Undecimated Wavelet Transform Based Contrast Enhancement

Numan Unaldi, Samil Temel, and Süleyman Demirci

Abstract—A novel undecimated wavelet transform based contrast enhancement algorithmisproposed to for both gray scale andcolor images. Contrast enhancement is realized by tuning the magnitude of approximation coefficients at each level with respect to the approximation coefficients of one higher level during the inverse transform phase in a center/surround enhancement sense.The performance of the proposed algorithm is evaluated using a statistical visual contrast measure (VCM). Experimental results on the proposed algorithm show improvement in terms of the VCM.

Keywords—Image enhancement**,** local contrast enhancement, visual contrast measure.

I. Introduction

ONE of the key features of a digital image which affects its perceptual visual quality is the image contrast. Therefore many image processing techniques have been proposed to enhance the contrast in an image. Some of those are global histogram modification techniques, such as gamma adjustment, logarithmic compression, contrast stretching, levels/curves methods and histogram equalization (HE). However, those conventional methods generally have very limited performance such that some features may be lost during the image processing. Maintaining and boosting the local contrast which is related with the perceptual sharpness and losing fine features in an image may be vital especially when the enhanced image is used for detection/recognition of objects in that image. Progressive image enhancement techniques have been developed which not only accounts in compressing the dynamic range but also improving the local contrast thereby achieving high quality of vision.

Wavelet-based image enhancement is mainly used to enhance the perceptual quality of an image. Due to its band-pass nature, through which edges in an image can be located, the WT is well suited for improving the edge features in an image. By appropriately modifying edges, sharpness, and the local contrast can be enhanced leading to improved visual quality. Multi-scale image contrast enhancement has been proposed and implemented using either wavelets, especially in medical imaging application [1]-[5], or curvelet [6] transform for color and gray scale image enhancement. Velde [1] proposes modifying the wavelet coefficients in a contrary way to the coefficient thresholding in wavelet denoising algorithms, strengthening the weakest edges (small valued coefficients) and leaving the strongest edge unmodified. In

Numan Unaldi, Samil Temel, and Süleyman Demirci are with the Turkish Air Force Academy, 34149Yesilyurt, Istanbul, Turkey.

[6], Velde's approach is realized in a curvelet domain with a slight modification to the mapping function applied for modifying the wavelet coefficients.

Fu *et al.* [3] analyzing HE in the spatial domain, propose a method in wavelet domain to achieve contrast enhancement. They first perform the HE in the spatial domain and then perform the WT on the equalized image. Then, all approximation-coefficients are squared. They claim that this process compensates for the information that was lost during the HE process. Peng*et al.* [5] propose an approach using shift invariant wavelet transform for the contrast enhancement of radiographs. The edge information of radiographic images is extracted and protected by exploiting cross-scale correlation among wavelet coefficients, while noise is smoothed out in the wavelet domain. Radiographs are then reconstructed from the transform coefficients modified at multi-scales by a nonlinear enhancement operator. Qin and El Sakka [7] propose a wavelet-based method for contrast/edge enhancement. The proposed method histogram equalizes the image represented by the normalized approximation-coefficients, while high-boost filtering the detail-coefficients at selected resolution levels separately to achieve robust contrast and edge enhancement.

In [8], a method to improve the perceptual quality of wavelet compressed images has been proposed. They model edges using the edge model of [9]. Edge parameters are modified in order to approach them to the ideal edge model. Edges are then reconstructed. Since the ideal edge model is not natural, neither are the algorithm results.

In [10], a wavelet-based dynamic range compression and contrast enhancement model with color restoration which is inspired by the latest form of the retinex theory of color vision [11], [12] i.e. center-surround retinex, is proposed to improve the visual quality of digital images captured in high dynamic range scenes with non-uniform lighting conditions. The fast image enhancement algorithm provides dynamic range compression preserving the local contrast, tonal rendition and color constancy simultaneously.

In this paper, we introduce a novel undecimated wavelet transform (UWT) based contrast enhancement technique is proposed, where the inter-ratios of the approximation coefficients at consequent scales of the UWT of an intensity image are utilized to modify the approximation coefficients in a center/surround sense. The approximation coefficients at a coarser scale are obtained by low-pass filtering the approximations in a finer one. The contrast enhancement is realized by tuning the magnitude of each coefficient with respect to its surrounding coefficients at the course of the inverse transform resulting in a contrast enhanced intensity

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image. A color restoration process based on relationship between spectral bands and the luminance of the original image is applied to convert the enhanced intensity image back to a color image. The performance of the proposed algorithm is evaluated using the statistical visual contrast measure (VCM).

II. UNDECIMATED WAVELET TRANSFORM

The undecimated UWT of a 1D signal c_0, W using the filter bank (h,g) is a set $W = \{w_1, \ldots, w_J, c_J\}$ where w_j are the wavelet coefficients at scale j and c_J are the coefficients at the coarsest resolution. The "à trous" (meaning 'with holes' in French) algorithm [13]-[15] can be applied in order to obtain wavelet coefficients at one resolution from another using the following equations:

$$c_{j+1}[l] = \left(\overline{h}^{(j)} * c_j\right)[l] = \sum_k h[k]c_j\left[l + 2^j k\right]$$
$$w_{j+1}[l] = \left(\overline{g}^{(j)} * c_j\right)[l] = \sum_k g[k]c_j\left[l + 2^j k\right] \quad (1)$$

