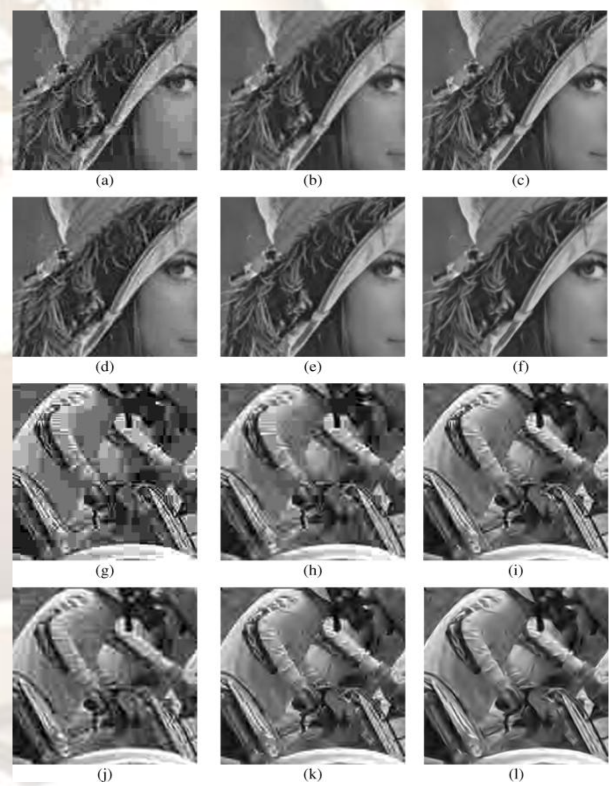
To solve the above equation we rewrite equation in matrix form

$$\min_{\boldsymbol{x}} \left\{ (\mathbf{C}\boldsymbol{x} - \mathbf{d})^2 \right\}$$

Where **C** and **d** are composed of **a,b,λ,h,** and the decoded pixels **y.**The CADU system design is asymmetric: the encoder is a simple and inexpensive process, while the decoder involves solving a rather large-scale optimization problem described . The computation bottleneck is in inverting an **n×n** matrix, where n is the number of pixels to be jointly recovered. Instead of inverting the matrix $\mathbf{C}^T\mathbf{C}$ directly, we solve numerically via differentiation using the conjugate gradient method. The solution is guarantied to be globally optimal for the objective function is convex.

IV.EXPERIMENTAL RESULTS

Extensive experiments were carried out to evaluate the proposed image coding method, in both PSNR and subjective quality. We compared the CADU method with the adaptive downsampling-based image codec proposed by Lin and Dong . The latter was reportedly the best among all previously published downsampling-interpolation image codecs , in both objective and subjective quality. Note that all existing image codecs of this type were developed for DCT-based image compression, whereas the CADU method is applicable to wavelet-based codecs as well. Therefore, we also include in our comparative study JPEG 2000, the quincunx coding method [9], and the method of uniform down-sampling at the encoder and bicubic interpolation at the decoder. The bicubic method in the comparison group and the CADU method used the same simple encoder: JPEG 2000 coding of uniformly down-sampled prefiltered image. The difference is in the upconversion process: the former method performed bicubic image interpolation followed by a deconvolution step using Weiner filter to reverse the prefiltering, instead of solving a constrained least squares image restoration problem driven by autoregressive models as described in the proceeding section .



Comparison of different methods at 0.2 bpp. (a) JPEG; (b) Method ; (c) J2K; (d) CADU-JPG; (e) Bicubic-J2K; (f) CADU-J2K; (g) JPEG; (h) Method; (i) J2K; (j) CADU-JPG; (k) Bicubic-J2K; (l) CADU-J2K.