where '*' is the convolution operator and $\overline{h}[n] = h[-n], n \in Z$ is the time-reversed of the discrete-time filter with an impulse response $h[n]$ and $h^{(j)}[l] = h[l]$ if $l/2^j$ is an integer and 0 otherwise. For example when $j=1$,

$$h^{(1)} = \left(\ldots, h[-2], 0, h[-1], 0, h[0], 0, h[1], 0, h[2], \ldots\right)$$ The reconstruction of the signal c_j is realized via:

$$c_j[l] = \frac{1}{2}\left[\left(\widetilde{h}^{(j)} * c_{j+1}\right)[l] + \left(\widetilde{g}^{(j)} * w_{j+1}\right)[l]\right] \quad (2)$$

where $\widetilde{h}$ and $\widetilde{g}$ are the filters corresponding to analysis filter pairs h and g, respectively. The only exact reconstruction condition [13] for the filter bank $(h, g, \widetilde{h}, \widetilde{g})$ is given by,

$$H(z^{-1})\widetilde{H}(z) + G(z^{-1})\widetilde{G}(z) = 1 \quad (3)$$

where $H(z)$ is the z-transform of a filter h and so on. This condition determines how one should design the synthesis type filter bank given the analysis filters providing a higher degree of freedom when compared the DWT. Extension of the à trous algorithm to 2D is straightforward and can be realized by the convolution of c with the separable filter hg (i.e. convolution first along the columns by h and then convolution along the rows by g). At each scale, three wavelet images, $w^h, w^v,$ and w^d each of which has the same size as the original image, representing edges along horizontal, vertical and diagonal directions are produced.

In [13], it is shown that using non-bi-orthogonal filter banks, one can build the UWT. One example to this is:

$$h^{1D}[k] = [1,4,6,4,1]/16 \quad, k = [-2,..,2]$$
$$h[k,l] = h^{1D}[k]h^{1D}[l] \quad (4)$$
$$g[k,l] = \delta[k,l] - h[k,l]$$

where δ is defined as $\delta[0,0] = 1$ and $\delta[k,l] = 0$ otherwise. This filter bank is one widely used in analyzing the astronomical data. Following the exact reconstruction condition, it can be shown that for the above analysis filter bank $\widetilde{h} = \widetilde{g} = \delta$ can be taken as synthesis filters yielding perfect reconstruction. Then just by co-additions of all scales perfectly reconstruct the original image:

$$c_0[k,l] = c_J[k,l] + \sum_{j=1}^{J}\sum_{n=1}^{3} w_j^n[k,l] \quad (5)$$

where n stands for the three orientations at each scale.

III. ALGORITHM

The proposed contrast enhancement algorithm is applied to value (V) component of the HSV color space which is regarded as the intensity image given in (6).

$$I(x, y) = \max\left[I_r(x, y), I_g(x, y), I_b(x, y)\right] \quad (6)$$

where $I_{rg,b}$ are the RGB components of the original color image in the RGB color space. J level (in our implementation J=5) UWT is applied to the intensity image using the "à trous" algorithm to get the approximation coef. $c_J[k,l]$ at scale J and wavelet coef. $w_j^n[k,l]$ at scales j. For each scale

$$c_j^{enh}[k,l] = \begin{cases} 255c_j^{norm}[k,l]\dfrac{c_j[k,l]}{c_{j+1}[k,l]} & \text{for } \dfrac{c_j[k,l]}{c_{j+1}[k,l]} < 1 \\ c_j[k,l] & \text{otherwise} \end{cases} \quad (7)$$

is conducted, where $c_j^{norm}[k,l]$ are normalized coefficients to the range [0,1]. $c_0^{enh}[k,l]$ is the resulting enhanced intensity image. Thus the center surround enhancement is achieved utilizing the ratios between subsequent scales.

For evaluation of the proposed technique, statistical visual contrast measure (VCM) [16] is used. The VCM is a stand-alone external metric that can be used to determine the visual quality. Computationally, the VCM is given by

$$VCM = 100.Rv/Rt \quad (8)$$

where Rv is the number of regions in an arbitrary image that exceed a specific threshold for regional signal standard deviation, and Rt is the total number of regions into which the image has been divided.

IV. RESULTS AND DISCUSSION

The proposed algorithm has been applied to Toyoma Database. From our observations and obtained VCM results we can conclude that the algorithm is capable of enhancing the local contrast well. Besides, the produced colors are always consistent with the colors of the original images having a balanced rendition The enhancement results are shown in Fig. 1 while the VCM results are given Table I.

TABLE I
VCM RESULTS

IMAGE	ORIGINAL	ENHANCED
KP01.BMP	37	92
KP03.BMP	27	51
KP05.BMP	83	92
KP06.BMP	37	53
KP07.BMP	50	64
KP08.BMP	83	86
KP13.BMP	61	80
KP16.BMP	13	27
KP20.BMP	32	41
KP21.BMP	44	53
KP22.BMP	24	39
KP23.BMP	31	42
KP24.BMP	38	68

Fig. 1 Color image enhancement results: Left column: original, right column: enhanced images. The images are in the same order with the names given in Table I

V. CONCLUSION

An undecimated wavelet transform based contrast enhancement algorithm to provide higher visual quality improving the local contrast and resulting in a balanced tonal rendition has been developed for the enhancement of color images. Experiments conducted for evaluating the improvement showed that proposed technique is promising in the contrast enhancement of both gray scale and color images.

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