Image	Rate (bpp)	Methods						
		DCT-based			Wavelet-based			
		JPEG	Method [7]	CADU-JPG	J2K	Bicubic-J2K	Quincunx	CADU-J2K
Lena	0.10	N/A	N/A	27.69	30.19	30.13	30.29	30.42
	0.15	25.57	28.77	29.48	31.85	31.82	32.02	32.19
	0.20	28.77	30.67	30.72	33.21	32.88	33.28	33.35
	0.25	30.58	31.63	31.66	34.27	33.43	34.23	33.98
	0.30	31.81	32.39	32.48	35.02	33.82	34.91	34.46
Leaves	0.10	N/A	N/A	23.83	25.67	25.69	25.71	26.05
	0.15	N/A	N/A	25.61	27.51	27.26	27.91	28.02
	0.20	24.14	26.33	26.78	28.99	28.29	29.33	29.43
	0.25	26.64	27.62	27.87	30.16	28.92	30.75	30.45
	0.30	27.86	28.58	28.73	31.35	29.42	32.01	31.22
Flower	0.10	N/A	N/A	22.42	24.16	24.10	23.99	24.25
	0.15	N/A	N/A	24.24	25.67	25.72	25.62	25.92
	0.20	22.08	25.13	25.47	26.98	26.71	26.88	27.09
	0.25	24.84	26.40	26.43	27.98	27.78	27.87	28.04
	0.30	26.01	27.27	27.08	28.78	28.65	28.72	28.84
Bike	0.10	N/A	N/A	20.20	21.38	21.34	21.30	21.55
	0.15	N/A	N/A	21.25	22.42	22.37	22.30	22.63
	0.20	20.74	21.83	21.97	23.28	23.25	23.29	23.61
	0.25	21.84	22.73	22.53	24.08	23.81	24.09	24.18
	0.30	22.66	23.46	23.03	24.68	24.33	24.77	24.90

TABLE: PSNR (DB) RESULTS FOR DIFFERENT COMPRESSION METHODS

The superior visual quality of the CADU-J2K method is due to the good fit of the piecewise autoregressive model to edge structures and the fact that human visual system is highly sensitive to phase errors in reconstructed edges

We believe that the CADU-J2K image coding approach of down-sampling with directional pre-filtering at the encoder and edge-preserving upconversion at the decoder offers an effective and practical solution for subjective image coding.

Some viewers may find that JPEG 2000 produces somewhat sharper edges compared with CADU-J2K, although at the expense of introducing more and worse artifacts. However, one can easily tip the quality balance in visual characteristics to favor CADU-J2K by performing an edge enhancement of the results of CADU-J2K. some sample results of JPEG 2000 and CADU-J2K at the bit rate of 0.2 bpp after edge enhancement. For better judgement these images should be compared with their counterparts . As expected, the high-pass operation of edge enhancement magnifies the structured noises accompanying edges in images of JPEG2000. In contrast, edge enhancement sharpens the images of CADU-J2K without introducing objectionable artifacts, which further improves the visual quality.

The CADU-J2K decoder has much higher complexity than the decoder based on bicubic interpolation. A close inspection of the reconstructed images by the CADU-J2K decoder and the bicubic method reveals that the two methods visually differ only in areas of edges. Therefore, an effective way of expediting the CADU-J2K decoder is to invoke least squares noncausal predic- tive decoding, which is the computation bottleneck of CADU, only in regions of high activity, and resort to fast bicubic inter- polation in smooth regions. If a decoder is severely constrained by computation resources, it can perform bicubic interpolation everywhere in lieu of the CADU restoration process. Such a re- source scalability of the decoder is desired in application sce- narios when decoders of diverse capabilities are to work with the same code stream.

V.CONCLUSIONS

This paper deals with new, standard-compliant approach of coding uniformly down-sampled images, which outperforms JPEG 2000 in both PSNR and visual quality at low to modest bit.Hence the proposed method is not only a simple, practical algorithm, but also an effective algorithm. When compared with the previous results, with this algorithm better results were obtained. The proposed approach says that a lower sampling rate can actually produce higher quality images at certain bit rates. By feeding the standard methods downsampled images, the new approach reduces the workload and energy consumption of the encoders, which is important for wireless visual communication.

VI.FUTURE SCOPE

This system(algorithm) has important application in the modern world such as Telemedicine and other communication applications.

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